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Evaluation of Residual Geo-mechanical Characteristics of Rocks from Akure, Ado-Ekiti and Ikare-Akoko Quarries in Southwest Nigeria

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ABSTRACT: The objective of this paper is to evaluate the Residual Geo-mechanical Characteristics of Rocks from Akure, Ado-Ekiti and Ikare-Akoko Quarries in Southwest Nigeria using appropriate standard techniques.Data obtained show that residual ultimate compressive strength (UCS) values under in-situ circumstances were, in order, 70.56 MPa, 72.9 MPa, and 76.27 MPa. It was shown that when the concentrations of acid and base in the immersion solution increased, the samples' UCS decreased. Compared to samples with coarser grains, those with finer grains (as determined by the microstructure analysis) retained a comparatively higher UCS value even after being submerged in an acidic and alkaline medium. The samples that were soaked in 0.75M, 1.5M, and 3.0M of acid and base showed varying degrees of deterioration during the second wetting cycle in the water medium, despite not being detected to be damaged during the first cycle. However, the durability was found to decrease much more when the medium was turned acidic and alkaline.

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The assessment of geomechanical characteristics in rock masses—especially soft rock masses—has significantly improved in recent years. This is somewhat attributable to enhanced computational approaches and partially to upgraded measuring apparatus. Improved tools and apparatus for both in situ and lab investigations provide a more precise assessment of soft rock masses' characteristics. Improvements in Data Mining (DM) methodologies provide more effective decision-making instruments. Better characterisation of the geomechanical characteristics of rock masses is made possible by the combination of more potent computational techniques and enhanced instruments. The assessment of geotechnical qualities is highly unpredictable because to the variety of rock formations and the time and financial burden of acquiring subsurface data. The complexity of the underlying geological processes and the inherent challenges in geomechanical characterization add to the uncertainty (ASCE, 1996; Ike *et al.*, 2021; Sousa *et al.*, 1997; Yufin*et al.*, 2007; Miranda, 2007; Miranda *et al.*, 2009; Sousa, 2010). Consequently, in situ and laboratory testing are frequently used in conjunction with empirical approaches to evaluate geomechanical parameters (Bieniawski, 1989; Barton, 2000; Hoek, 2007a, b; Miranda *et al.*, 2018). In situ tests are typically used to characterize

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deformability by applying a load in a certain manner and measuring the resulting deformations of the rock mass.

When assessing the mechanical characteristics of soft rocks, such as conglomerates and residual rock masses, heterogeneities in the rock masses are crucial. This is true of the residual granite formations in Porto, where the rock mass's behavior is highly erratic (Miranda *et al*., 2014). Therefore, proper precautions must be taken while designing and building engineering systems like tunnels, such as ongoing tunnel face characterisation and real-time monitoring to prevent mishaps (Miranda, 2007; Sousa, 2010; Sousa and Einstein, 2012).

Granitic residual soils are a type of residual soil that originates from the in situ weathering of granitic intrusive rocks exposed at or near the surface. These types of soils are common in many parts of the world, and their geotechnical characteristics have been studied in a number of places, including Brazil (Townsend, 1985; Coutinho, *et al*., 2015), China (Niu, *et al*., 2017; Lin, *et al*., 2021), Hong Kong (Wang and Yan, 2006), Malaysia (Salih, 2012), Portugal (Viana, *et al*., 2006), South Korea (Jeong, *et al*., 2000), and Thailand (Jotisankasa and Mairaing, 2010). However, when pore pressure increases, numerous studies have been conducted on the reduction of fracture energy, capillary tension, friction, and effective stress. Only the effects of the fluid acidity and alkalinity of the surrounding environment were noted. The impact of the rock environment's acidity and alkalinity on the rock's residual geomechanics properties was the main focus of this study. There were several Uniaxial Compressive Stress Tests, Abrasion A laboratory model with different alkalinity and acidity conditions was used to assess the resistance or slake durability of a variety of rock samples. Additionally, the impact of the simulated environment on the mineralogical composition was noted. In addition, porosity measurements and point load tests were performed under various circumstances. According to several reviews on the properties of geomechanics, rock strength, for example, can be defined as the rock's capacity to withstand deformation and fracture due to internal friction and cohesive properties. A strength index is required for the application of engineering categorization. The challenge lies in establishing a practical application through experience, as the manner of loading greatly affects the outcome. Less resistance to tensile strength and more resistance to understanding are provided by Rock Strength. Strength is mostly determined by the mineral content of the rock; monomineral rock has a generally higher strength than polynomial rock, which typically contains weaker minerals. The size, depth of occurrence, and degree of metamorphism of minerals all affect their strength, which decreases as a mineral's dimensions grow. (Pate, 1973; Eyankware, *et al*., 2021 Morrow *et al*., 2000). Soft rocks, on the other hand, have a uniaxial comprehensive strength (UCS) that is higher than soil and lower than that of hard rocks. Physical attributes, sample preparation, size, saturation, and mineral content have an impact on this (Bieniawski 1981; Ulakpa, *et al*., 2021; Igwe, *et al*., 2022). Since the uniaxial compressive strength of intact rock serves as a fundamental metric for both rock mass categorization and rock mass strength criteria, the behavior of rock material during compression is significant. The dispersion of quartz, hornblende, and biotite in particular was compared with the mechanical properties of the rocks in previous studies on the effects of petrophysical properties on rock mechanical properties. These results demonstrated some degree of significant influence on the mechanical properties of the rocks. Other studies focused on point counting analyses of modal composition, grain size distribution, and average grain size. Over four decades of research have been conducted to determine how moisture content affects the behavior of rocks. It is often linked to phenomena like crack propagation and capillary suction. The majority of scientists concur that when moisture content rises, any given soft rock's strength will diminish. Strength and moisture content do not, however, usually correlate linearly. Hawkins and McConnell (1992) noted that most sandstone types exhibit an abrupt strength loss between 0% and 1% moisture content, with only a slight strength reduction above 1% moisture content. Schmitt *et al*. (1992) found similar results for the Vosges and Fountainebleau sandstones, which exhibit an exponential correlation, while the Tournemire sandstone showed a relatively linear correlation. The objective of this paper is to evaluate the Residual Geo-mechanical Characteristics of Rocks from Akure, Ado-Ekiti and Ikare-Akoko Quarries in Southwest Nigeria.

MATERIALS AND METHODS

Sample collection: The rock samples were collected in lump form from three distinct places. One came from an Akure quarry, while the other came from Ado-Ekiti and Ikare-Akoko. These samples had the following tags: DD1, DD2, and DD3. Using the Mansory Machine, they were meticulously formed into a cuboid shape measuring 110 mm in height and 54 mm in length and width. To ensure that the samples ready for UCS were precisely the right size, these were later polished on a lapping machine.

Petrographic Analysis: A chip from each sample and those immersed in various concentration of hydrochloric acids and Sodium Hydroxide were prepared for thin section analysis so as to determine the petrographic properties which provide insight into various microscopic features of rocks which might significantly impact the strength of the rock as shown in Fig. 1,2 and 3 respectively. A thin section analysis was conducted on a chip from every sample, as well as those that were immersed in different concentrations of hydrochloric acid and sodium hydroxide, to ascertain the petrographic properties. These properties offer an understanding of the various microscopic characteristics of rocks that could have a substantial impact on their strength as shown in Table 1, 2, and 3 respectively.

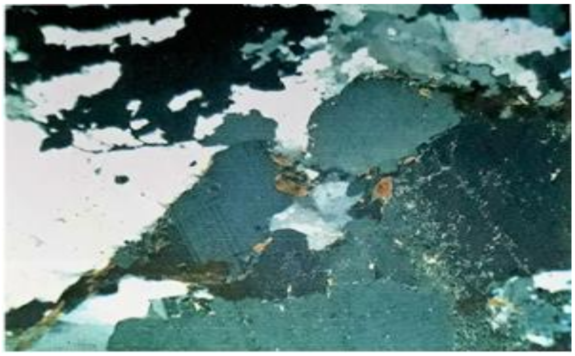

Fig. 1: Micrograph Picture of Sample DD1

Fig.2: Micrograph Picture of Sample D

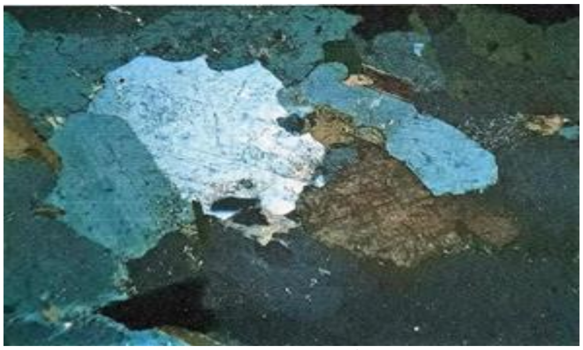

Fig. 3: Micrograph picture of Sample DD3

Table 1: Mineralogical Composition of Sample DD1

Minerals	1st Count	2nd Count	3rd Count	Total	% of the Mineral (%)
Quartz	5	4	6	15	30.61
Biotite	7	-	2	9	18.37
Microcline	8	6	4	18	36.73
Plagioclase	-	1	1	2	4.08
Opaque	-	1	1	2	4.08
Mymalcite	1	2	-	3	6.12
Ground Total				49	

Texture: Medium Coarse Grain

Table 2: Mineralogical Composition of Sample DD2

Minerals	1st Count	2nd Count	3rd Count	Total	% of the Mineral (%)
Quartz	8	4	12	24	36.36
Biotite	8	-	4	12	18.18
Microcline	8	5	6	19	28.78
Plagioclase	2	-	-	2	3.03
Opaque	3	3	1	7	10.6
Mymalcite	-	2	-	2	3.03
Ground Total				66	

Texture: Medium Coarse Grain

Table 3: Mineralogical Composition of Sample DD3

Minerals	1st Count	2nd Count	3rd Count	Total	% of the Mineral (%)
Quartz	5	4	6	15	30.61
Biotite	7	-	2	9	18.37
Microcline	8	6	4	18	36.73
Plagioclase	-	1	1	2	4.08
Opaque	-	1	1	2	4.08
Mymalcite	1	2	-	3	6.12
Ground Total				49	

Texture: Fine Grain

Packing Density and Packing Proximity: The degree of interlocking, or the kind of grain to grain contact and the number of contacts per grain, packing density, or the measure of grain packing arrangements, and packing proximity, or the measure of the spacing between grains, were ascertained along traverses per thin section. By using Kahn's (1956) approach, packing density and packing proximity were measured see equation 1 and 2. The packing proximity for every sample is determined to be 100, indicating that the grains boundaries are what cause the proximity reported in these samples and that pores are not apparent.

Acid and Base Preparation: Conical volumetric flask was used to measure the required quantity of acid in solution and the required mass of base, respectively. Both quantities were meticulously weighed on a weighing balance as shown in equation 4. Distilled water was used to dilute each weighed and measured base and acid to the necessary milliliters per litre.

$$\text{Packing Density} = \frac{Summedlengthofgrainsmeasuredalongtranverse}{Lengthoftranerseline} \times 100 \quad (1)$$

PD DD1 = 99.5% ; PD DD2 = 98.22% ; PD DD3 = 99.8%

$$\text{Packing Proximity} = \frac{Sumofgraintgraincontactsalongtranverseline}{Totalnumberofcontactsencounteredalongtranverseline} \times 100 \quad (2)$$

$$Wmass\ HCl = \frac{\text{Molar Mass of HCl} \times \text{\% Purity of the Acid}}{SpecificGravityoftheAcid} \quad (4)$$

Rock Density and Porosity Determination: The weight of a rock divided by the weight of an equivalent volume of water was used to calculate the specific density of the rock samples as shown in Table 4.Density of the samples were determined using equation 5;

$$\text{Density} = \frac{\text{(Weight in air)}}{(Weightinair - WeightinWater)} \quad (5)$$

Water buoys up anything inside it by one gram per cubic centimeter of displacement because it has a density of one g/cm^3. As a result, the volume of the rock sample in cm^3 is equal to the weight in air less the weight in water see Table 5.

Table 4: Densities of Rock Samples

S/N	Rock Sample	Rock Density (g/cm3)
1	DD1	2.77
2	DD2	2.810
3	DD3	2.920

The Porosity of a sample could be easily calculated, since the pore volume (Vp) of the sample could be calculated using equation 6

$$Vp = \frac{Saturatedweight - Ovendriedweight}{Densityoftheporefluid\ (water)} \quad (6)$$

While the Bulk Volume V_b= *Height* × *Length* × *Breadth* (m^3)
So Porosity is calculated as using equation 7;

$$Porosity(\phi) = \frac{Vp}{Vb} \times 100\% \quad (7)$$

After the samples were placed on a tray above the water in the bell jar and the jar was evacuated, the majority of the air was taken out of the pores. After that, the samples are thrown into the sea, and atmospheric pressure is restored. After that, water can enter the pores that have been cleared. However, a caliper was used to measure the samples directly in order to determine the bulk volume.

Table 5: Porosity

S/ N	Rock Sample	Initial Weight (g)	Saturated Weight (g)	Oven Dried Weight(g)	Height (m)	Length (m)	Breadth (m)	Bulk Volume (m3)	Weight diff (kg) (Wsat–Wdried)
1	DD1	35	22.365	2.77	0.118	0.057	0.051	0.000333	0.004
2	DD2	32.1	20.676	2.810	0.114	0.059	0.056	0.000377	0.003
3	DD3	36	23.6712	2.920	0.105	0.07	0.056	0.000413	0.003

Determination of Uniaxial Compressive Strength of Rock Samples: Using a compression crushing machine, the rocks' Uniaxial Compressive Strength was ascertained. This was done in compliance with ASTM D6951/D6951M-09, (2015). In order to stop flying chips during sample failure, safety guards were closed and the rock specimens to be analyzed were put on the machine platen see Fig. 4. By closing the release valve and installing guards on the switch power pack, the exhaust circuit was sealed off, enabling the pump to generate pressure and start the ram. When the load was applied, the gauge displayed the failure loads and the failure loads were recorded.

The Uniaxial compressive Strength was determined using equation 8, and Table 6

$$Co = \frac{P\ (AppliedPeakLoadkN)}{Width(m) \times Height\ (m)} \quad (8)$$

Slake Durability Test: Samples were soaked in 0.75 M, 1.5 M, and 3.0 M of acid and base from each of the three locations. Water, a somewhat acidic and slightly alkaline medium, and one medium are used for the experiment. A sample of each of the aforementioned samples, each consisting of 10 rock lumps with a combined mass of 45–75g; the greatest grain size of the rock was 3 mm. The lumps were shaped like rough rounds. These samples were put in a clean drum and dried at a temperature of 105˚C until the mass remained constant. Usually, the drum and sample are recorded. After that, the lid was put back on, and the drum was connected to the motor and set in the trough. After adding slaking fluid—typically water heated to 200 ˚C —to the trough, it was circulated for 200 revolutions over the course of ten minutes. After removing the drum from the trough and the cover, the drum and the sample section that was kept are dried at 105˚C to a consistent mass. After cooling, the mass B of the drum plus the sample that was kept is noted. Following a repetition of the previous three stages, the mass C of the drum and the sample that was kept were measured and recorded. After that, the drum was thoroughly cleaned and its mass D was noted as shown in Table 7 and 8 respectively.The percentage ratio of the final to beginning dry sample masses is used to construct the Slake Durability Index (Second Cycle) using equation 9:

$$\text{Slake Durability Index Id2} = \frac{C-D}{A-D} \times 100\ \% \quad (9)$$

Additionally, samples from these sites were submerged in different acidic (HCl) and alkaline (NaOH) concentrations for ninety (90) days in order to establish their petrographic analysis, porosity, and Uniaxial Comprehensive Strength.

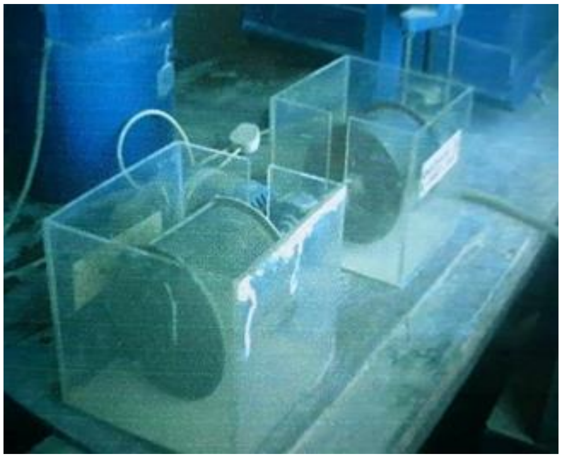

Fig. 4: Slake Durability Testing Machine

Table 6: Uniaxial compressive strength of the samples

S/N	Rock Sample	Force (kN)	Breadth (m)	Height (m)	Area (m^2)	UCS (Mpa)
1	DD1	400	0.054	0.105	0.00567	70.546
2	DD2	390	0.056	0.10	0.00535	72.897
3	DD3	450	0.055	0.11	0.0059	76.271

Table 7: Slake durability test for samples in acidic and alkaline solutions

		Medium acid solution Water medium		Medium Alkaline solution water medium			
S/N	Sample	Id2 (%)	Sample	Id2 (%)	Sample	Id1 (%)	Id2 (%)
1	DD1-13	96.82	DD1-12	96.55	D1-13	93.22	89.83
2	DD1-9	97.82	DD1-11	96.67	D1-9	97.87	93.62
3	DD1-1	97.96	DD1-7	95.24	D1-1	96.29	92.59
4	DD3-3	97.72	DD2-2	98.36	D3-3	98.53	95.59
5	DD1-6	98.07	DD2-3	98.00	D1-6	98.46	96.92
6	DD2-4	97.22	DD1-4	97.56	D2-4	97.14	95.71

Table 8: Uniaxial Compressive Strength of Samples in HCl and NaOH

		Uniaxial Compressive Strength of Samples in acidHCl		Uniaxial Compressive Strength of Samples in alkaline (NaOH	
S/N	Molarityof Acid (M)	UCS (kN/m2)	UCS (Mpa)	UCS (kN/m2)	UCS (Mpa)
1	6.0	12962.96	12.963	19047.6	19.047
2		7476.64	7.476	24922.1	24.922
3	3.0	11864.41	11.864	21008.4	21.008
4		7619.05	7.619	18796.9	18.797
5	1.5	35346.10	35.346	34632.0	34.632
6		22570.82	22.571	37037.0	37.037
7	0.75	29320.99	29.321	48558.9	48.559
8		59587.47	59.588	47364.4	47.364
9	0.1	37126.72	37.127	15000.0	15.000
10		37735.85	37.736	18867.9	18.867

RESULTS AND DISCUSSION

Influence of Mineral Content: Except for samples DD1-5 and DD3-1, which were submerged in 0.1 M HCl and NaOH, respectively, and were predicted to have the maximum resistance but did not, it was shown that the strength of the rocks decreases as the concentration of acid and base increases. possessing, in that order, 90 kN and 110 kN of compression forces (Fig. 5, and Fig.. 6).

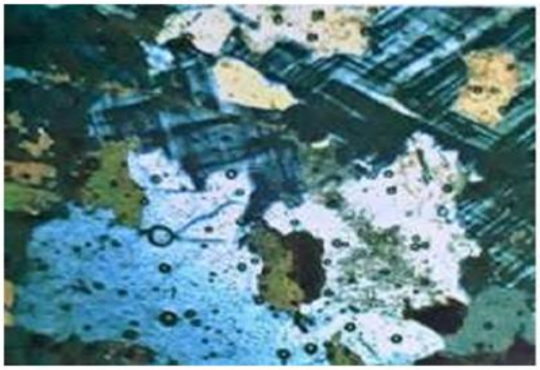

Fig.5: Photomicrograph image of 1st side of DD1-5soakedin 0.1 M ofNaOH

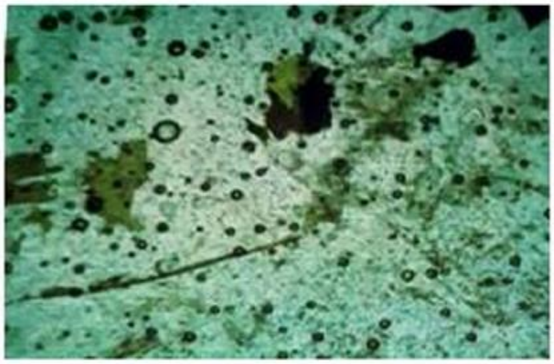

Fig.6: Plane polarized image showing the colored minerals alone (Biotite) in the 1st side

The sample had considerable NaOH penetration, which led to microfracturing, according to the photographic examination. It is suggested that this is the cause of the poor strength. This can be seen in Fig. 7 and Fig. 8photomicrograph. Despite being treated in 0.75 M of HCl, sample DD3-3 also displayed the greatest value of UCS. The observed effect of particle size on mechanical properties can be attributed to the presence of fine grains in Sample DD3.In a similar vein, the kinds, concentrations, and combinations of minerals found in various rocks vary, as does the elemental makeup of each mineral. Furthermore, the length of the transportation distance has an impact on the rocks' structure and morphology. According to Hofmann et al. (2013) and Hao et al. (2021), the strength value of sandstone rose as the size of its grains increased. Sample DD3-3, with its maximum strength of 76.271 Mpa, is the result as shown in Fig. 9 to 12 respectively.

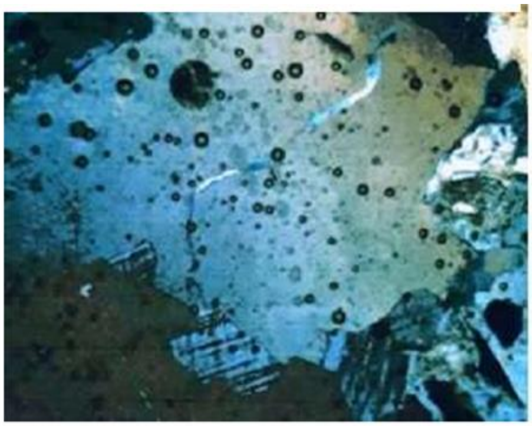

Fig. 7: Photomicrograph image of 2nd side of DD1- 5 soaked in 0.1 M of NaOH

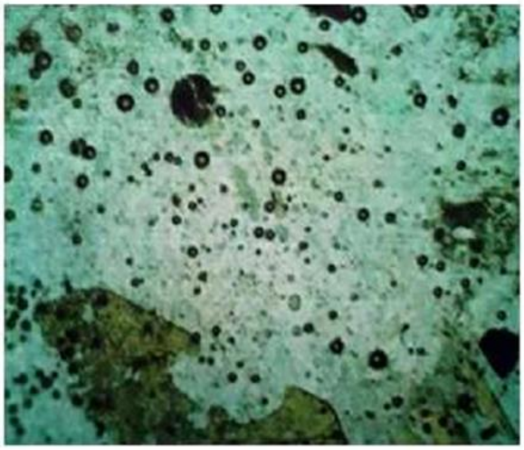

Fig.8: Plane polarized image of DD1-5 showing the colored minerals alone (Biotite) in the 2nd side

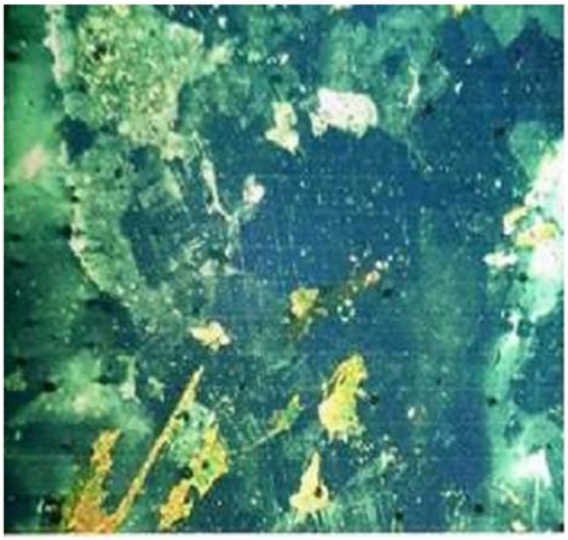

Fig. 9: Photomicrograph image of 1st side of DD1-2 soaked in 0.1 M of HCl

Fig. 10: Plane Polarized image of 1st side of DD1-2 soaked in 0.1 M of HCl

Fig.11: Photomicrograph image of 2nd side of DD1-2

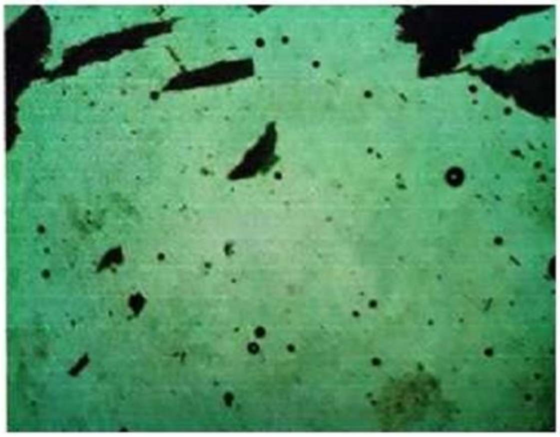

Fig. 12: Polarized image of 2nd side of DD1-2 soaked in 0.1 M of HCl

Others followed suit, with the UCS of the Samples decreasing as HCl and NaOH concentrations increased.

Effect of concentration of Acid and Base on Abrasion Resistance (Slake Durability): In the first cycle of the slake durability test, samples soaked in 0.75 M, 1.5 M, and 3.0 M of both acid and base were found to preserve their weight in the water medium, but to disintegrate in the acidic and alkaline medium see Fig. 13 to 16. The wetting cycle in the water medium had an impact on the rock samples' abrasion resistance, which rises with the concentration of acid or base they are soaked in.

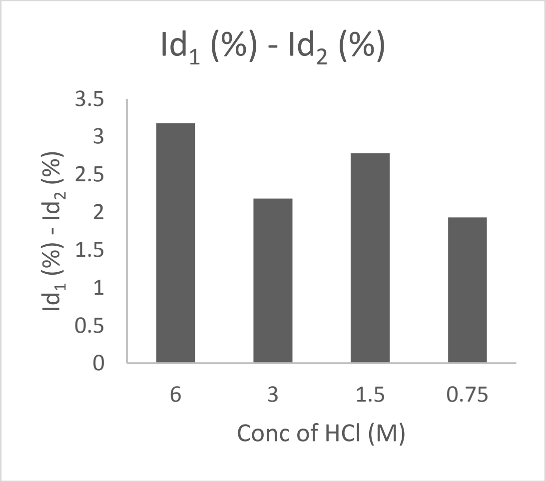

Fig. 13: Slake durability of samples in Acidic Solution using water as the medium

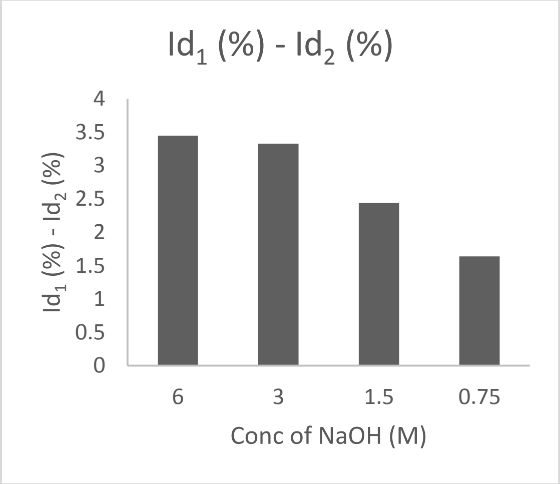

Fig. 14: Slake durability of samples in alkaline solution using water as the medium.

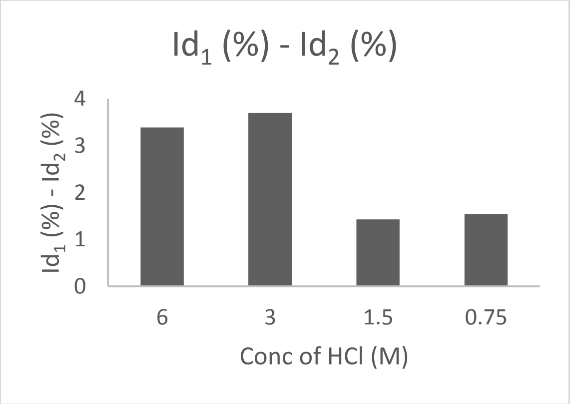

Fig. 15 Slake durability of samples in acidic solution using slightly acidic medium

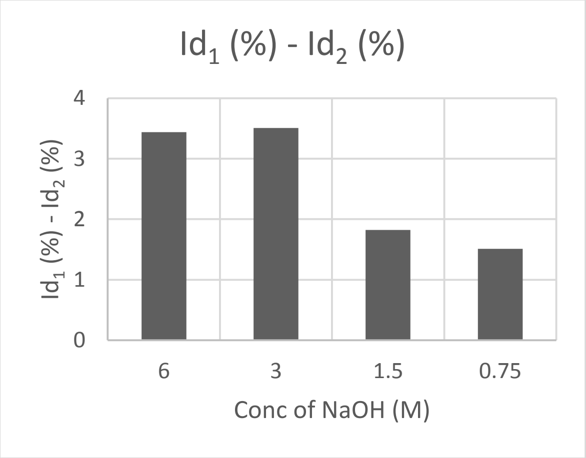

Fig. 16: Slake durability of samples in alkaline solution using slightly acidic medium

Effects of Acid Concentration on Uniaxial Compressive Strength: The density and compressive, flexural, and tensile strengths of concrete cured in acidic water are adversely affected by an acidic curing environment. When compared to rocks in lower concentrations, it was found that rocks soaked in higher acid concentrations had lower uniaxial compressive strengths. Honglei *et al*. (2020) assert that the mechanical properties of rock mass are significantly impacted by the amount of water or moisture present.

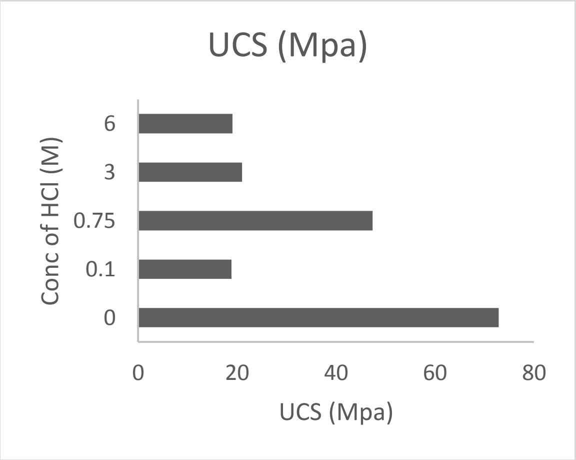

Fig. 17: Strength of Samples soaked in alkaline medium in respond to Concentration of NaOH

Rock engineering dangers may result from minor variations in moisture content that have a substantial impact on the mechanical and deformation characteristics of the rock. The results are consistent with a research by Honglei *et al*. (2020).This also applies to samples that are submerged in alkaline solutions. In contrast, samples DD 1–5 and DD3–1, which are submerged in 0.1M NaOH, diverged from the pattern and had values that are erratically opposite to the strength–concentration trend. It appears likely that the geomechanics qualities of rocks, such as strength, are significantly influenced by weathering and the degree of acidity and alkalinity of the surrounding environment see Fig. 17 and 18 respectively.

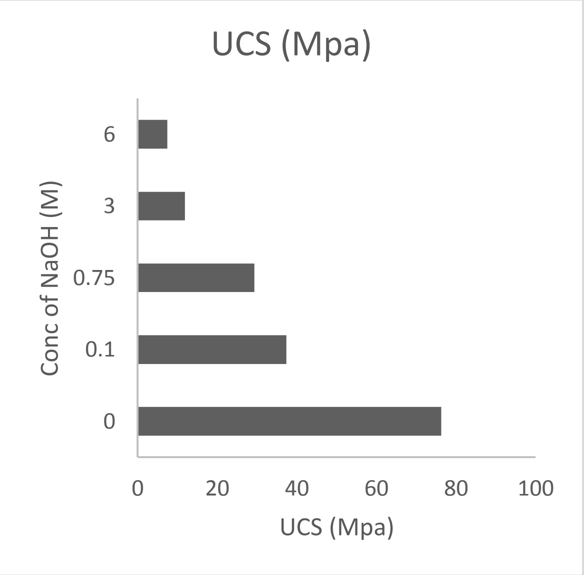

Fig. 18: Strength of Samples soaked in acidic medium in respond to Concentration of HCl.

Conclusion: Common in-situ and laboratory testing were explained, and numerous case examples were used to demonstrate the outcomes of various tests. Improved testing apparatus, both in-situ and in the lab, and the use of sophisticated numerical models for interpretation are often necessary for improving predictions.The majority of the time, a lack of data makes it necessary for geotechnical engineers to employ complex sensitivity analysis techniques. Numerical simulations are one method of gathering data, but the human creation of this data takes a lot of preparation time.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability: Data are available upon request from the first author.

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