Comparison of the Strength of Two Different Rock Samples.

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ABSTRACT

This study was to determine the strength of two different rock samples of igneous rock - granite and metamorphic rock - marble samples. A well structured and organized experiment was used to carry out the empirical research. The sample comprised of two different rock types that was broken into size different sizes. The tables of readings collected were used to plot a graph of force against area from which the minimum stress required to fracture the different rock samples were obtained. The result revealed that the stress required to fracture the sampled igneous rock – granite is of the order of 8.82 x 10^6NM^2, for sampled metamorphic rock-marble, it is of the order of 5.7x10^6 NM^{-2}. Therefore the stress required to fracture the various rock samples should be borne in mind when using any of the rock samples in any engineering work.

(Keywords: metamorphic, igneous, rock, fracture, stress, marble, granite)

INTRODUCTION

The Earth's crust consists of rocks. A rock is any mineral material of the Earth. All rock differs from one another in texture, structure, color, permeability, mode of occurrence and degree of resistance to denudation. All rocks are classified into three major types:

(i) Igneous rock
(ii) Metamorphic rock
(iii) Sedimentary rock

Igneous Rock

Igneous rock (derived from the Latin root ignis meaning fire) is one of the three main rock types. Igneous rock is formed through the cooling and solidification of magmas or lava. It may form with or without crystallization, either below the surface as intrusive (plutonic) rock or on the surface as extrusive (volcanic) rocks. Igneous rock is characterized as follows:

(a) Crystalline in structure
(b) Non-stratified (i.e., do not occur in layers)
(c) Do not contain fossils
(d) Usually hard and impervious
(e) Resistant to erosion and other elements of climate

Intrusive igneous rocks are formed from magna that cools and solidifies within the crust of a planet. Surrounded by pre-existing rock (called country rock) the magma cools slowly, and as a result these rocks are coarse grained. The mineral grain in such rock can generally be identified with the naked eye. This type of rock can also be classified according to the shape and size of the intrusive body and its relation to the other formations into which it intrudes. Typical intrusive formations are batholiths, stocks, laccoliths, sills, and dikes.

Coarse grained intrusive igneous rock which forms at depths within the crust are termed as abyssal; while those formed near the surface are termed hypabyssal. Hypabyssal igneous rocks are formed at a depth in between the Plutonic and volcanic rocks. Hypabbyssal rock are less common than Plutonic or volcanic rock and often form like's, sills, laccoliths.

Extrusive igneous rock are formed at the crusts surface as a result of the partial melting of rock within the mantle and crust Extrusive igneous rock cool and solidify quicker than intrusive igneous rock. Since the rock cool very quickly, they are fine grained. It is much more difficult distinguish between the different types of extrusive igneous rock than between different types of intrusive igneous rock because the minerals in extrusive igneous rock are mostly fine-grained. Generally the mineral constituents of fine-grained extrusive igneous rock can only be determined by examination of thin sectors of the rock under a microscope.

Magma which is melted rock with or without suspended crystals and gas bubbles, rises because it is less dense than the rock from which it was created. When it reaches the surface, magma is extruded onto the surface either beneath water or air which is called Lava. Eruptions of volcanoes into air are termed subaerial whereas those occurring underneath the ocean are termed submarine. Black smokers and mid-ocean ride basalt are examples of submarine volcanic activity.

Igneous rocks are classified according to mode of occurrence, texture, mineralogy, chemical composition, and the geometry of the igneous body. The classification of many types of igneous rocks can provide us with important information about the condition under which they formed. Two important variables used for the classification of igneous rocks are particle sizes which largely depend upon the cooling history, and the mineral composition of the rock.

Feldspars quartz or feld spathoids, olivine's, pyroxenes, amphiboles and mica's are all important minerals in the formation of almost all igneous rocks, and they are basic to the classification of these rocks. All other mineral are regarded as non-essential and are called accessory minerals.

For example, rocks containing quartz (are solica in composition; are solica –over saturated while rocks with field spathord's are silica- under saturated because feld spathord's cannot coexist in a stable association with quartz.

Igneous rocks which have crystals large enough to be seen are called phanerites which implies intrusive origin; those with crystals too small to be seen are called aphanite which implies extrusive origin. An igneous rock with larger clearly discernible crystals embedded in a finer-grained matrix is termed porphyry. Porphyritic texture develop when some of the crystals grow to considerable size before the main mass of the magma crystallizes as finer-grained uniform mineral.

Most magma only entirely melts for small parts of their history. They are mixes of melt and crystals and sometimes of gas bubbles. Melts, crystals and gas bubble usually have different densities, and so they can separate as magmas evolve, magma composition can be determined by process other than practical melting and fractinal crystallization. For instance, magmas commonly interact with rocks they intrude, both by melting those rocks and by reacting with them. Magmas of different composition can mix with one another. In rare cases, melts can separate into two immiscible melts of contrasting composition.

Metamorphic Rock

Metamorphic rock is the result of the transformation of existing rock types, the prololith, in a process called metamorphism, which means "change in form". According to Hickman and Evans, 1991, the prololith is subjected to heat and pressure (temperature greater than 150 to 200^{o}C and pressures of 1500 bars) causing profound physical and/or chemical change. The prololith may be sedimentary rock, igneous rocks or another older metamorphic rock. They may be formed simply by being deep beneath the earth's surface, subjected to high temperature and the great pressure of the rock layers above it. They can form from tectonic processes such as continental collisions which cause horizontal pressure, friction and distortion. They are also formed when rock is heated up by the intrusion of hot molten rock called magma from the Earth's interior. Metamorphic rocks are characterized as follows:

(1) May occur in large or strata
(2) The rock may be hard or soft
(3) They are not crystalline in structure
(4) Exist in different colors and texture
(5) May contain fossils

Some examples of metamorphic rocks are gneisi, slate, marble, schist and quartzite. By recrystallization, perculia rocks of very distinct types are often produced. Thus shales may pass into large crystals of andalusite, staurolete, garnet, kyanite and sillimanite all derived from the aluminous content of the original shale.

A considerable amount of mica (both muscovite are biotite is often simultaneously formed and the resulting product has a close resemblance to many kinds of schist.

Limestone, if pure, are often turned into coarsely crystalline marbles, but if there was an admixture of clay or sand in the original rock, such minerals as garnet, epidote, and idocrase will be present. Sandstones when greatly heated may change in to coarse quartzites composed of large clear grains of quartz.

Metamorphic rocks make up a large part of the Earth's crust and are classified by textures and by chemical and mineral assemblage (metamorphic facies). Textures are separated into foliated and non-foliated categories. Foliated rock is a product of differential stress that deforms the rock in one plane, sometimes creating a plane of cleavage. For example, slate is a foliated metamorphic rock, originating from shale. Non-foliated rock does not have plane patterns of strain. Rocks that were subjected to uniform pressure from all sides or those that lack mineral with distinctive growth habits will not be foliated. Slate is an example of a very fine-grained foliated metamorphic rock while phyllite is medium, schist is coarse, and gneise is very coarse-grained. Marble is generally not foliated which allows its use as a mineral for sculpture and architecture.

Another important mechanism of metamorphian is that of chemical reactions that occur between mineral without them melting. In the process, atoms are exchanged between the mineral, and thus news mineral are formed. Many complex high temperature reactions may take place and each mineral assemblage produced provide a clue as to the temperature and pressures at the time of metamorphism.

Metamorphic minerals are those that form only at the high temperature and pressure associated with the process of metamorphism these mineral know as in dex mineral include sillimanite, kyarilte, anduclusite and some garnet. Other mineral such as olivines, pyroxenes amphiboles, micas, feldspars and quartzes may be found in metamorphic rocks but are not necessarily, the result of metamorphism.

PURPOSE OF STUDY

The purpose of this study is:

(1) To investigate the problem of failure of samples of the three major types of rock namely igneous, metamorphic and sedimentary.

(2) To ascertain the minimum tensile stress necessary to fracture the samples of rock chosen.

LITERATURE REVIEW

One of the basic goals of rock mechanics has been to provide useful methods for predicting failure strength and associated parameters such as strain to failure and the effects of porosity and elastic moduli. The large number of competing effects that influence the fracture process has precluded the development of a universal law which can be used in any practical way to predict fracture strength for an arbitrary rock. As a result, a variety of classification systems have been developed to be used as predictive tools in estimating the load bearing capacity of various rock types. Many attempts at developing failure criteria have relied on empirical fits to data sets of fracture strength, although increasingly sophisticated theoretical formulations, especially focusing on micromechanical deformation mechanisms, are also appearing.

At high pressures, strength eventually becomes insensitive to pressure, a response generally referred to as plastic or ductile, even though the microscopic mechanisms may still remain brittle for some silicates (Ashbyand and Sammis, 1990). Because of the curvature inherent in failure envelopes of real rocks, various investigators have proposed non-linear-failure criteria, most of which are empirical in nature.

The transition from uniformly distributed deformation to shear localization has been analyzed theoretically from a continuum point of view. One example involves an instability or bifurcation, that develops in the strain field as the result of strain weakening. Then when a small region yields, in response to the applied boundary conditions it becomes weaker than its surroundings and tends to continue deforming. According to Takahashi and Koide, 1989, this process tends to localize strain into a shear band. In principal, the localization process does not require strain – weakening. This is an area of active research both theoretically and experimentally.

“The monitoring of acoustic emission (AE) has proven to be one of the more powerful tools available in analyzing brittle fracture” (Lockner, 1993). This non-destructive technique records the acoustic waves (generally in the 200 to 2000 KHZ range) that are spontaneously radiated during impulsive micro crack growth or slip. The simplest procedure is to count the number of AE pulses during deformation. There is generally a good correlation between AE rate and inelastic strain rate so that the AE rate can be used to quantify damage accumulation occurring in the sample. According to other studies have analyzed full wave forms of AE signals and, in particular, first motions in an attempt to infer source characteristics and focal mechanisms. Numerous studies also confirmed that AE event amplitudes obey the power law frequency magnitude relation observed for earthquakes (Zhaoyong, Naiguang and Mishirong, 1990).

According to Rice (1992) a recent breakthrough occurred in which it was recognized that a fluid pressure gradient from the center of the fault zone to the walls of the fault would allow high fluid pressure and vanishing shear strength in the interior, and at the same time not result in hydro-fracture of the surrounding country rock. Since this type of model requires a stable gradient in fluid pressure, it suggests that mature faults with thick gouge zones are likely to be weaker than immature narrow faults. This model may also explain the apparent weakness of low-angle thrust faults.

EXPERIMENTAL METHODOLOGY

Samples of the two types of rocks – igneous and metamorphic were collected from different parts of Nigeria. Granite, which is an example of igneous rock, was collected in Auchi in Edo State, while marble, which is an example of metamorphic rock, was collected in Enugu in Enugu State and at Oza-nogogo in Delta State.

The first sample called marble (metamorphic rock) was broken into smaller pieces of six different sizes. The diameters of the different sizes were measured using a micrometer screw gauge. From the values of the diameter obtained, the radius was also calculated. Subsequently the area of the different sizes of the rock sample was calculated using the formula below:

Area, $A = \pi r^2$

Where π = a constant whose value is 3.142.

After the measurement of the different area, the six different sizes of the sample rock were individually fractured by adding different weights on the cracker (Figure 1). At the end of the fracturing process, the weight that brought about the fracturing was read and recorded correspondingly together with the measured area.

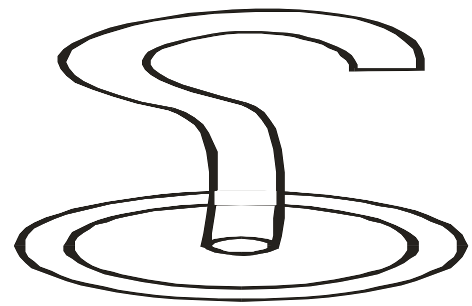


Figure 1: The Cracker.

Six different readings of force (weight) capable of fracturing different sizes of rock sample were obtained for each sample. The procedure was repeated for the other rock sample of granite rock.

Three sets of readings were obtained for marble and granite. These readings are shown in Tables 1 and 2.

DATA ANALYSIS, INTERPRETATION AND DISCUSSION OF RESULTS

At the end of the experiment the table of values obtained for the various rock types are stated below. The table of values obtained from metamorphic – marble is listed in Table 1. Table 2 shows a reading collected from igneous rock – granite

From the reading recorded in Tables 2 and 1, graphs of weight (force) measured in Newton (N) was plotted against area (A) measured in meter squared (m^2). The graph as obtained by Mathematics 6 software is shown below.

Table 1: Calculated Values for Metamorphic Rock.

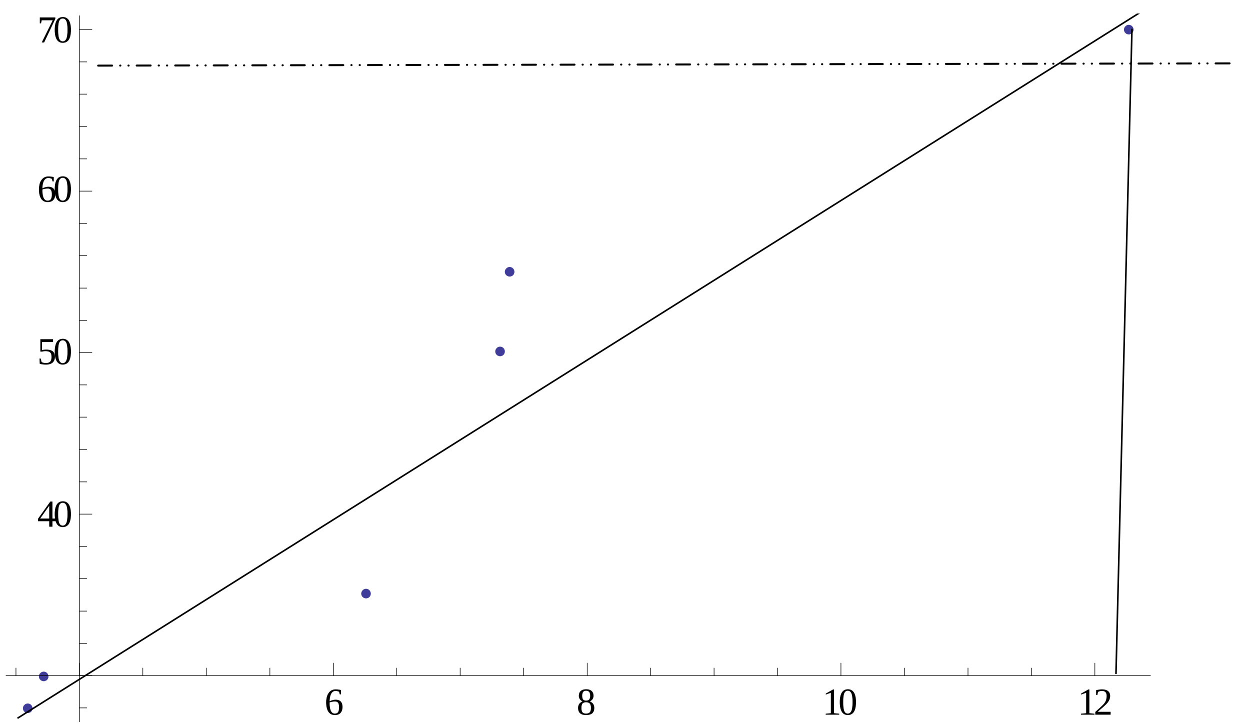
Size	Diameter (cm)	Radius (m)	Area (m^2)	Mass (kg)	Force (N)
1	0.215	$1.08x10^{-3}$	$3.63x10^{-6}$	2.80	28
2	0.218	$1.09x10^{-3}$	$3.73x10^{-6}$	3.00	30
3	0.282	$1.41x10^{-3}$	$6.25x10^{-6}$	3.50	35
4	0.305	$1.52\ x10^{-3}$	$7.31x10^{-6}$	5.00	50
5	0.306	$1.53x10^{-3}$	$7.40x10^{-6}$	5.50	55
6	0.397	$1.98x10^{-3}$	$12.26x10^{-6}$	7.00	70

Table 2: Calculated Values for Igneous Rock.

Size	Diameter (cm)	Radius (m)	Area (m^2)	Mass (kg)	Force (N)
1	0.200	$1.00x10^{-3}$	$2.142x10^{-6}$	3.00	30
2	0.203	$1.02x10^{-3}$	$3.24x10^{-6}$	3.50	35
3	0.230	$1.15x10^{-3}$	$4.16x10^{-6}$	5.00	50
4	0.290	$1.45\ x10^{-3}$	$6.16x10^{-6}$	6.00	60
5	0.305	$1.53x10^{-3}$	$7.31x10^{-6}$	7.00	70
6	0.3111	$1.56x10^{-3}$	$7.60x10^{-6}$	8.00	80

ListPlot[{{3.60,28.0},{3.73,30.0},{6.25,35.0},{7.31,50.0},{7.40,55.0},{12.26,70.0}}]

METAMORPHIC Rock-MARBLE



Area ($x10^{-6}$)

From the plotted graph, the slope was calculated in order to obtain the minimum stress necessary for the fracture of rock.

$$Slope = \frac{Force}{Area} = \frac{70-30}{12.3-5} = \frac{40}{7.3x10^{-6}} = \frac{40}{0.0000073} = 5479452.05Nm^{-2}$$

Slope = Tensile Stress = 5.74×10^6 Nm^{-2}

Based on the readings recorded in Table 2, a graph of weight (force) in Newton (N) was plotted against area (A) measured in meters squared (m^2). The graph as obtained by Mathematical 6 software is as shown below:

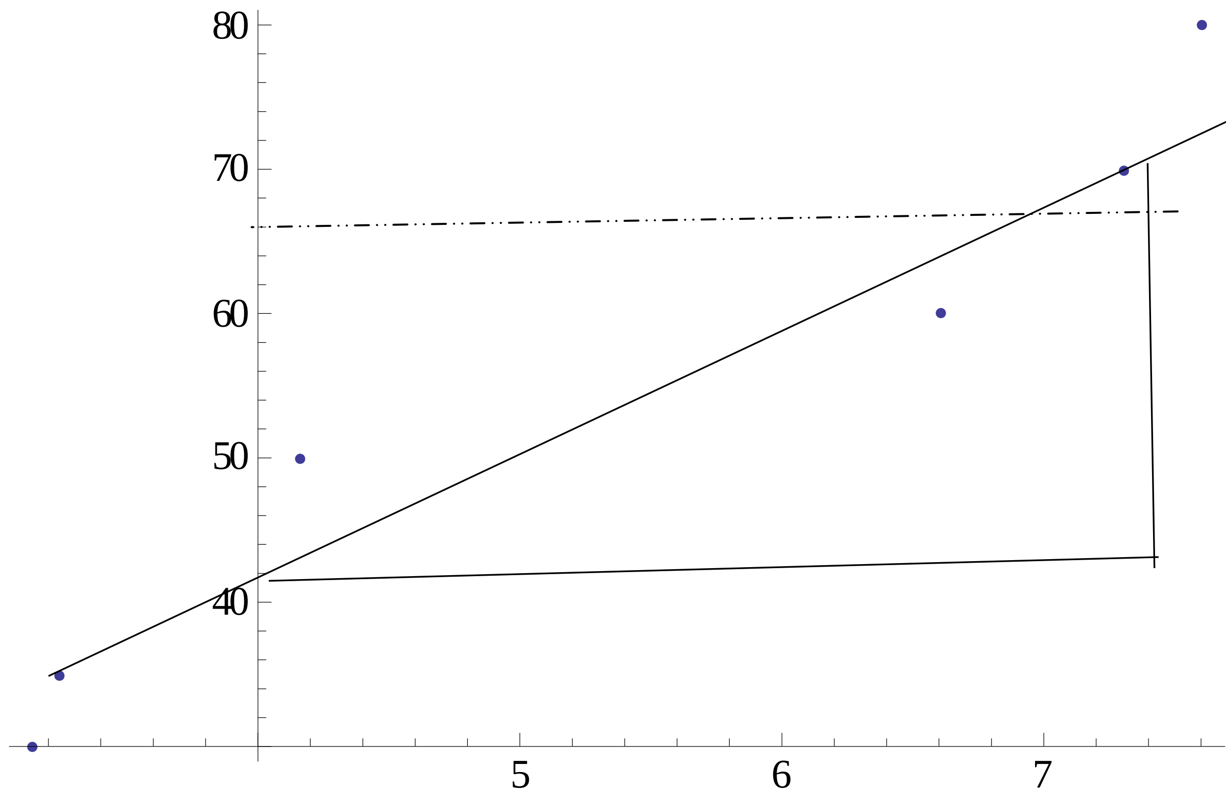
From the plotted graph, the slopes, was calculated in order to obtain the minimum stress necessary for the fracture of rock slope,

$$Slope = \frac{Force}{Area} = \frac{70-40}{7.4-4} = \frac{30}{3.4x10^{-6}} = \frac{30}{0.0000034} = 8823529.41Nm^{-2}$$

Slope = Tensile Stress = 8.82×10^6 Nm^{-2}

ListPlot[{{3.142,30.0},{3.24,35.0},{4.16,50.0},{6.61,60.0},{7.31,70.0},{7.60,80.0}}]

IGNEOUS Rock-GRANITE



Area ($x10^{-6}$)

SUMMARY AND CONCLUSIONS

From the results obtained, it is observed that the minimum stress required to fracture a sample of an igneous rock (granite) is 8.82×10^6 Nm^{-2}.

Also for the sample of metamorphic rock, (marble) considered/investigated, it will require a minimum stress of 5.74×10^6 Nm^{-2}.

The results obtained from the empirical research showed that granite an igneous rock required more stress to fracture in comparison with marble a metamorphic rock.

RECOMMENDATION

It is thereby recommended that geologists, engineers, and other disciplines in the Earth's sciences, such as pedology, geomorphology, and geochemistry should put into consideration the knowledge of the minimum tensile stress required to fracture the different rock samples before using any of the two types of rock for any engineering work such as construction of roads, bridges, tunnels, canals, sculpture work, houses, excavations, etc.

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