REPORT

Aim

To determine the physio-mechanical properties of SHALE rock samples.

Introduction

Shale is a fine-grained sedimentary rock composed of silt and clay-sized particles. Typically formed in quiet depositional environments such as deep ocean floors, lagoons, and lakes, shale exhibits a fissile characteristic—meaning it tends to split into thin layers. Shale primarily consists of quartz and clay minerals, with lesser amounts of feldspar, carbonates, and organic matter. The layered structure and mineral content make shale a unique rock type with distinct physical and mechanical properties.

Understanding these properties is crucial for various applications, particularly in the fields of geotechnical engineering, hydrocarbon exploration, and environmental science. Shale’s behaviour under different stress conditions directly influences the design and safety of structures like tunnels, dams, and hydraulic fracturing operations in oil and gas extraction. This project aims to determine the physio-mechanical properties of shale through various tests, including the Uniaxial Compressive Strength (UCS) test, the Brazilian tensile strength test, and the triaxial compression test.

Why We Need Physio-Mechanical Properties

Physio-mechanical properties are essential for predicting the behaviour of shale under various conditions. Shale's mechanical characteristics are influenced by its density, porosity, mineral composition, grain size, and effective pressures. These properties are vital for:

- **Mining and Drilling:** Shale’s hardness and fracture toughness affect drilling operations and the selection of appropriate mining techniques.
- **Geotechnical Engineering:** Understanding shale's strength and deformation behaviour is crucial for designing stable foundations and underground structures.
- **Hydraulic Fracturing:** Shale's response to stress helps in assessing the feasibility and efficiency of hydraulic fracturing for hydrocarbon extraction.
- **Environmental Stability:** Knowledge of shale’s properties aids in evaluating its stability and response to environmental changes, such as groundwater flow and seismic activity.

Fundamentals

The strength and deformation properties of shale are critical for designing structures that interact with it. Appropriate strength parameters must be determined to ensure that designs align with the specific characteristics of the shale in the bearing strata. Before any major construction or heavy loading is applied, it is necessary to evaluate the shearing failure possibilities and plan appropriate tests to determine the strength properties of the shale.

Physio-Mechanical Properties of Shale

Shale's performance is closely tied to its physio-mechanical characteristics. These properties are divided into physical and mechanical categories, each playing a significant role in practical applications.

Physical Properties of Shale:

- **Colour:** Shale's colour can range from grey and black to green, red, or brown, depending on its mineral content.
- **Lustre:** Shale may exhibit a dull, earthy, or sometimes slightly shiny lustre, influenced by its mineralogy.
- **Hardness:** Shale varies from very soft, where it can be easily scratched with a fingernail, to moderately hard, requiring a knife to scratch.
- **Density:** Shale typically has a density ranging from 2.0 to 2.8 g/cm³, depending on its composition.
- **Specific Gravity:** The specific gravity of shale reflects its mineral composition and can range from about 2.2 to 2.8.
- **Porosity:** Shale is known for its low permeability and variable porosity, often affecting fluid storage and flow within the rock.
- **Moisture Content:** Shale can retain significant moisture, which influences its mechanical properties and stability.
- **Fracture Patterns:** Shale often displays a tendency to fracture along its layers, showing conchoidal or irregular fracture patterns.
- **Volatile Matter:** Shale may contain organic material that releases gases upon heating, impacting its behaviour under thermal stress.
- **Fixed Carbon:** In organic-rich shales, the fixed carbon content is a measure of the non-volatile carbon remaining after volatile components are driven off.

Mechanical Properties of Shale:

- **Uniaxial Compressive Strength (UCS):** UCS is a measure of the maximum stress shale can withstand under uniaxial loading before failure. This property is crucial for understanding the load-bearing capacity of shale in construction and extraction activities.
- **Tensile Strength:** Shale's tensile strength indicates its resistance to being pulled apart and is essential for assessing its behaviour under tensile stress conditions.
- **Elastic Modulus:** The elastic modulus of shale measures its stiffness, indicating how much it deforms under a given load. Higher values suggest greater resistance to deformation.
- **Poisson's Ratio:** This ratio describes the relationship between lateral and axial strains in shale when subjected to axial loading. It helps predict how shale will deform under stress.
- **Shear Strength:** Shear strength determines the shale's ability to resist sliding along internal planes and is critical for evaluating slope stability and failure potential.
- **Point Load Strength:** The point load strength test provides an index for estimating other strength properties and helps classify shale based on its load-bearing capacity.

UCS TEST

The uniaxial compressive strength test determines the sample's compressive strength, which plays an essential role in the design of the underground structure. In this test, we determine the compressive strength by applying a compressive load on the sample until failure occurs in the core by a fracture in the middle using compressive testing machines. The stress value at this failure is the compressive strength of the specimen. This test primarily aims to define and characterise intact rock's strength.

Universal Testing Machine

Test Observations-

Sample	L1	L2	L3	L avg	D1	D2	D3	D avg
1	142.48	142.49	142.52	142.4967	54.24	54.18	54.49	54.303
2	141.03	141.37	141.17	141.19	54.20	54.29	54.58	54.3567
3	130.45	130.23	130.32	130.333	54.98	54.99	54.04	54.67

Calculations-

$$\varepsilon_a = \frac{\Delta l}{l_o}$$

where, l_o = original measured axial length

Δl = change in measured axial length (defined to be positive for a decrease in length)

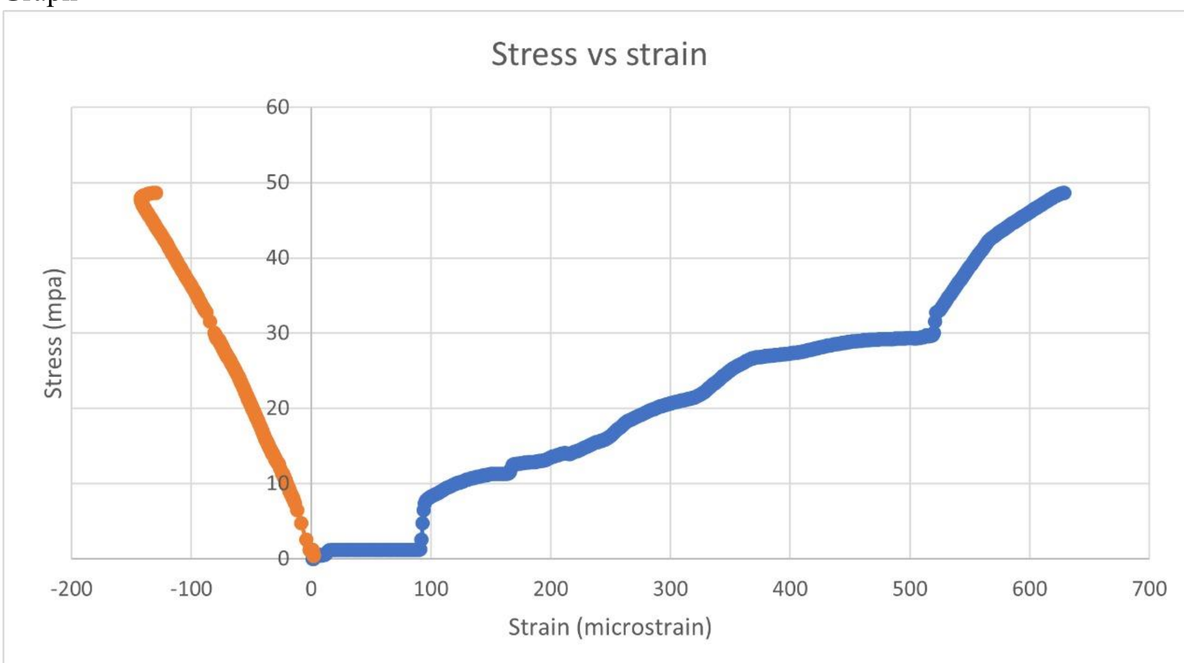
$$\varepsilon_d = \frac{\Delta d}{d_o}$$

where, d_o = original undeformed diameter of the specimen

Δd = change in diameter (defined to be negative for an increase in diameter)

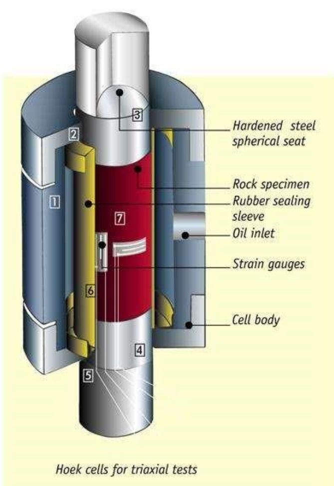
$$\sigma = \frac{P}{A_o}$$

Graph-



TRIAXIAL COMPRESSION TEST

In the triaxial compression test, A cylindrical specimen of coal is enclosed in an impermeable membrane loaded axially to failure in compression and then exposed to confining pressure. The axial loading is applied by a compressive testing machine and the confining pressure is by the oil pressure through an external source. The objective of this test is to determine the strength of a cylindrical coal specimen subjected to triaxial compression. From the results of this test, we can calculate the values of internal friction and cohesion of the coal sample.



HOEK CELL

TRIAXIAL TESTING MACHINE

Test Observations-

Specimen No.	Average specimen diameter(mm)	Average specimen length(mm)	Confining pressure(MPa)	Axial load (kN)	Axial stress(MPa)
1.	54.80	103.32	0	93.66	39.37
2.	54.69	103.44	2	115.93	49.37
3.	54.62	104.10	4	125.43	53.55

Calculation-

$$\boldsymbol{\emptyset = arc\sin\frac{m-1}{m+1}}$$

$$\boldsymbol{C = b\sin\frac{1-sin\emptyset}{2\,cos\emptyset}}$$

$$\sigma_1 = \frac{\text{Axial Load}\times 1000}{\left(\frac{22}{7}\times\left(\frac{D_{avg}}{2}\right)^2\right)}$$

formulas used for calculation :-

$$\sigma_1 = \sigma_3 N\phi + 2C\sqrt{N\phi}$$

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

$$m = N\phi = \frac{1+\sin\phi}{1-\sin\phi}$$

so, $$\sigma_1 = \sigma_3\left(\frac{1+\sin\phi}{1-\sin\phi}\right) + \frac{2C\cos\phi}{1-\sin\phi}$$

$$C = \frac{\sigma_{ci}\ (1-\sin\phi)}{2\cos\phi}$$

$$\phi = \sin^{-1}\left(\frac{3.96-1}{3.96+1}\right)$$

$$\phi = \sin^{-1}(0.59)$$

$$\phi = 36.15^\circ$$

$$C = \frac{39.37\,(1-\sin(36.15^\circ))}{2\cos 36.15^\circ}$$

$$C = \frac{39.37\,(1-0.59)}{1.6} = 10.08$$

Calculations :-

• sub-group (I)

$\sigma_3 = 0$, Davg = 54.80 mm

Axial load at failure = 93.66 kN

$$\sigma_1 = \frac{93.66 \times 1000}{\frac{22}{7} \times \frac{(54.80)^2}{4}} \frac{N}{mm^2} = 39.37 \text{ MPa}$$

• sub-group (II)

$\sigma_3 = 2$ MPa , Davg = 54.69 mm

Axial load at failure = 115.93 kN

$$\sigma_1 = \frac{115.93 \times 1000}{\frac{22}{7} \times \frac{(54.69)^2}{4}} \frac{N}{mm^2} = 49.37 \text{ MPa}$$

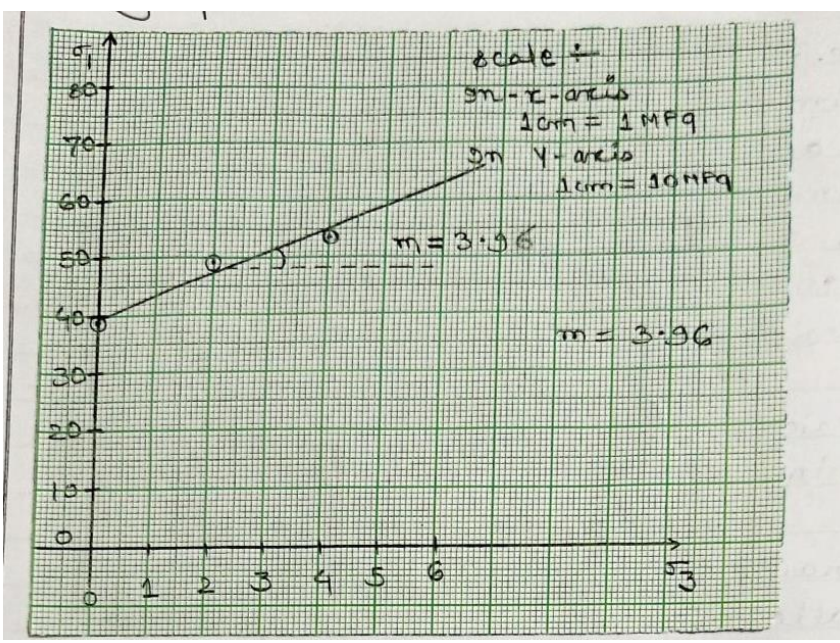
• sub-group (III)

$\sigma_3 = 4$ MPa , Davg = 54.62 mm

Axial load at failure = 125.43 kN

$$\sigma_1 = \frac{125.43 \times 1000}{\frac{22}{7} \times \frac{(54.62)^2}{4}} \frac{N}{mm^2} = 53.55 \text{ MPa}$$

Graph:



BRAZILIAN TEST

The Brazilian test is conducted to indirectly measure the tensile strength of the sample. A material's tensile strength is the amount of stress it can withstand before collapsing when stretched or pulled. In this method, we grip the cylindrical sample at two ends with some fixing material, and then apply the tensile force at the two ends. Due to gripping difficulties, applying an axial tensile force to the rock sample for determining the tensile strength is not a successful method.

TEST APPARATUS

Test Observations-

	THICKNESS (MM)				DIAMETER (MM)					
Sample	L1	L2	L3	L avg	D1	D2	D3	D avg	Load at failure(N)	Tensile strength(MPa)
1	27.62	27.70	27.66	27.66	54.40	54.46	54.24	54.37	7800	3.30
2	28.52	28.48	28.84	28.60	54.40	54.52	54.36	54.42	10460	4.28
3	27.01	26.73	26.89	26.87	54.54	54.60	54.30	54.58	8700	3.77

Calculations-

The tensile strength test is to verify the tensile strength of rock samples or its resistance against fracturing. Direct tensile test on rock samples is relatively difficult to undertake and the Brazilian test offers an indirect method to measure tensile strength. The term 'indirect tensile' implies that load is applied under compression. The figure below shows the typical mode of failure associated with tensile stress:

- Tensile strength of the rock specimen is then calculated from the formula,

$$\sigma_t = \frac{2P}{\pi D t}$$

- where,
- σ_t = Brazilian tensile strength of the rock specimen
- P = Peak failure load of the specimen
- D = Diameter of the specimen
- t = Thickness of the specimen

RESULT

MECHANICAL PROPERTIES	VALUES
POISSON’S RATIO	0.1596
YOUNG MODULUS	0.11298 GPa
UNIVERSAL COMPRESSIVE STRENGTH	48.68 MPa
TENSILE STRENGTH	3.78 MPa

Conclusion-

UCS TEST -
The purpose of this test is to determine the stress-strain curves and Young's modulus and Poisson's ratio of a specimen of regular geometry in uniaxial compression.

TRIAXIAL COMPRESSION TEST-
This test determines the strength of cylindrical specimens subjected to triaxial compression. From the results of this test, the values of internal friction and cohesion of the material can be calculated. Three different types of triaxial compression tests can be conducted in the laboratory. The tests are designed to determine the strength of cylindrical specimens as a function of confining pressure. In each of the three test types, the strength envelope is produced differently.

BRAZILIAN TEST-
By using the Brazil test, the determination of the uniaxial tensile strength of prepared specimens was done. In the experiment, we found most materials fail in tension at their uniaxial tensile strength at their tensile strength when one principal stress is tensile and the other finite principal stress is compressive with a magnitude not more than three times tensile principal stress.

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