Insights in Mining Science & Techonology
ISSN: 2689-4629

Research Article
Volume 1 Issue 4 - November 2019
DOI: 10.19080/IMST.2019.01.555567

Insights Min Sci technol

Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process

Akinbinu Victor Abioye*

Department of Mining Engineering, Federal University of Technology, Nigeria

Submission: October 22, 2019; **Published:** November 25, 2019

***Corresponding author**: Akinbinu Victor Abioye, Department of Mining Engineering, Federal University of Technology, Nigeria

Abstract

This research work is intended to study the post-failure characteristic behaviour of rocks and the techniques of controlling the post-failure regime based on the mechanism of rocks deformation process. It is impossible to determine the post-failure regime of rocks using conventional laboratory testing equipment. As rock specimens are often in an unstable state at the point of failure as most testing machines tend to be soft. Rock specimens break explosively at their ultimate strength and no further information could be obtained. The only practical means is the use of closed-loop servo-controlled system, which is difficult to achieve. Stress-strain deformation tests were conducted using both conventional and unconventional method (i.e. the closed loop servo-controlled testing machine) in accordance to ISRM [1]. Normalised pre-failure curves were constructed to show the stages in the deformation process. The author's use of normalised pre-failure curves enables identification of additional type of deformation process with very brittle response under axial loading. The difficulty in obtaining the post-failure curves increases as the total volumetric strain approaches a positive value. In other words, difficulty in obtaining the post-failure curves increases from the first type to the second type and finally the additional third type deformation process. For the first and second types, the four stages of deformation process are identifiable while only three stages of deformation process could be identified with the third type. It was practically impossible to determine the post-failure regime for the third type as result of high accumulated strain energy. The first type contains the Class I and progress to Class II with low strength soft brittle rocks. The second type shows entirely Class II characteristic behaviour. The third type is extremely brittle under axial loading, resulted in explosive failure, so its class could not be determined. Testing the third type without confinement could cause equipment damage. Identification of the deformation process with the rock classes using conventional test could guide the personnel conducting tests using closed-loop servo-controlled system, if dangerous situation or equipment damage could occur (especially with the third type deformation process) so that testing is performed safely. It could also be useful in understanding the total process of specimen deformation, routine determination of rock classes, and estimation of the rock's brittleness (e.g. brittle for Class II and less brittle or ductile for Class I).

Keywords: Post-failure; Pre-failure normalised curves; Conventional testing equipment; Closed-loop servo-controlled system; Deformation process; Rock classes

Introduction

There is difficulty with the laboratory determination of the post-failure curve of rocks using conventional equipment. Rock specimens are often in an unstable state at the point of failure as most testing machines tend to be soft. Rock specimens break explosively at their ultimate strength and no further information could be obtained. Simon et al. [2] observed that the laboratory determination of the post-failure properties during uniaxial compression test on brittle rocks is often difficult to realize. Shimizu et al. [3] concurred that there are still complications in achieving post-failure stress-strain curves of brittle rocks in the laboratory experiments. Javier & Alejano [4] opined that significant success has not been achieved in terms of methodologies for estimating reasonably good post-failure behaviour, mainly due to the difficulties associated with defining a model that adequately reflects observed complete stress–strain curves. However, Alejano et al. [5] obtained quite reproducible post-failure results for unconfined compressive tests in moderately weathered granite. Similarly, Brijes [6] presented post-failure tests on coal and coal measure rock specimens obtained from various coal mines in West Virginia and Hiawatha. Nonetheless, it is almost impossible to obtain a good post failure curves on homogeneous hard brittle rocks without explosive breakage in unconfined condition.

A closed loop servo-controlled testing machine is the only practical way to avoid explosive breakage of rock specimen when the ultimate strength is reached. Figure 1 shows the principle of a closed loop, servo-controlled testing machine. A transducer is attached to the rock specimen. It generates a signal that is compared with the program instruction where constant strain rate or deformation is considered as the control variable. If the transducer signal is not equal to the program instruction value, the hydraulic system automatically adjust the servo-valve until the transducer signal agrees with the program value. The efficiency of the testing machine therefore depends on the capability of the servo-valve to respond quickly enough to correct the error and prevent release of strain energy after the peak strength of the rock is reached.

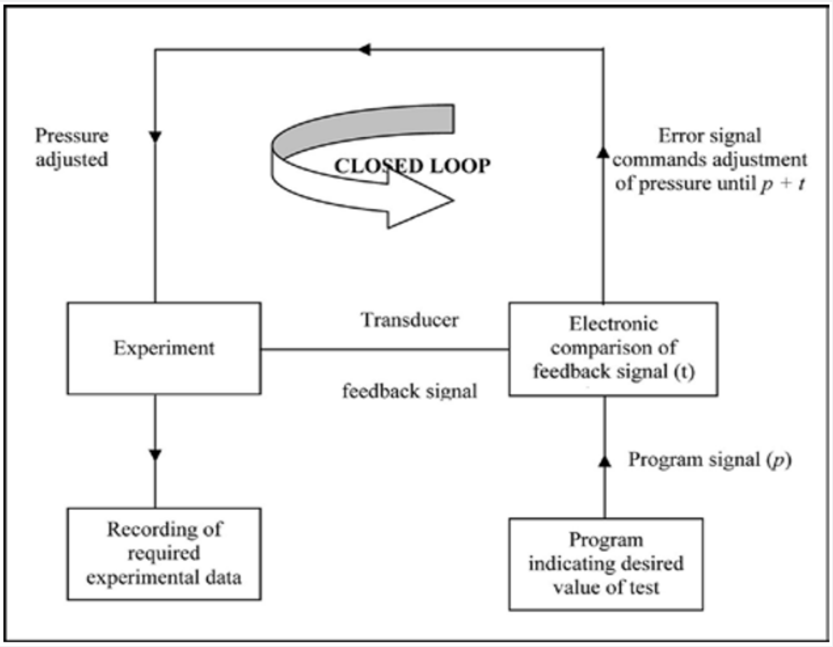

Figure 1: Principles f Closed-Loop Servo-Controlled System [24].

Class I and Class II Rocks

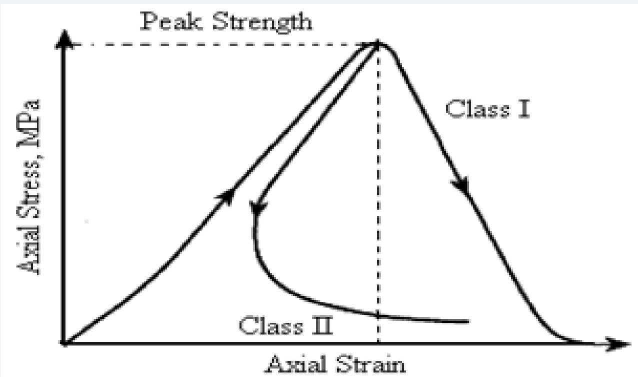

Figure 2: Classification of rock into Class I and Class II Behaviour in Uniaxial Compression Tests [1].

Figure 2 shows the pre-failure and post-failure stress-strain curves that were obtained from a closed-loop servo-controlled testing machine. Wawersik & Fairhurst [7] classified rocks into Class I and Class II according to their failure behaviour in a uniaxial compression test. Beyond the post-peak region, either the curve increases continuously in strain or it does not. If it increases in strain, it is Class I, if it does not, then it is a Class II rock. He et al. [8] demonstrated that the striking difference between Class I and Class II types was the increase in non-elastic strain. Both Class I and Class II rocks tend to decrease in elastic strain in the post-failure region with a decrease in the load-bearing capacity. They showed that the difference between Class I and Class II was the magnitude of the non-elastic strain. In other words, if the decrease in elastic strain is accompanied by a faster increase in non-elastic strain, the rock demonstrates Class I, otherwise it shows Class II behaviour.

The research question, therefore, is it possible to identify rock classes from conventional testing results? This research therefore intended to study the possibility of identifying the rock classes (Class I or Class II) based on the rocks' deformation process studied from normalised axial stress-volumetric strain curves using tests result from conventional machine. A closed loop servo-controlled testing machine which is the only practical way to determine rock classes is a difficult test to perform (requiring enough personnel training and vigorous specimen preparation). The use of conventional test to classify rocks (into Class I or Class II) will be useful in understanding the total process of specimen deformation and in the routine determination of rock classes. In addition, it would be helpful in the estimation of the rock's brittleness (e.g. brittle for Class II and less brittle or ductile for Class I) since the post-failure part is the part that characterizes the brittle behaviour of a rock.

Similarly, the knowledge of the post-peak behaviour of rocks will assist in the evaluation of the potential failure of an excavation and the rock burst potential near underground openings (e.g. Class I failure gradual, Class II failure explosive). Identification of these deformation processes with their rock classes could

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

guide the personnel conducting tests with closed-loop servo-controlled system, if dangerous situation or equipment damage could occur so that testing is performed safely.

Literature review

Deformation and fracture characteristics of brittle rock have been studied by many researchers [7,9,10]. The common agreement among them is that the failure process occurs in stages. The stages are determined from stress-strain characteristic curves obtained from axial and lateral deformation measurements during laboratory uniaxial compression test.

Brace et al. [11] & Bieniawski [12] evaluated stress-strain behaviour of a deformed material and classified the deformation steps in the brittle fracture process (Figure 3) as follows:

a) Closing of cracks (or crack closure) (stage I),

b) Linear elastic deformation (or fracture initiation) (stage II),

c) Stable fracture propagation (or Critical energy release) (stage III),

d) Unstable fracture propagation (or material failure) (stage 1V) and

e) Failure and post-failure behaviour (or structure failure) (stage V).

In order to evaluate the stages of deformation in rocks, Martin [13] conducted uniaxial compression tests on cylindrical samples of continuous, homogenous, isotropic, linear and elastic (CHILE) massive Lac du Bonnet Granite obtained from the Underground Research Laboratory (URL) at 420m below ground surface. The test was carried out to identity a suitable site for the disposal of radioactive wastes. The stages in the failure process are identified in the stress-strain curves (Figure 3).

Similarly, a study of compression tests on two South African hard rocks, namely a Norite (igneous rock) and Quartzite (metamorphosed sedimentary rock) was done in “order to eliminate, for the purpose of” the “investigation, the influence of non-homogeneity and anisotropy on the mechanism of rock” failure [9] (Figure 4). It shows similar steps in the failure process (Figure 3). The steps in the failure process in Figures 3 & 4 are discussed next.

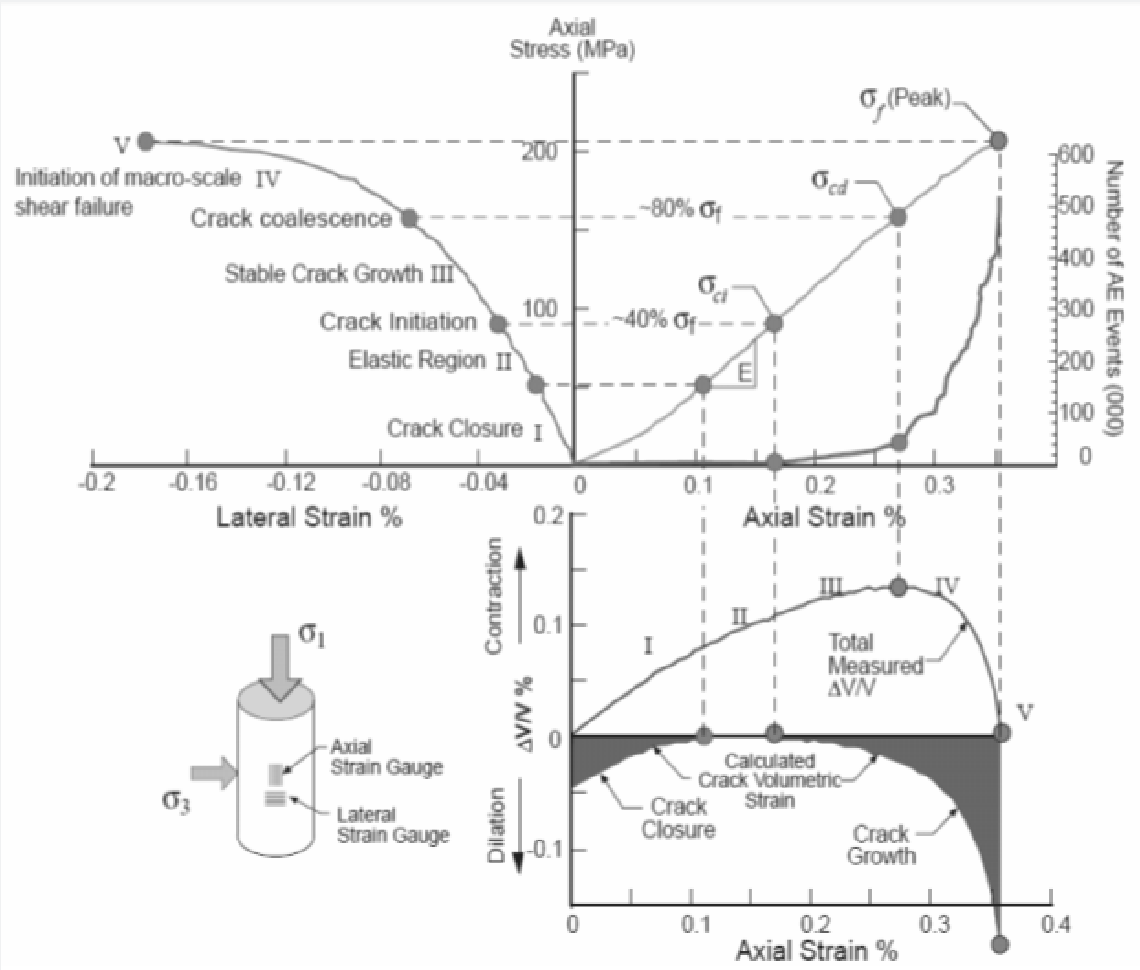

Figure 3: Stress-strain Diagram showing Stages in the Failure Process [10,13].

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

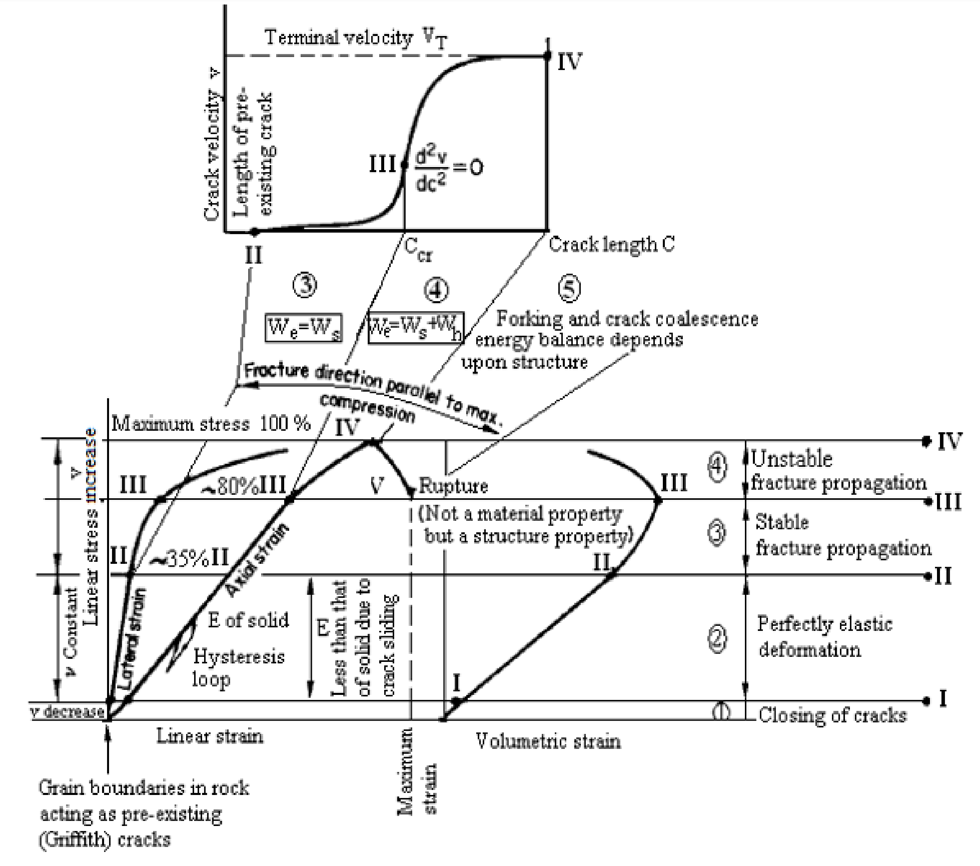

Figure 4: Mechanism of Brittle Fracture of Rock in Compression showing stages in the Failure Process [21].

Crack closure occurs during the early stage of loading (crack closure corresponds to Stage 1 in Figures 3 & 4). At this stage, the stress-strain curve is slightly inclined towards the axial strain. As a result, the pre-existing cracks inclined to the applied load are closed [14]. At the crack closure stage, the stress-strain curve is nonlinear and expresses an increase in axial stiffness (i.e. deformation modulus). The size of this nonlinearity depends "on the initial crack density and geometrical characteristics of the crack population" [14]. After the bulk of pre-existing cracks are closed, linear elastic deformation takes place. During the elastic deformation stage, the relationship between stress-strain curves is linear (Stage II in Figures 3 & 4). The elastic constants (Young's modulus, Poisson's ratio) of the rocks are estimated from this linear portion of the stress-strain curve. Crack initiation stress (Figure 4) represents the stress level when micro-fracturing begins. Zhang et al. [15] defined crack initiation as the stress level that marks the start of dilation and crack propagation.

Besides, crack propagation is considered as either stable or unstable [13]. Stable crack (fracture) propagation begins at the end of Stage II while unstable propagation starts at Stage IV. At Stage III, cracks increase by a small quantity as a result of an increase in stress, but these do not continue to extend in this stage to form macroscopic failure. At this stage (Stage III) fracture propagation is a function of the applied stress. At the beginning of crack propagation, it obeys Griffith's criteria in Equation 1. During the stable condition, crack development can be arrested by the removal of the applied stress. On the other hand, unstable crack growth occurs at the point of reversal of the volumetric strain curve (Figures 3 & 4). This stage is known as the point of critical energy release or crack-damaged stress threshold [13]. Bieniawski [16] defined unstable crack propagation as the condition which occurs when the relationship between the applied stress and the crack length ceases to exist. Therefore, this is when the crack growth velocity, takes over in the propagation process. Unstable fracture propagation starts when the strain energy release rate in Equation 1 attains a critical value [17]. The cracks continue to extend because of the strain energy stored within the specimen.

In addition, the velocity of the crack propagation increases from Stage III and reaches its maximum (terminal velocity) at Stage IV (Figure 4). In the opinion of Craggs [18], as crack velocity increases, the force needed to uphold crack propagation decreases. Using Craggs analysis Bieniawski [9] claimed that at the onset of unstable fracture propagation, the fracture process is self-sustaining until failure. According to Robert and Wells [19]; Dulaney and Brace [20]; and Bieniawski [9], the terminal velocity is given by:

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

$$V_T = \sqrt[0.38]{\frac{E}{\rho}} \qquad (1)$$

Where VT is the terminal velocity; E is the modulus of elasticity and ρ is the density of the rock. Also, the increase in velocity causes a general increase in volume (dilation). Figure 5 shows dilatancy in Quartzite under uniaxial compression test. Using dilatancy, failure process was grouped into regions [21] (Figure 5). Yathavan & Stacey [22] summarized the procedure for obtaining the stages of the deformation process from laboratory tests, as shown in Table 1. This summary is adopted in this work to plot the stress-strain curves and to identify the stages of the deformation process.

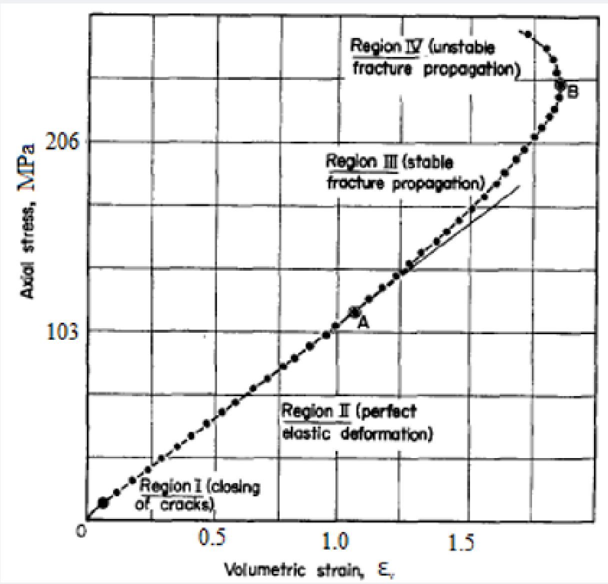

Figure 5: Classification of rock into Class I and Class II Behaviour in Uniaxial Compression Tests [1].

Table 1: Method of Identification of Deformation stages based on Stress-Strain Curves [22].

	Identifying Methods	Crack Closure	Crack Initiation	Crack Damage
Brace, Brace et al. 1963; [9,12]	Axial strain	Point of nonlinear Zone changes to linear zone		
	Lateral strain		Point of departure from linearity to non-linearity	
	Volumetric strain		Point of departure from linearity to non-linearity	Point of reversal
[10]	Crack Volumetric strain		Dilation begins after crack volume unchanged during elastic deformation	

Method for Determining Axial Stress-Volumetric Strain Curves

Stress-strain curves were determined for different 18 rocks types (ranging from soft Quartz Arenite of 35 MPa to Quartzite2 of about 514 MPa; and with different rock types, igneous, sedimentary and metamorphic) in unconfined uniaxial compression test using conventional Amsler rock testing machine in accordance to ISRM [1]. Stress-axial, radial and total volumetric strain curves were constructed according to Martin & Chandler [10] and Bieniawski [21] to show the stages in the deformation process (Table 1) and group them into the different deformation process.

Method for the determination of post-failure regime of rocks in uniaxial compression

During the uniaxial compression testing to determine the post-failure stress-strain curves using the servo-controlled testing machine, the following control steps were employed: The axial extensometer was installed at 1200 apart and contacts the specimen at 25% and 75% of its full length while the circumferential extensometer was located at mid-height of the specimen. The specimen was then installed on the lower platen of the load unit assembly. A small preload was applied with the force cell drive to contact the specimen in force control mode using the output of the axial force as the feedback signal. This made the specimen 'seat' to the lower loading platen and the upper loading platen becomes spherically seated. The readings of both axial, radial extensometer and axial force were reset to zero. Ductile (i.e. less brittle) specimens were continuously loaded at an axial strain rate of 0.001mm/mm/sec. This was continued up to 70% of the predetermined peak load of the specimen determined using the conventional method. After this point the loading rate was reduced by switching to a lower strain rate of 0.000001 mm/mm/sec. The loading continued at an axial strain rate of 0.000001 mm/mm/sec until the applied load drops close to 50% of its peak load. At this point, a post-failure load-deformation curve was obtained.

In the case of specimens with a brittle behaviour (i.e. Class II), the control switch over method is as follows. The control mode was switched from axial force to axial strain control mode. The specimens were continuously loaded at an axial strain rate of 0.001 mm/mm/sec. This was continued up to 70% of the predetermined peak load of the specimen. At 70% of peak load, instead of a slower or reduced axial strain rate, the control mode was switched to circumferential control mode at a rate of 0.0001mm/mm/sec. This continued until the applied load reduces to about 50% of peak load. At this point a post-failure

 How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

load-deformation curve was obtained. Five tests were performed per each rock type and the average result reported.

Results and Discussion

The author use of normalised pre-failure curves enables identification of another type of deformation process with very brittle response under axial loading in additional to Martin & Chandler [10] and Bieniawski [12]. Together there are three types of deformation process. The first type has a negative total volumetric strain and with a point of reversal at crack damage stress. The second type has positive total volumetric strain with reversal point at crack-damaged stress and the third type has a positive total volumetric strain without a reversal point. Relationships exist among the different volumetric strain curves [23]. The difficulty in obtaining the post-failure curves increases as the total volumetric strain approaches a positive value. In other words, difficulty in obtaining the post-failure curves increases from the first type to the second type and finally the third type. For the first and second types, the four stages of deformation process are identifiable while only three stages of deformation process are identifiable with the third type. For rocks that exhibit the first type of deformation process, the normalised stress-axial, radial and total volumetric strain curves and post-failure curves are shown in Figures 6-9 as example for the type. The post-failure stress-strain curves for this type of rock was relatively easy to perform.

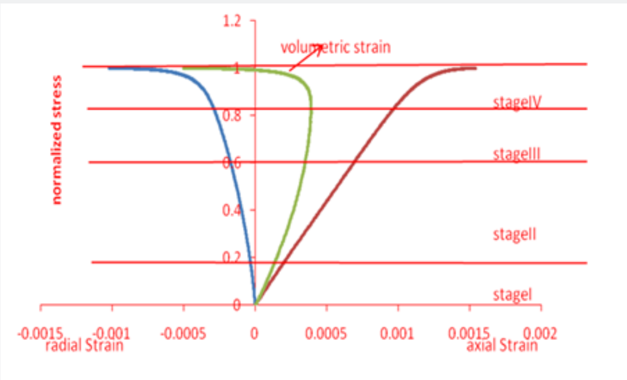

Figure 6: Normalized Stress-Strain Curves, Marble specimen.

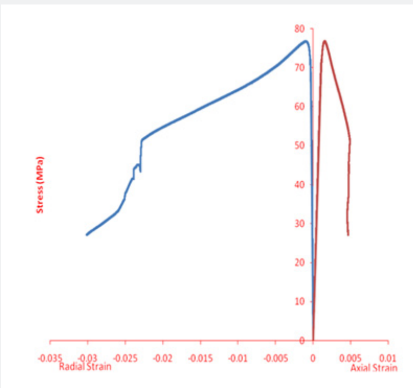

Figure 7: Post-failure Stress-Strain Curves, Marble specimen.

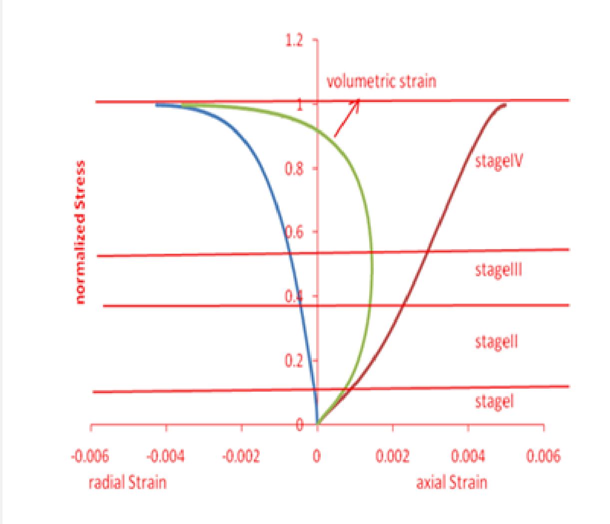

Figure 8: Normalized Stress-Strain Curves, Sandstone Specimen.

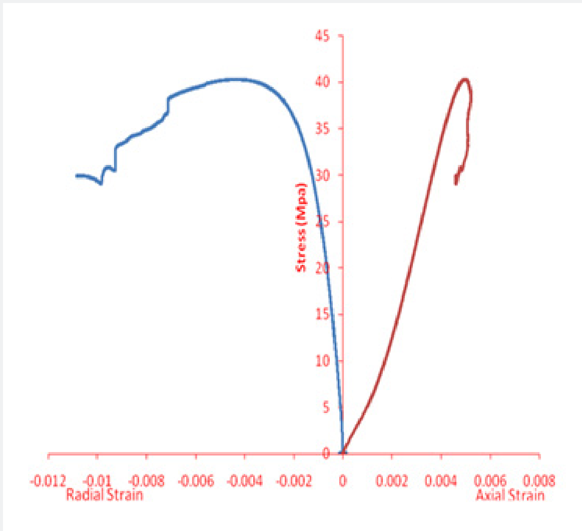

Figure 9: Post-failure Stress-Strain Curves, Sandstone Specimen.

Figures 10 & 11 show the second type and the stages of deformation process. For this type of stress-axial, radial and total volumetric strain curves, the process of unstable crack propagation (stage IV) has a small duration and for this reason cracks propagate by their own accord. Thus, the rocks exhibit a higher velocity of micro-crack propagation. This made it difficult to control the post-failure curves than the type one stress-axial, radial and total volumetric strain curves because of the short duration of the crack damage stress threshold to rupture. The normalized stress-axial, radial and total volumetric strain curves and the post-failure curves are shown in Figures 10-13. For the third type of stress-axial, radial and total volumetric strain curves, the crack induced stress and the structural failure of the rock specimen occurred together (Figures 14-16). There was no reversal of the total volumetric strain so there was

 How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

continued decrease in rock volume. The control feedback, the circumferential strain, does not continuously increase with the applied load after the peak load. Instead, the deformation became a self-sustaining failure and, as a result the micro-cracking of the material continued its own accord. Furthermore, unstable crack growth occurs at the onset of the crack initiation stress. The critical energy release rate or crack damage stress threshold started much earlier for this type of curve than observed with others. Under this condition, the relationship between the applied stress and the crack length ceases to exist and other parameters, such as the crack growth velocity, take control of the propagation process.

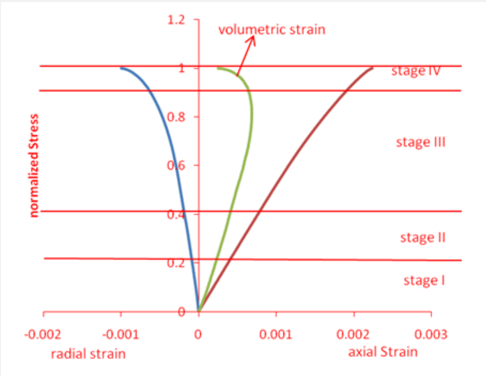

Figure 10: Normalized Stress-Strain Curves, Troctolite specimen.

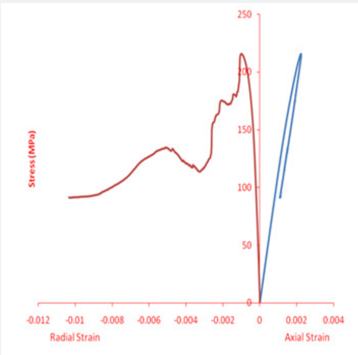

Figure 11: Post-failure Stress-Strain Curves, Troctolite specimen.

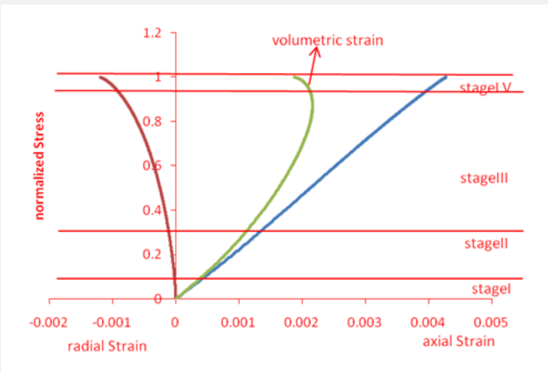

Figure 12: Normalized Stress-Strain Curves, Quartzite 1 specimen.

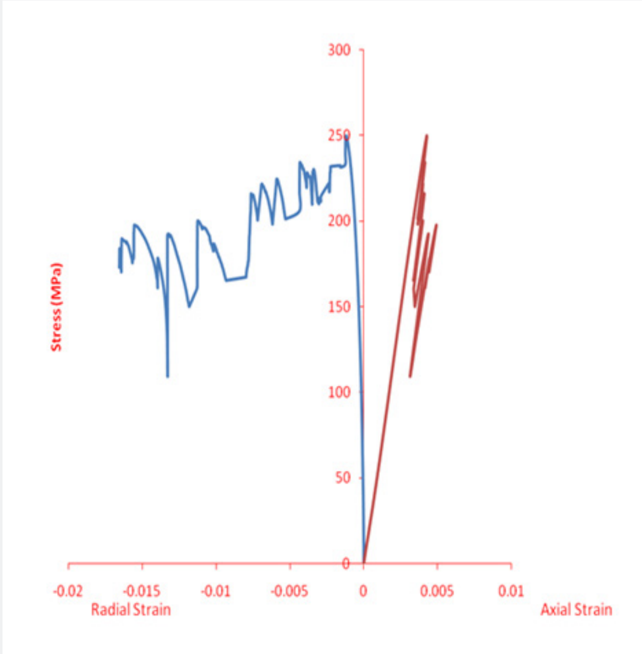

Figure 13: Post-failure stress-strain curves, Quartzite 2 Specimen.

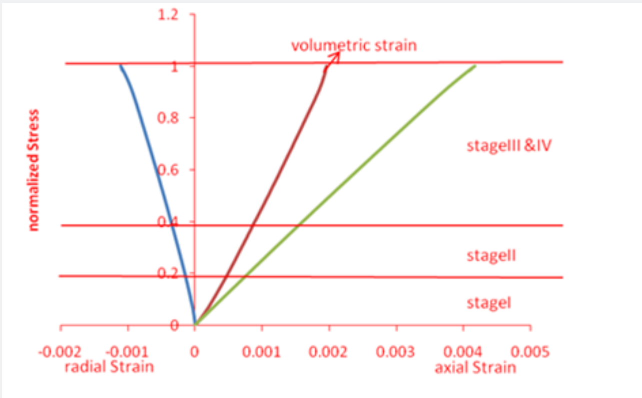

Figure 14: Normalized Stress-Strain Curves, Gabbro specimen.

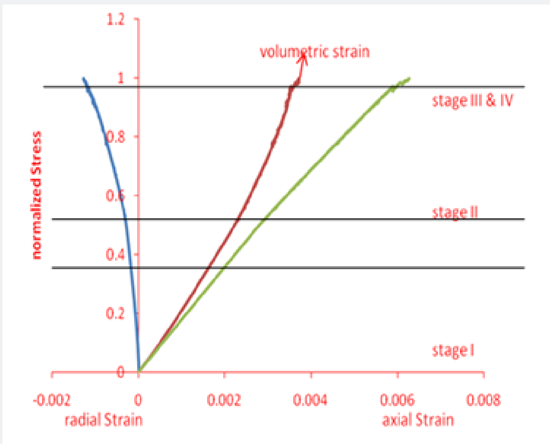

Figure 15: Normalized stress-strain curves, Quartzite specimen.

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

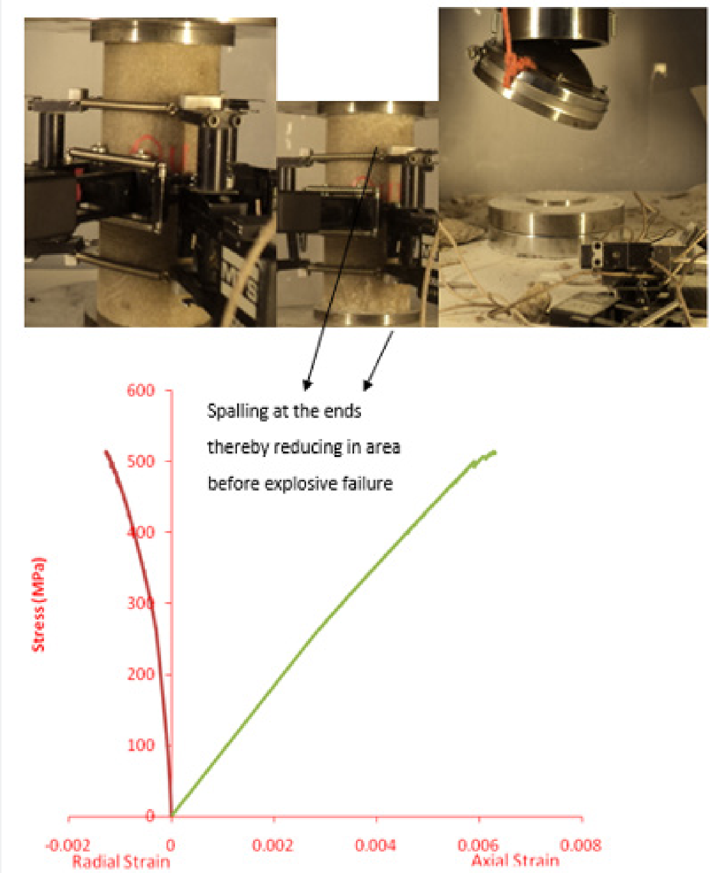

Figure 16: Explosive Damage of Testing Equipment to determine Post-failure Curves for Quartzite2.

Conclusion

This work has demonstrated the possibility of using results from conventional laboratory equipment to be classified rocks into Class I and Class II with the use of deformation process of rocks constructed according to Martin & Chandler [10] and Bieniawski [21]. It is therefore possible to have knowledge of the post-failure regime of rocks using conventional testing system. Three types of deformation curves were identified. The first type has a negative total volumetric strain and with a point of reversal at crack damage stress. The second type has positive total volumetric strain with reversal point at crack-damaged stress and the additional third type has a positive total volumetric strain without a reversal point. The difficulty in obtaining the post-failure curves using close-loop system increases as the pre-failure total volumetric strain approaches a positive value. In other words, difficulty in obtaining the post-failure curves increases from the first type to the second type and finally the third type. For the first and second types, the four stages of deformation process are identifiable while only three stages of deformation process could be identified with the third type. The first type contains the Class I and progress to Class II with low strength brittle soft rocks e.g. Quartz Arenite. The second type is entirely Class II rocks. Identification of the deformation process could guide the personnel conducting tests using closed-loop servo-controlled system, if dangerous situation or equipment damage could occur especially with the third type deformation process so that testing is performed safely. In addition, could be useful for understanding the total process of specimen deformation and routine determination of rock classes. It could indicate rocks brittleness (e.g. brittle for Class II and less brittle or ductile for Class I) since the post-failure part is the part that characterizes the brittle behaviour of a rock. Moreover, the knowledge of the post-peak behaviour of rocks will assist in the evaluation of the potential failure of an excavation and the rock burst potential near underground openings (e.g. Class I failure gradual, Class II failure explosive) [24].

Further Research

Further research could be initiated to study the normalised pre-failure curves to serve as a measure of rocks brittleness potential and for predicting fragmentation. As it has been shown that there is a connection between obtaining the post-failure curves and the total volumetric strain approaches a positive value, therefore the total volumetric strain may be explore for predicting/estimating post-failure moduli of rocks. In addition, such research could study the first type of deformation process in order to demarcate precisely the line between the rocks that contains the Class I and low strength soft brittle Class II

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

rocks. Additionally, research could be initiated to study various sensor guidance technologies that could improve the control performance of closed-loop servo-controlled testing system for post-failure determination of very brittle rocks. Sensor based programmable systems such as laser scanning, infrared (IR), ultrasonic and high speed micro-acoustic sensors etc. could be explore for reliably and safely operating control of the third type of deformation process with very brittle response under axial loading.

Acknowledgment

This article is a part of a PhD thesis approved by The University of the Witwatersrand South Africa. The School of Mining Engineering, University of the Witwatersrand South Africa is acknowledged for providing support towards the success of this research. Specifically, the Centennial Trust Fund for Rock Engineering is appreciated for funding part of this research. Rock Engineering Department, Aalto University Finland is equally acknowledged for allowing part of the work to be done there.

References

1. (2007) International Society for Rock Mechanics Commission on Testing Methods. ISRM suggested methods for rock characterization, testing and monitoring. In Ulusay R, Hudson JA (Eds.), Draft ISRM suggested method for the complete stress-strain curve for intact rock in uniaxial compression. Ankara, Turkey: Pergamum Press Ltd published for Commission on Testing Methods, International Society for Rock Mechanics.
2. Simon R, Aubertin M, Deng D (2003) Estimation of post-peak behaviour of brittle rocks using a constitutive model for rock joints. Proceedings of the 56th Canadian Geotechnical Conference, 4th joint IAH-CNC/CGS Conference (2003 NAGS conference) (9), Winnipeg, Canada.
3. Shimizu H, Koyama T, Ishida T, Chijimatsu M, Fujita T, et al. (2010) Distinct element analysis for Class II behaviour of rocks under uniaxial compression. International Journal of Rock Mechanics and Mining Sciences 47(2): 323-333.
4. Javier A, Alejano LR (2013) Dilation in granite during servo-controlled triaxial strength tests. International Journal of Rock Mechanics & Mining Sciences 61: 43-56.
5. Alejano LR, Posada D, Rodriguez-Doon A (2009) Servo-controlled strength tests on moderately weathered granite. In: Proc. of the EUROCK 2009 symposium. Rock engineering in difficult ground conditions. London: CRC. Taylord & Francis Gr. Soft Rock & Karts, pp. 181-186.
6. Brijes M & Dachao N (2013) Experimental investigation of the effect of change in control modes on the post-failure behaviour of coal and coal measures rock. International Journal of Rock Mechanics & Mining Sciences 60: 363-369.
7. Wawersik WR, Fairhurst C (1970) A study of brittle rock fracture in laboratory compression experiments. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 7(5): 561-564.
8. He C, Okubo S, Nishimatsu Y (1990) A study of the Class II behaviour of rock. Rock Mechanics and Rock Engineering 23(4): 261-273.
9. Bieniawski ZT (1967b) Mechanism of brittle fracture of rock: Part II-experimental studies. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 4(4): 407-423.
10. Martin CD, Chandler NA (1994) The progressive fracture of lac du bonnet Granite. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 31(6): 643-659.
11. Brace WF, Paulding BW, Scholz C (1966) Dilatancy in the fracture of crystalline rocks. J Geophysics Res 71: 3939-3953.
12. Bieniawski ZT (1967a) Stability concept of brittle fracture propagation in rock. Engineering Geology 2(3): 149-162.
13. Martin CD (1993) The strength of massive lac du bonnet Granite around underground openings. (Doctoral Dissertation). University of Manitoba, Winnipeg.
14. Eberhardt E, Stead D, Szczepanik Z (1998) Crack initiation and propagation in Granite and granodiorite from the 130m and 420m levels of the URL. Manitoba, Canada: Atomic Energy of Canada Limited.
15. Zhang C, Chu W, Liu N, Zhu Y, Hou J (2011) Laboratory tests and numerical simulations of brittle Marble and squeezing schist at Jinping II hydropower station, China. Journal of Rock Mechanics and Geotechnical Engineering 3(1): 30-38.
16. Bieniawski ZT (1967c) Mechanism of brittle fracture of rock: Part I-theory of the fracture process. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 4(4): 395-404.
17. Kemeny J, Cook NGW (1986) Effective moduli, non-linear deformation and strength of a cracked elastic solid. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 23(2): 107-118.
18. Craggs JW (1960) On the propagation of a crack in an elastic-brittle material. Journal of the Mechanics and Physics of Solids 8(1): 66-75.
19. Roberts DK, Wells AA (1954) The velocity of brittle fracture. Engineering 178: 820-821.
20. Dulaney EN, Brace WF (1960) Velocity behaviour of a growing crack. Journal of Applied Physics 31(12): 2233-2236.
21. Bieniawski ZT (1967d) Mechanism of brittle fracture of rock: Part III-fracture in tension and under long-term loading. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 4(4): 425-430.
22. Yathavan K, Stacey TR (2004) Laboratory observations relevant to fracture initiation at low stress levels. South African National Institute of Rock Engineering, SANIRE–The Miner's Guide through the Earth's Crust.
23. Akinbinu VA, Ajaka EO, Afu DJ (2018) Evaluation of volumetric strain quantities and types of volumetric strain curves under failure-deformation process of hard brittle rocks. Mining of Mineral Deposits. 12(4): 73-81.
24. Hudson JA, Brown ET, Fairhurst C (1971) Optimizing the control of rock failure in servo-controlled laboratory tests. Rock Mechanics and Rock Engineering 3(4): 217-224.

How to cite this article: Akinbinu Victor Abioye. Determination of Class I and Class II rocks from Conventional method based on the Mechanism of rock Deformation Process. Insights Min Sci technol.2019; 1(4): 555567. DOI: 10.19080/IMST.2019.01.555567

DOI: 10.19080/IMST.2019.01.555567