Rock Sample Characterization Based on Textural Features, Strength Properties and Signal Emission Levels under Application of Uni-axial Compressive Stress

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Abstract

The field of Rock Mechanics is taken to include all studies relative to the physical and mechanical behaviour of rocks and rock masses and the applications of this knowledge for the better understanding of geological processes and in the fields of Engineering. The corner-stone of any practical rock mechanics analysis or rock engineering is the geological data base upon which the definition of rock types, structural and material properties are based.

1.Introduction.

The nature and distribution of structural features within the rock mass is known as rock structure which can have a dominant effect on the response of a rock mass to mining operations. It can influence the choice of a mining method and the design of mining layouts because it can control stable excavation spans, support requirements, subsidence, cavability and fragmentation characteristics. At shallow depths and in de-stressed areas, structurally controlled failures may be the prime concern in excavation design. At depth and in areas of high stress concentration, the influence of structure may be less marked, and limiting the induced boundary stresses or energy release rates may be more important considerations.

Many engineering decisions are based on a combination of geological and rock mechanics data. The geological database upon which the definition of rock types, structural and material properties are based upon, plays a significant role in rock mechanics. Mechanical properties of rocks can be measured quantitatively but most of the petrographic descriptions (mineral composition and texture) are qualitative. So it is important to develop a more systematic means of combining and correlating the petrographic data and corresponding mechanical properties of rock masses.

The determination of the *Texture Coefficient* (T.C.) is a technique of Applied Petrography, developed by two Australian researchers, Howarth and Rowlands (1986), to quantitatively express the concept of rock texture. Texture is defined as the description of the form, dimensions and dispositions of the mineral grains constituting the rocks. The Texture Coefficient (T.C) takes into account, through microscopic image analysis of thin sections of intact rock, the profile (or grain-shape), orientation and degree of interlocking of grains, as well as the relative proportions of grains and matrix. It can be used as a predictive tool for rock strength as it returns highly statistically significant correlations with rock strength.

The term acoustic emission (AE) is widely used to denote the phenomenon in which a material or structure emits elastic waves of shock type and sometimes of continuous type caused by the sudden occurrence of fractures or frictional sliding along discontinuous surfaces. Microcracking in a stressed rock can be detected by monitoring acoustic emission and hence acoustic emission is important in understanding the fracturing process. The study of the statistical distribution of the AE and the relation of the parameters to the process of fracturing helps in determining the probability of total fracture. Magnitude-frequency relation of AE events of rocks are strongly influenced by the homogeneity or inhomogenity of stress distribution in the medium.

2. Literature Review.

2.1Formation of rocks

A rock is a combination of minerals and does not have any specific combination. A main determining factor in the formation of minerals in a rock mass is the chemical composition of the mass, for a certain mineral can be formed only when the necessary elements are present in the rock. Calcite is most common in limestones, as these consist essentially of calcium carbonate; quartz is common in sandstones and in certain igneous rocks which contain a high percentage of silica.

Other factors are of equal importance in determining the natural association or paragenesis of rock-forming minerals, principally the mode of origin of the rock and the stages through which it has passed in attaining its present condition. Two rock masses may have very much the same bulk composition and yet consist of entirely different assemblages of minerals. The tendency is always for those compounds to be formed which are stable under the conditions under which the rock mass originated. A granite arises by the consolidation of a molten magma at high temperatures and great pressures and its component minerals are those stable under such conditions. Exposed to moisture, carbonic acid and other sub-aerial agents at the ordinary temperatures of the Earth's surface, some of these original minerals, such as quartz and white mica are relatively stable and remain unaffected; others weather or decay and are replaced by new combinations. The feldspar passes into kaolinite, muscovite and quartz, and any mafic minerals such as pyroxenes, amphiboles or biotite – are often altered to chlorite, epidote, rutile and other substances.

These changes are accompanied by disintegration, and the rock falls into a loose, incoherent, earthy mass which may be regarded as a sand or soil. The materials thus formed may be washed away and deposited as sandstone or siltstone. The structure of the original rock is now replaced by a new one; the mineralogical constitution is profoundly altered; but the bulk chemical composition may not be very different. The sedimentary rock may again undergo metamorphism. If penetrated by igneous rocks it may be recrystallized or, if subjected to enormous pressures with heat and movement during mountain building, it may be converted into gneiss, not very different in mineralogical composition though, radically different in structure to the granite which was its original state.

2.2 Textural Coefficient.

Texture Coefficient (T.C) has been developed by Howarth and Rowlands (1987), to quantitatively express the concept of rock texture. Texture is defined as the description of the form, dimensions and dispositions of the mineral grains constituting the rocks. The Texture Coefficient takes into account, through microscopic image analysis of thin sections of intact rock, the profile (or grain-shape), orientation and degree of interlocking of grains, as well as the relative proportions of grains and matrix.

2.2.1 Rock Texture and Rock Strength

Textural features affecting rock strength are: grainsize, shape and degree of interlocking, porosity (crack and pore), grain orientation and the nature of grain boundaries. Compositional features requiring investigation are strength properties, and percentages of component grains and cementing materials.

- *Grain Size*
  The yield stress increases when the mean grain size decreases.
- *Packing Density*
  Correlation of packing density (the space in a given area occupied by grains) with strength shows that as packing density (sandstones) increases, the values of uniaxial and tensile strengths and Young's modulus also increase.
- *Grain Shape*
  As the axial stress on a sample was brought towards the uniaxial compressive strength, the roughness (deviation of the grain from a circle) of grains when viewed in thin section decreased. This decrease in roughness (a higher degree of circularity) was caused by grain boundary and internal grain cracking, indicating that grain shapes were continually changing during stressing phenomena.
  There is a relationship between grain shape, fracture propagation and rock strength.
- *Degree of Interlocking*
  Igneous and metamorphosed sedimentary rocks, in which grains have been tightly packed and well cemented, severe interlocking of the grains can occur, resulting in a considerable increase in the applied stress required to propagate grain boundary cracks. As the axial stress approaches the uniaxial compressive strength, degree of interlocking decreases (indicating grain boundary and internal grain cracking).
- *Quartz Content*
  Sandstones with high quartz contents have higher strength properties than those with lower quartz contents. However, it is structural interlocking of the quartz grains and not quartz content by itself that influences strength properties.
- *Porosity*

  In sedimentary rocks all strength properties fall with increase in porosity.
- *Grain Boundaries*
  Central to brittle fracture mechanisms in rocks are the existence of pre-existing cracks -- these usually occur at grain boundaries. Grain boundaries are preferred sites for long thin cracks.
- *Texture Models*
  These models indicate the role of grain size and grain density in determining rock strength.

2.2.2 Quantitative Assessment of Rock Texture

Rock textures were assessed using microscopic image analysis of thin sections. The method of quantitative assessment of rock texture consists of four components:

i) Measurement and analysis of grain circularity

ii) Measurement and analysis of grain elongation

iii) Measurement and quantification of grain orientation

iv) Weighting of results based upon degree of grain packing

The procedure for analysis can be reduced to the following formula:

$$TC = AW\left[\left(\frac{No}{No+N1} \times \frac{1}{FFo}\right) + \left(\frac{N1}{N0+N1} \times AR1 \times -AF1\right)\right]$$

Where,

TC = textural coefficient

AW = Grain packing weight

FF_0 = arithmetic mean of discriminated form-factors

AR_1 = arithmetic mean of discriminated aspect ratios

AF_1 = angle factor, quantifying grain orientation

N_0 = number of grains whose aspect ratio is below a pre-set discrimination level

N_1 = number of grains whose aspect ratio is above a pre-set discrimination level

Individual analysis consists of selecting a reference area or "observation window", containing twenty to thirty rock grains, then processing this image to obtain the geometrical parameters; area, perimeter, length, breadth and angle, for each grain. Area and perimeter are calculated directly, however length and breadth are defined as being the maximum and minimum Feret's diameters (Fig 3.2), respectively calculated every five degrees around the grain image.

The deviation (elongation) is best measured using the grain's *aspect ratio* (AR). This is defined simply as the ratio of the grain's length to breadth. Thus for increasing elongation, the aspect ratio increases.

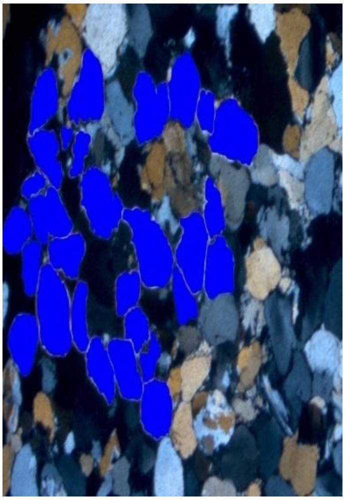


Fig2.1 Observation window of thin section - Quartzite

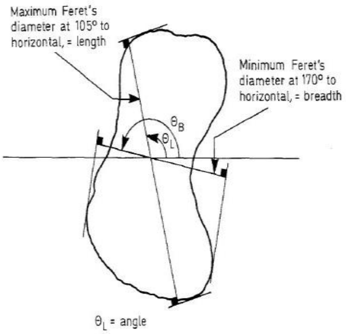


Fig 2.2 Maximum and minimum Feret's diameters (length and breadth), and ANGLE

Form factor is a measure of a grain's deviation from circularity. This deviation may occur in two ways; elongation of the shape, or increased "roughness" of the grain's perimeter.

Roughness is best measured directly using the grain's form factor. Form factor is defined thus:

FORM FACTOR = 4 x π x (AREA) / (PERIMETER) ^{2}

For a perfect circle, the form factor is 1.0. As a shape deviates from circularity, (by elongation or increased roughness), the form factor decreases. To differentiate between mode of deviation with respect to which measurement was to be made in the analysis, an aspect ratio discrimination level of 2.0 was introduced. Thus the arithmetic mean of the form factors was calculated for all grains falling below this level, whereas the arithmetic mean of the aspect ratios was calculated for all particles above this level. To maintain continuity in equation 1, the form-factor term was inverted to ensure that as a grain deviates from circularity, the result from either method of measurement, increases.

Angular orientation of grains was quantified by the development of an ANGLE FACTOR. This factor was only calculated for grains regarded as being elongated, i. e. their aspect ratio was greater than 2.0. The ANGLE FACTOR was calculated by a class weighted system applied to the absolute, acute angular differences (β), (i. e. 0^0 - 90^0), between each and every elongated grain.

Thus for a group of N grains the number of unique angular differences is

$$(N-1)+(N-2)+\ldots+2+1 = \frac{N(N-1)}{2}$$

Therefore, five grains will have:

4+3+2+1=10

Unique angular differences (β)

The angular differences are then separated into nine classes, each of which is weighted. The classes and weightings are presented in Table

1.

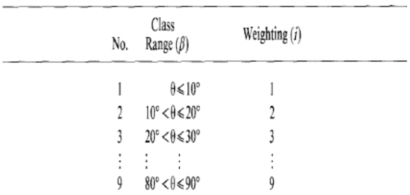


Table 1. *Classes and Weightings for Absolute, Acute Angular Differences* (β)

No.	Class Range (β)	Weighting (i)
1	$\theta \leqslant 10°$	1
2	$10° < \theta \leqslant 20°$	2
3	$20° < \theta \leqslant 30°$	3
⋮	⋮ ⋮	⋮
9	$80° < \theta \leqslant 90°$	9

The ANGLE FACTOR is calculated by summing the products of the class weightings and the fractions of the total number of angular differences in each class:

$$\textit{ANGLE FACTOR*} = \sum_{i=1}^{9} \left(\frac{Xi}{\frac{N(N-1)}{2}} \right) \times i$$

Where, ***N*** = total number of elongated particles

Xi **=** number of angular differences in each class

I **=** weighting factor and class number

***** Note that AF1 = (ANGLE FACTOR)/5

The recommended procedure will ensure that the *maximum* values of ANGLE FACTOR and AF1 are approximately 5.0 and 1.0 respectively. For a truly randomly oriented group of particles the maximum values of ANGLE FACTOR and AF1 are exactly 5.0 and 1.0 respectively. For 50 parallel elongated grains (i.e.: angular differences (fl) = 0 ~ the AF1 is 0.2, and for 50 grains at right angles to each other, the AF1 is 1.0.

The computational procedures involved in deriving the ANGLE FACTOR are best illustrated by a simple example. Fig 2.3 a shows three particles A, B and C with the defined parameter ANGLE (0L in Fig. 1) being 0^0, 60^0 and 130^0 respectively.

Number of elongated particles = 3 (N)

Angular orientations from horizontal (Θ):A(0^0); B(60^0); C(130^0)

Number of unique angular differences = N(N-1)/2=3

Absolute, unique angular differences (β)

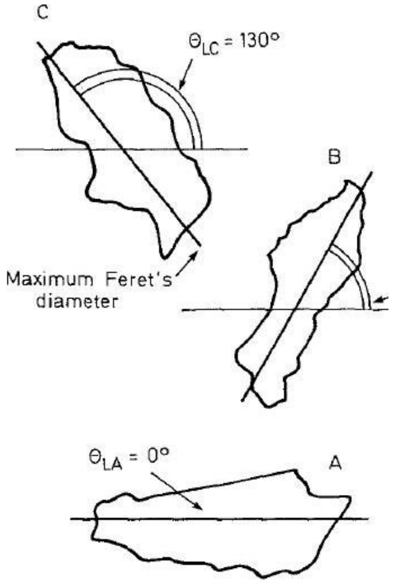


Fig 2.3 Illustrating aspects of the deviation of the ANGLE FACTOR

(a) an example showing 3 grains and the defined parameter angle (Θ_L)
(b) illustrating the definition of 'acute angular difference'

(i) $\Theta_{LA} - \Theta_{LB} = | 0^0 – 60^0 | = 60^0$

(ii) $\Theta_{LA} – \Theta_{LC} = | 0^0—130^0 | = 130^0$

(iii) $\Theta_{LB} - \Theta_{LC} = |60^0—130^0|= 70^0$

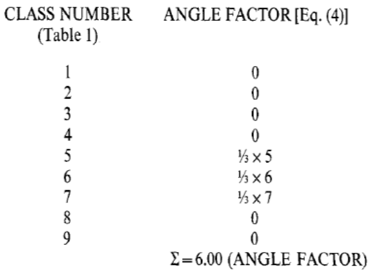
Acute, absolute, unique angular differences (β) are found by subtracting 180^0 from any absolute angular difference greater than 90^0 . The final figure is the modulus of that result.

i.e. (i) $\Theta_{LA} - \Theta_{LB} = 60^0$

(ii) $\Theta_{LA} – \Theta_{LC} = |130 – 180| = 50^0$

(iii) $\Theta_{LB} - \Theta_{LC} = 70^0$

ANGLE FACTOR calculation



CLASS NUMBER (Table 1)	ANGLE FACTOR [Eq. (4)]
1	0
2	0
3	0
4	0
5	⅓ × 5
6	⅓ × 6
7	⅓ × 7
8	0
9	0
	Σ = 6.00 (ANGLE FACTOR)

- The angle factor AF_1 used in is obtained by dividing the ANGLE FACTOR by 5, this ensures that the factor is numerically very similar to the other factors and does not influence the texture coefficient disproportionately.

- $AF_1 = 6.00/5 = 1.20$.

The minimum number of grains counted should be in the range 30-50. This will eliminate any bias in favour of the ANGLE FACTOR.

The final term in Eq. (1), AW, represents an area weighting, based upon the grain packing density in any observation window. The texture coefficient is scaled down according to the percentage area of grains in the total reference area. This factor is only apparent when dealing with sandstones. A typical example is shown in Fig. 4. The texture coefficient is reduced by 49 % from 1.51 to 0.74 due to the grain packing weighting.

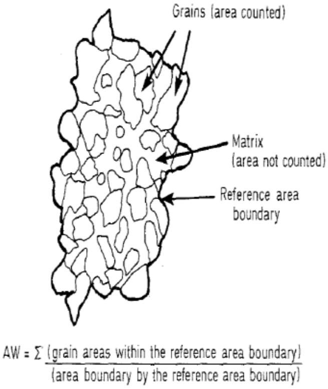


Fig 2.4Thin section grain outline.

2.3 Acoustic Emission

Acoustic emission (AE) waves are elastic waves due to dislocation motions in a solid such as cracking. It is common experience that the failure of a concrete specimen under load is accompanied by a considerable amount of audible noise. In certain circumstances, some audible noise is generated even before ultimate failure occurs. Sub-audible sounds can be detected at stress levels of perhaps 50% of the ultimate strength. With the sophisticated equipment available today, sound can be detected at much lower loads, in some cases below 10% of the ultimate strength. These sounds, both audible and sub-audible, are referred to as acoustic emission and they are defined as the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material. Acoustic emissions, which occur in most materials, are caused by irreversible changes, such as dislocation movement, twinning, phase transformations, crack initiation, and propagation, debonding between continuous and dispersed phases in composite materials.

The deformation process of brittle rock under incremental compression may be commonly divided into 5 stages in terms of emission rates:
I.At low stresses, the closure of pre-existing cracks with low aspect ratio at large angles to the compression axis produces low frequency acoustic emissions.
II. At higher stresses, the activity dies down to a very low level.
III. Further increase in stress again builds up steadily increasing AE (exponentially).
IV. As the failure approaches the frequency increases super-exponentially with time.
V. Very rapid acceleration of higher frequency acoustic emission activity immediately before and during failure.

The first Laboratory measurement of acoustic emission phenomenon caused by the fracturing of solid materials was carried out by Japanese seismologist Kishinouye(1937). He measured high frequency elastic waves caused by fractures resulting from the bending of a beam-shaped wood specimen for the purpose of simulating the temporal variation of the activity of 1930 Ito earthquake swarm in Japan. In the 1940`s, Obert and Duvall (e.g. 1945) carried out laboratory experiments on AE phenomenon as a part of their research on the problems of mine design and rock burst prevention.

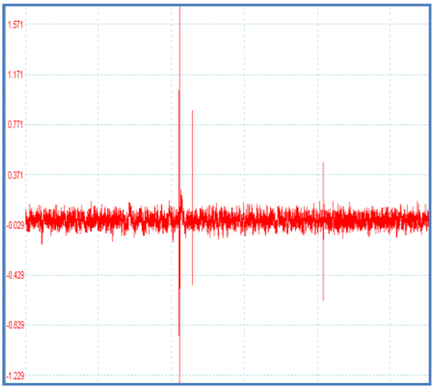


Fig2.5: Atypical acoustic signal in voltage-time scale

2.3.1 AE activity under some simple loadings

The temporal variation of AE activity of rocks and rock-like materials, which are heterogeneous brittle materials, is measured using following experimental arrangement.

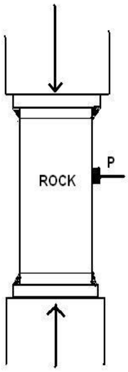


Fig 2.6: Simple Experimental system of AE measurement in the laboratory under Uniaxial Compression

2.4 Sensors

2.4.1 Piezo electric sensor

Applications:

- Vibration monitoring and compensation
- Machine condition monitoring
- Abuse event detection

Piezoelectric sensors are used to sense movement or vibrations in many applications. A piezoelectric sensor comprises a piezoelectric crystal which is typically mechanically coupled to an object which produces a mechanical movement. In piezoelectric materials, an applied electric field results in elongations or contractions of the material.

Piezoelectric sensors find applications in converting slight vibrations and stress of objects under measurement into electric signals with the piezoelectric effect of their materials find applications in various fields. Piezoelectric sensors are used as transducers because a potential difference is generated when the sensor is subject to a pressure change. A detection system is electrically coupled to the piezoelectric sensor and senses, for example that a vehicle has passed over the sensor.

Piezo-electric vibration sensors are intended for general use in systems for vibration measurements and machine condition monitoring.

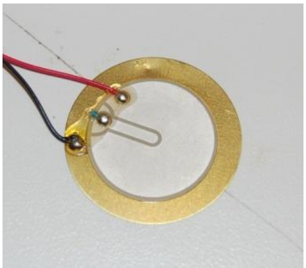


Fig 2.7 Piezo electric sensor

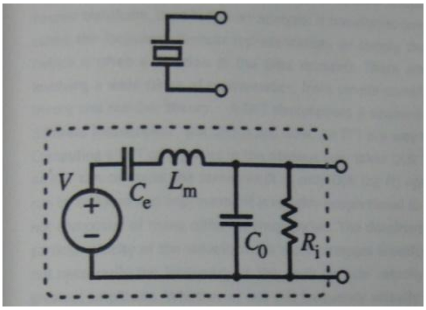


Fig 2.8 Electronic equivalent circuit of Piezo sensor

2.4.2 Acoustic pressure sensor:

Acoustic sensors monitor high frequency emissions generated by friction and the impact of flowing material or mechanical parts. The sensors can also sense the turbulence of gases or liquids leaking through valves and flanges. When matter vibrates between 0 Hz and 200 kHz, it creates acoustic energy. Sound energy between 20 Hz and 20 kHz can be detected by humans. Acoustic sensors detect high-frequency acoustic energy between 75 kHz and 175 kHz. Acoustic energy travels quickly through dense materials (metal) and poorly through less dense materials (air). Because the acoustic sensors are mounted directly to the external wall of the chute work, other plant noises are well below 75 kHz and effectively ignored by the sensors.

The acoustic sensors contain a specialized piezocrystal and filter circuit that responds effectively to the high-frequency band between 75 kHz and 175 kHz. As the crystal is excited by the acoustic energy, it produces a continuous electrical signal in direct proportion to the level of acoustic energy received. The sensor output of 0 to 10 V DC can be applied to a PLC or to an optional control unit for a programmable alarm relay or 4 to 20 mA signal output.

Fig 2.9: Acoustic sensor/Microphone

METHODOLOGY

3.1 Preparation of samples

3.1.1 Specimen design

Specimens of NX size (54mm) diameter are cored in the laboratory using rock core drills. Then the cores are cut to a length of 10.8-11.00 cm on a rock cutting machine. The two ends of the cylinder are smoothened to remove irregularities (within 0.02 mm) and they have to be perpendicular to the length of the specimen (within 0.001 radian or 0.05 mm in 50 mm).

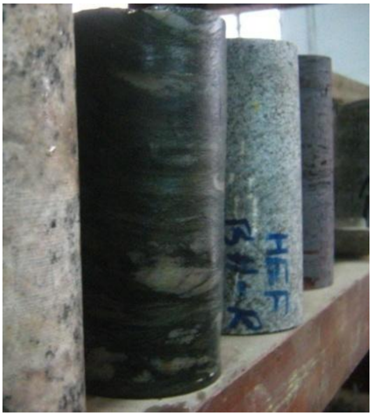


Fig 3.1: Core samples for UCS tests

Fig3.2: Thin sections of rock samples

3.1.2 Thin sections

For each rock sample, one chip was sliced in a direction parallel to the end faces of cylindrical specimen. The slice of rock is attached to a glass slide using any soluble adhesive like Canada balsam. The section is then polished to a thickness ranging from 2-12µm.

3.2 Thin sections and petrographic analysis

The thin sections are studied under optical polarising microscope. Grain parameters like size, perimeter, area, orientation, aspect ratio, etc were measured using *Leica QWin PLUS* –software for quantitative measurement of multiple parameters.

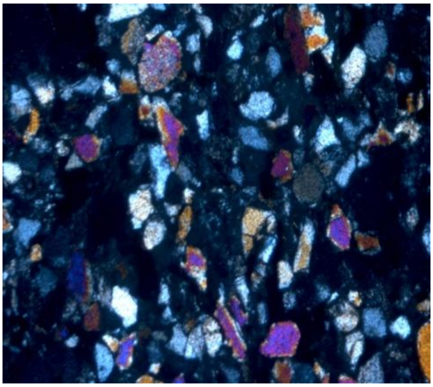


Fig 3.1: Microscope image of sandstone

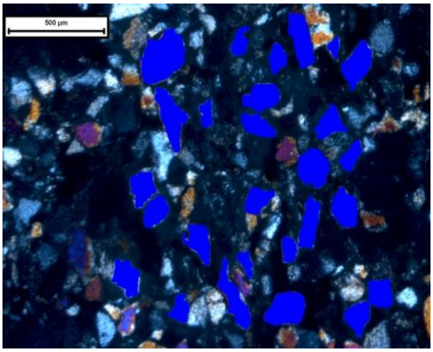


Fig 3.2: Tracing grains within reference boundary

3.3 Determination of UCS (ISRM method)

Uniaxial compressive strength is defined as the stress at failure under uniaxial compression and it can be determined by the given equation:

$$\boldsymbol{C_o = \frac{P}{A}}$$

Where: $\boldsymbol{C_o}$ = Uniaxial Compressive Strength(MPa)

$\boldsymbol{P}$ = Peak load at failure (KN)

$\boldsymbol{A}$ = Cross Section area (m^2)

The compressive strength is represented by the maximum principal stress in the Mohr's Diagram where the minimum principal stress (confining pressure) is equal to zero. The stress value at failure is defined as compressive strength $Co = \sigma_1$. The uniaxial compressive strength of the rock depends on the internal factor such as mineralogy, grain size, porosity and external factors.

Suggested techniques for determining the uniaxial compressive strength and deformability of rock material are given by the *International Society for Rock Mechanics* Commission on Standardization of Laboratory and Field Tests (ISRM Commission, 1979). The essential features of the recommended procedure are:

Fig 3.3 Experimental setup for UCS testing

(a) The test specimens should be right circular cylinders having a height to diameter ratio of 2.5–3.0 and a diameter preferably of not less than NX core size, approximately 54 mm. The specimen diameter should be at least 10 times the size of the largest grain in the rock.

(b) The ends of the specimen should be flat to within 0.02 mm and should not depart from perpendicularity to the axis of the specimen by more than 0.001 rad or 0.05 mm in 50 mm.

(c) The use of capping materials or end surface treatments other than machining is not permitted.

(d) Specimens should be stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, and tested in that condition.

(e) Load should be applied to the specimen at a constant stress rate of 0.5–1.0 MPa s−1.

(f) Axial load and axial and radial or circumferential strains or deformations should be recorded throughout each test.

(g) There should be at least five replications of each test.

3.4 Signal Measurement

PC Oscilloscope/PICOSCOPE:

The Picoscope 3424 is the ideal 4-channel oscilloscope for general purpose and specialist, high precision use. This high resolution oscilloscope connects to the USB port on laptop or desktop PC; along with providing the power for the Picoscope, the USB connection provides fast data transfer and makes the oscilloscope quick and easy to set up and use. A PC **oscilloscope** is a type of electronic test instrument that allows signal voltages to be viewed, usually as a two-dimensional graph of one or more electrical potential differences (vertical axis) plotted as a function of time or of some other voltage (horizontal axis). Although an oscilloscope displays voltage on its vertical axis, any other quantity that can be converted to a voltage can be displayed as well. In most instances, oscilloscopes show events that repeat with either no change or slow changes. The oscilloscope is one of the most versatile and widely-used electronic instruments.

Oscilloscopes are widely used when it is desired to observe the exact wave shape of an electrical signal. In addition to the amplitude of the signal, an oscilloscope can measure the frequency, show distortion, show the time between two events (such as pulse width or pulse rise time), and show the relative timing of two related signals.

Fig 4.3: Picoscope

3.4 Samples used in this investigation

Various rock samples which have been tested for this work include:

1) *Sandstone*
2) *Quartz Chlorite Schist (QCS)*
3) *Granulite*
4) *QCS (Uranium)*
5) *Haemetite*
6) *Serpentine*
7) *Quartzite*
8) *Limestone(white)*
9) *Dolerite*
10) *Black granite*
11) *Limestone (gray)*
12) *Shale*
13) *Granite (gray)*
14) *Quartzite*

RESULTS

4.1 Physical and strength properties

Temperature	: 20.00 (deg C)
Humidity	: 80.00 (%)
Rate	: 0.50 MPa/s

Table 4.1.1 Results of Uniaxial Compression test

S.No	Sample	Length(cm)	Dia(cm)	Weight(g)	Density	UCS(MPa)	Young's Modulus(MPa)
1	Sandstone(2)	10.7	5.2	507	2232.2757	11.25112	1332.78319
2	Quartz Chlorite Schist	10.7	5.4	775	3164.1768	85.1317	20090.21253
3	Granite	10.7	5.4	752	3070.2722	77.41878	13817.08549
4	Granulite	11.1	5.6	720	2634.898	98.61613	19413.65201
5	QCS(Uranium)	10.5	5.4	736	3062.1844	69.6623	14735.10844
6	Haematite	11.6	5.7	1505	5086.9696	79.80409	18499.3184
7	Serpentine	9.9	5.5	611	2599.0281	25.9	12739.756
8	Quartzite(2)	7.8	5.4	461	2581.9578	193.89	23971.90292
9	Limestone	12.9	5.4	738	2499.2487	66.34	21500.83484
10	Dolerite	12.1	5.5	857	2982.6371	102.55	32451.95386

4.2 Texture Analysis

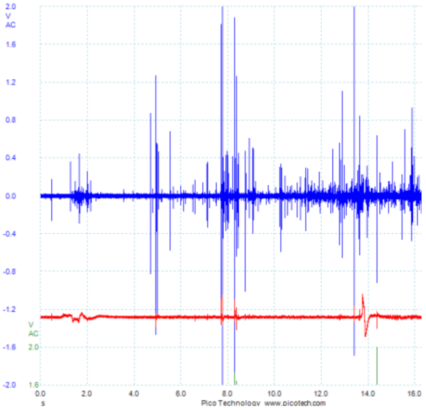
Table 4.2 Average grain parameters (QWin PLUS) along with TC and UCS values

Sample	AW	N0/(N0+N1)	FF0	AR1	AF1	TC	UCS
Sandstone(2)	0.27	0.8148	0.6333	2.48	0.6	0.423	11.25
Black granite	0.7	0.8182	0.49	2.32	1	1.464	46.41
Limestone	0.45	0.5652	0.5496	2.49	0.72	0.8109	66.34
Granite	0.8	0.9167	0.5387	2.07	0.2	1.5015	77.42
Shale	0.6	0.8461	0.6665	2.63	0.8	0.9522	87.79
Granulite	0.46	0.6538	0.5369	2.43	0.49	0.7479	98.62
Grey granite	1	0.8571	0.622	2.02	0.6	1.55	105.06
Quartzite	1	0.9655	0.6797	2.06	1	1.491	157.26
Quartzite(2)	1	0.9333	0.6857	2.16	1	1.505	193.89

4.3 Acoustic Emission data

4.3.1 Raw data

Sample interval: 20 µs; Sample rate 50kS/s;



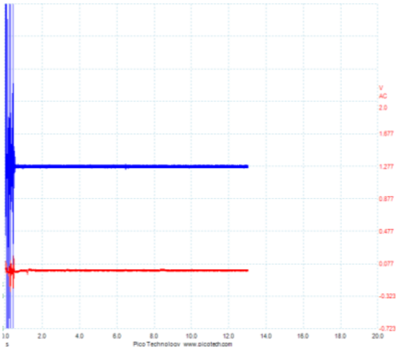


Fig 4.1 Sensor signals as captured by picoscope

Sample: **Sandstone**

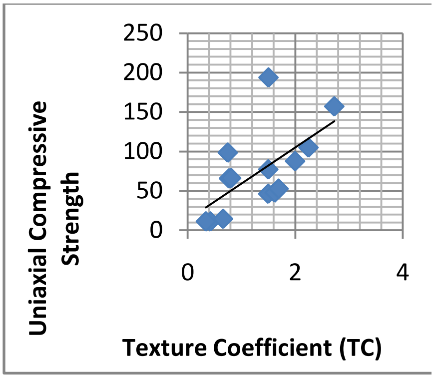
Channel A (Blue): Piezo electric signal

Channel B (Red): Acoustic signal

4.3.2 Signal Processing

The signal data recorded by picoscope during the failure time of rock is stored in multiple pages, each page containing *voltage* Vs *time* data for a time interval of 20 seconds. The sample interval being 20 µs, there are 1000000 data entries in each page. To analyse the data, .psdata files can be converted to .csv format and then imported to MATLAB.

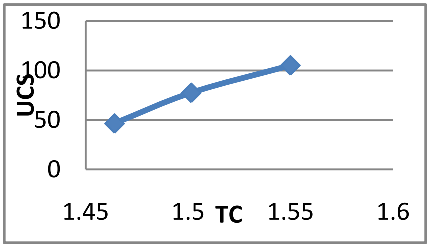
DISCUSSION



Graph 5.1: Correlation of TC and UCS values

- Igneous rocks

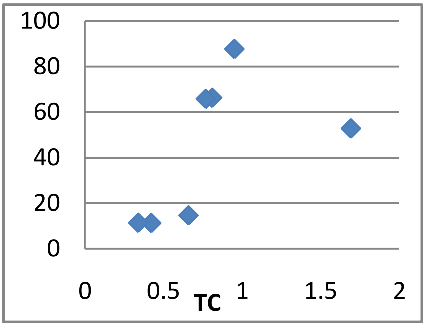
Sample	TC	UCS
Black granite	1.464	46.41
Granite	1.5015	77.42
Grey granite	1.55	105.06



Graph 5.1.1: Igneous rocks

- Sedimentary rocks

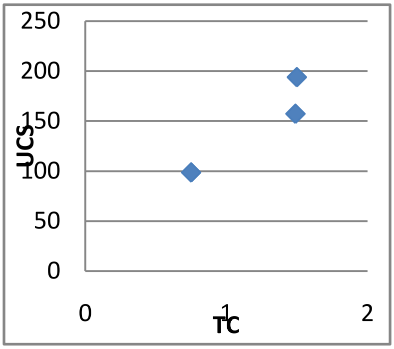
Sample	TC	UCS
L sand stone	0.34	11.35703
Sandstone	0.423	11.25
M sand stone	0.66	14.62291
Hard sand stone	0.77	65.8507
Limestone	0.8109	66.34
Shale	0.9522	87.79
Lime stone (gray)	1.694	52.84433



Graph 5.1.2: Sedimentary rocks

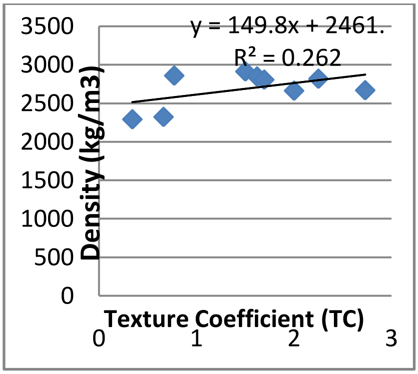
- Metamorphic rocks

Sample	TC	UCS
Granulite	0.75	98.62
Quartzite	1.49	157.26
Quartzite(2)	1.5	193.89



Graph 5.1.3: Metamorphic rocks

Specifically it can be noted that the mean value of TC progressively decreases from igneous, metamorphic to sedimentary. Therefore TC is a valid parameter to describe various types of rocks but it cannot predict mechanical properties accurately.



Graph 5.2: Correlation of TC and Densities

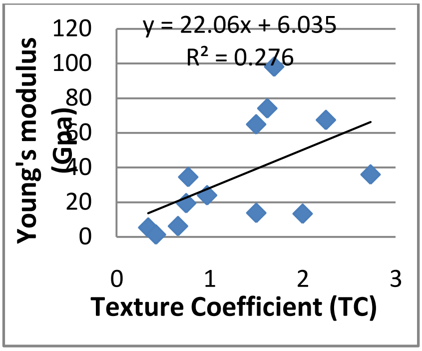


Fig. 5.3 Correlation of TC and E(Young's Modulus in GPa)

CONCLUSIONS

The results obtained from the experiments can be summarised as follows:

1) Texture Coefficient of various rocks (igneous, sedimentary and metamorphic) has been estimated according to the method proposed by Howarth and Rowlands.
2) Mechanical and intact rock properties (density, UCS, Young's Modulus) were presented and their relationship with the rock texture was statistically established.
3) Texture coefficient is simple in concept and empirical. The mechanical properties of the test rocks are significantly influenced by their texture. Texture coefficient and intact

rock property relationships are linear to some degree.

However, TC is not sufficient alone to assess all the rock properties, because hardness and abrasiveness of rock constituents, bonding structure, type and degree of cementation are not quantitatively involved in the determination of the texture coefficient. Therefore, the effects of these features on the performance of rock properties should be considered simultaneously, because there is no single test which determines the whole of the rock properties at the same time. The rock texture can be used as a predictive tool for assessing the mechanical performance, drillability, cuttability and wear performance of the rocks.

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