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Research article

Investigating the effects of porosity on the strength and mechanical behaviors of geo-materials' specimens

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Abstract

Porosity plays a crucial role in both natural and man-made materials, serving as a fundamental microstructural characteristic that has a significant impact on their physical properties. Soils and rocks in nature are porous materials that are usually saturated with different fluids such as water, oil and gas. Therefore, it is very important to investigate the properties of porous materials and a better understanding of porous materials properties can lead to progress in oil, mining, and civil industries. In this research, porous samples with different porosity percentages were made and analyzed. The laboratory generation of actual porosity within the rock-like material samples was one of a significant aspect of this research. 5 groups of samples with different percentage of porosities were prepared including: 20%, 15%, 10%, 5%, 2% porosity and classified in 5 groups of A, B, C, D and E, respectively. Various experimental tests were performed with loading rate .5 MPa per second on the samples and the mechanical parameters of the samples were determined. These experiments show that the uniaxial compression and tensile strengths and elastic modulus of the rock-like specimens decrease with increasing their porosity. The mechanical parameters' maximum values were associated with group E samples (with 2-3% porosity). This group demonstrated a strength of approximately 34 MPa, an elastic modulus of 36 GPa, and a tensile strength of 7.3 MPa. The minimum values were observed in group A (with 20% porosity), which exhibited a strength of approximately 13 MPa, an elastic modulus of 16 GPa, and a tensile strength of 2.7 MPa. The study also investigated the Poisson's ratio. The results indicate that Poisson's ratio increases with increasing porosity. The maximum Poisson's ratio was found in group A, which had 20% porosity and 11% Poisson's ratio, while the minimum value was found in group E, which had 2-3% porosity and 26% Poisson's ratio. the result show that Porosity has the greatest effect on the tensile strength parameter, which can change the tensile strength by 270% with a 20% change.

1. INTRODUCTION

Porous materials are found in nature as inanimate objects, such as soils and rocks [1]. Most of the rocks in nature are porous materials that are usually saturated with different fluids such as water, oil, and gas. In the oil industry, hydrocarbon reservoirs are created in sedimentary formations, and the main rocks of these reservoirs are sandstone and oil shale, and since porosity is an inseparable part of the reservoir rock [2]. Therefore, knowing these parameters as much as possible and their effect on the rock mechanical behavior can make the drilling and exploitation operations in this industry less challenging.

Porosity, a key microstructural parameter, holds immense importance for the physical properties of various natural and artificial materials. Its substantial influence can be observed in several aspects, including diffusion coefficient, elastic wave velocities, elastic moduli, Poisson's ratio, yield strength, rupture or ductile strength, thermal conductivity, electrical conductivity, fluid permeability, dielectric constant, and magnetic permeability [3]. So far, there have been many studies effects of porosity on behavior of different materials, most of which have been done on different metals and alloys, some of which are listed below.

Based on a study examining the effects of temperature on rocks, the results suggest that as the temperature elevates, there is an increase in connected porosity and permeability. Conversely, P-wave velocity, thermal conductivity, thermal diffusivity, specific heat capacity, uniaxial compressive strength, and Young's modulus exhibit a decrease [4]. Another research examined the influence of temperature on porosity and wave speed. The findings revealed that temperature caused an increase in porosity and a decrease in P-wave velocity [5]. In a study investigated the application of Portland cement porous concrete (PCPC) in urban roads, the findings indicate that as the porosity decreases, the strength of the sample increases at the 28-day mark [6]. A separate research study focused on concrete has determined that the presence of higher porosity and larger aggregate particle sizes leads to a decrease in the compressive strength, flexural strength, and splitting strength of porous concrete. On the other hand, the utilization of high-grade cement and high-quality aggregate has been found to enhance the strength of porous concrete [7]. In an independent study, scientists investigated the correlation between porosity and compressive strength in porous concrete using both empirical and theoretical methods. The results indicated that non-intrusive pores play a role in reducing the strength of the concrete. To assess the total porosity, an estimation technique was employed and then compared to the effective porosity. The study demonstrated a robust correlation between the estimated total porosity and the measured effective porosity. This estimation method proves valuable in situations where a dedicated apparatus for testing total porosity is not accessible [8]. A study was conducted to assess the quality characteristics and toxicity of coal bottom ash coarse aggregate, as well as analyze the mechanical properties of porous concrete based on different mixing rates of coal bottom ash. The findings indicated that the coal bottom ash coarse aggregate met the standards for soundness and resistance to abrasion, as required for concrete coarse aggregates. As the mixing rate of coal bottom ash increased, there was minimal impact on the void ratio and permeability coefficient. However, it was observed that the compressive and flexural strength of the porous concrete decreased [9]. In a study focusing on granulation dimensions, the findings indicated that specimens with a larger grain size exhibited lower UCS (Unconfined Compressive Strength) compared to specimens with a smaller grain size. Additionally, under identical loading conditions, specimens with a larger grain size experienced earlier damage initiation compared to those with a smaller grain size [10]. In a research investigation that focused on concrete admixtures, the study examined the effects of varying proportions of an air-entraining admixture (AEA). The results showed that increasing the percentage of AEA in the mixture led to changes in several parameters. Specifically, the air content, void ratio, water absorption, and slump flow diameter values all increased. In contrast, as the AEA percentage increased, the fresh and hardened density, plastic viscosity, yield stress, sieve stability, compressive strength, modulus of elasticity, and sonic velocity values decreased [11]. Scholars conducted a numerical study to investigate the relationship between porosity, aggressive agents, and the mechanical properties of Ultra High-Performance Concrete (UHPC). The study used a numerical model in PLAXIS 2D software to assess the effects of cement grade and porosity on tensile strength, flexural strength, and compressive strength. The results show that the proposed equations accurately predict the strength of cement grade concrete [12]. Another study investigated the impact of size and shape on the permeability and mechanical properties of porous concrete. The study found that the shape and size of the specimens had a significant impact on their permeability and mechanical properties. Various mixtures were created using two types of aggregates and three types of cement in different molds. Permeability tests were conducted on all specimens to assess the influence of shape and size. Cube, cuboid, and cylindrical specimens were used to measure compressive strength, flexural strength, and splitting strength. The study found that the strength of porous concrete is influenced by several factors, including porosity, aggregate size and type, and cement grade. The results indicate that there are significant differences in strength based on variations in size and shape [13].

The review has been described as experiment research. Useful numerical research has also been done so far on porosity, some of which are described below.

In the field of porosity, numerical investigations are typically conducted within the subfield known as poroelasticity [14]. It is a branch of material science and mechanics dedicated to describing porous materials. Biot constant coefficient is a significant aspect of poroelasticity theory, substantial investigation has been conducted within this field. The Biot coefficient plays a vital role in the classical poroelasticity theory, which examines the mechanics of porous materials that are saturated with fluid and composed of both elastic grains and an elastic skeletal structure. The Biot coefficient can be determined using the following equation:

$$\alpha = (1 - \frac{KS}{KD}) \quad (1)$$

In this context, KD represents the bulk modulus of the porous skeleton, while KS refers to the bulk modulus of the solid material that constitutes the porous skeleton. With soils, KS >> KD with the result that $\alpha \rightarrow 1$ [14].

The research examined the correlation between static and dynamic Biot coefficients within a carbonate oilfield located in southwest Iran. To determine the static Biot coefficients, stress loading tests, and volumetric strain measurements were conducted while varying confining and pore pressures. The dynamic Biot coefficients were calculated using ultrasonic measurements and rock physics modeling under normal environmental conditions. Two distinct workflows were utilized, both incorporating carbonate rock physics models that accounted for various types of pores [15]. The initial approach in the study involved applying the conventional Gassmann's theory, while the second approach utilized a simplified version with a preset C-factor exponent. The findings indicated that the dynamic Biot coefficient obtained from the second approach exhibited stronger agreement with the static Biot coefficient, primarily due to the improved accuracy of the estimated porosity model. Another investigation focused on the Biot coefficient demonstrated that alterations in pressure and temperature have an impact on both static and dynamic coefficients. As a result, when pressure and temperature rise, both coefficients tend to decrease [16]. During an independent numerical study on porous media, scientists have expressed their conviction that the Displacement Discontinuity Method (DDM), functioning as an indirect boundary element method, is highly suitable for addressing problems related to porous media. To derive the solution for a poroelastic DDM, they utilize a fundamental solution of a point displacement discontinuity within a poroelastic medium. Following that, they introduce a numerical formulation and implementation for the poroelastic DDM in software known as CEP-DDM (Constant Element Poroelastic DDM) [17]. The accuracy and validity of the proposed solution and the newly developed code are verified through the use of two analytical solutions, another numerical solution, and some field measurements. These results demonstrate a strong agreement between the proposed solution, the newly developed code, and the verified data. In a separate numerical investigation aimed at enhancing the Displacement Discontinuity Method, the time parameter was incorporated into the formulation of this method to calculate crack propagation within a specified time frame. The outcomes of this study were compared to those obtained through an analytical method. The numerical results demonstrated a satisfactory agreement and alignment with the analytical results at the corresponding time period [18].

Due to the formation of oil within permeable reservoirs, a different branch of proelastic analysis has been dedicated to studying these oil reservoirs. Many researchers actively engaged in this area of study, for example, an enhanced sequential fully implicit ESFI algorithm has been proposed which is an effective approach for reducing the computational iterations in solving poroelastoplastic problems in reservoir geomechanics and several numerical examples demonstrated its efficiency and accuracy [19]. A combined analysis of poroelastoplasticity and permeability was suggested to examine the phenomena of pore collapse and shear-induced compaction in hydrocarbon reservoirs. The outcomes of this research have the potential to offer valuable understanding regarding the response of reservoir rocks when fluids are extracted and can contribute to the assessment of reservoir performance [20]. In another paper, a coupled reservoir geo-mechanical modeling approach was used to evaluate the strain-dependent permeability in reservoirs. By incorporating the cap elastoplastic model and conducting numerical simulations, the paper provides insights into the mechanical behavior of rocks and its influence on reservoir productivity [21].

Previous experimental studies on porosity have primarily focused on metals and brittle materials. However, in this present study, we specifically investigate the influence of porosity on the porous samples of rock-like materials. The effects of porosity on the mechanical characteristics of the samples are also studied. It should be noted that the preparation of suitable rock-like specimens with the desired porosity was also one of the significant aspects of this research. The selection of a specific mixing plan and mixer for creating a porous sample is a crucial aspect of this research. Previous studies in the field of porosity have not been consistent, and porosity has been examined as a secondary parameter.

2. MATERIALS AND METHODS

The research employed an experimental approach as its methodology. Among the tests conducted, the uniaxial test was utilized. This test holds significant importance in rock mechanics, as it enables the computation of essential parameters such as uniaxial compressive strength, Poisson's ratio, and elastic modulus. The results obtained from this test play a crucial role in determining these properties. To conduct this test, the sample is prepared by the following specified standards:

The sample to be subjected to the test should have a vertical cylindrical shape, with a length-to-diameter ratio ranging from 2 to 3. The sample should have a diameter equivalent to the NX-size cores, which is approximately 54 mm. The size of the testing specimen must be a minimum of ten times greater than the largest aggregate found within its constituents. Both ends of the test sample should be flat, with a precision of 0.02 mm, and the deviation from perpendicularity to the sample axis should not exceed 0.001 radians (approximately 3.5 minutes) or 0.05 mm per 50 mm. The lateral surface of the test sample must be smooth and free from any significant irregularities. Throughout its entire length, the lateral surface of the sample should not deviate more than 0.3 mm. The diameter of the test sample needs to be measured precisely, with an accuracy of 0.1 mm, in two perpendicular directions at three different sections (upper, middle, and bottom). The average of these measurements is then utilized to calculate the cross-sectional area. Once the samples with standard dimensions are prepared for testing, a device with suitable hardness is employed to apply a force to the sample at a loading rate ranging between 0.5 and 0.1 MPa. The uniaxial compressive strength can be determined using the following equation [22]:

$$\sigma_c = \frac{P}{A} \quad (2)$$

Where A is the area of the loading surface and P is the force at the time of failure.

Young's modulus E, also known as the modulus of elasticity in tension or axial compression, is a mechanical characteristic that assesses the stiffness of a solid material under tensile or compressive forces applied in the longitudinal direction. It quantifies the correlation between tensile or compressive stress σ and axial strain ε within the linear elastic range of the material. Young's modulus is determined using the following equation [23]:

$$E = \frac{\varepsilon}{\sigma} \quad (3)$$

In the field of materials science and solid mechanics, Poisson's ratio υ is utilized to quantify the Poisson effect, which refers to the expansion or contraction of a material in directions perpendicular to the direction of loading. It is determined as the negative ratio of transverse strain to axial strain. Poisson's ratio is an indicator of the amount of transverse elongation relative to axial compression, particularly for small changes in these quantities. The majority of materials exhibit Poisson's ratio values ranging between 0.0 and 0.5. For soft materials, Poisson's ratio can be determined using the following equation [24].

$$\upsilon = \frac{d\varepsilon_{lateral}}{d\varepsilon_{axial}} \quad (4)$$

Another test used in this research was the Brazilian indirect tensile test. The Brazilian test is an indirect technique used to determine the tensile strength of rocks. It is based on the observation that when rocks are subjected to biaxial stress fields and one principal stress is compressive, they tend to fail in tension. In this test, a cylindrical rock specimen is loaded along its axis in a diametrical plane. Typically, the sample fractures along the line of diametrical loading, and the indirect tensile strength (Tb) can be derived from this fracture pattern [25]:

$$T_b = \frac{2P}{\pi L D} \quad (5)$$

In the Brazilian test, the indirect tensile strength (Tb) is determined by considering the load at failure (P) along with the length (L) and diameter (D) of the cylindrical specimen. Similarly, in the Brazilian disc test, disc-shaped specimens are employed. To enhance the loading conditions, curved jaw loading platens are utilized in this scenario. The tests that were used in this research were briefly described. In the following, the manufacturing and cutting of the sample to the standard size and the tests performed on it are examined.

2.1. Preparation Of Samples

To conduct tests on rock samples and investigate the influence of porosity on various mechanical parameters, it is necessary to keep all other variables constant while varying the dependent variable of interest. However, finding natural rocks with such specific conditions can be challenging, if not impossible. Therefore, to carry out the relevant tests, rock-like samples were created using cement, sand, and other concrete additives, as described below. The ratio of pore space to sample height was maintained below 0.1, following relevant standards [23].

To achieve this, five different levels of porosity were selected, namely 20%, 15%, 10%, 5%, and 2%. These levels were classified into five groups, labeled A, B, C, D, and E. After determining the appropriate dimensions, various mix designs were utilized and evaluated. Ultimately, the optimal mix design was identified based on the maximum even distribution of porosity and the absence of pore space deposition.

The final mix design selected entailed a water-cement ratio of 0.5, a sand-cement ratio of 2, and the inclusion of concrete additives. This particular mix design successfully fulfilled both aforementioned criteria to a satisfactory extent. Fig. 1 shows the used material for made samples. The above materials were mixed with different plans then the perfect sample was placed in water for 28 days.

Fig. 1. Materials used include: Sand, Sand sketch, Cement, Water, and Concrete additive.

The above materials were mixed with different plans then the perfect sample was placed in water for 28 days.

2.2. Porosity Measurement

Porosity (n, expressed as a percentage) is defined as the ratio of the accumulated (total) pore volume (Vp, measured in cm3) contained within a rock specimen to the bulk volume (Vb) of the specimen, and can be calculated using the following formula [26]:

$$n = 100 * \frac{Vp}{Vb} \tag{6}$$

The porosity of rock-like specimens prepared in this work is measured considering fully saturated samples (at a saturation ratio of 100%). It involves measuring the change in weight of the sample before and after it is submerged in a fluid. This method is based on Archimedes' principle, which states that the buoyant force acting on an object submerged in a fluid is equivalent to the weight of the fluid displaced by the object. Here's the general formulation of the Archimedes Method for porosity measurement:

The dry weight of the solid sample (Wd) was measured using a balance. The sample was immersed in a fluid (usually water) and allowed to saturate completely. Then, the weight of the saturated sample (Ws) was measured while it was submerged in the fluid. The sample was saturated with water in a desiccator and vacuum pump. Fig. 2 shows the desiccator machine.

Pore volume Vp equal to Buoyancy force (Fb) per water was calculated using the weight difference before and after immersion:

$$Vp = Fb/\rho_{water} = (Wd - Ws)/\ \rho_{water} \tag{7}$$

Fig. 2. Desiccator device used for saturation and determination of porosity.

Table 1 presents the outcomes of the density and porosity test.

Table 1. Density and porosity of group

NO.	Group Name	Density (Ton/$\boldsymbol{M^3}$)	Porosity (%)
1	A	1.83	20-21.5
2	B	1.87	15-15.4
3	C	1.96	9.7-10.5
4	D	2.1	4.5-5.1
5	E	2.2	2-3

Before testing, thin sections of the samples were prepared and examined to ensure homogeneity of porosity and materials in different groups. In this study, a polarizing microscope was used to measure the optical properties of minerals to determine their compositions.

For over a century, the traditional method of thin-section identification has relied on the visual observation of geological experts using an optical microscope [25]. However, to minimize human error, the analysis employed split desktop image analysis software, which is an industry-approved standard for determining rock fragmentation size. This involved inputting scaled photographs of the thin sections into the software, which facilitated the relevant analysis. The porosity percentages of the different groups were then re-examined and validated using the steps illustrated in the accompanying image.

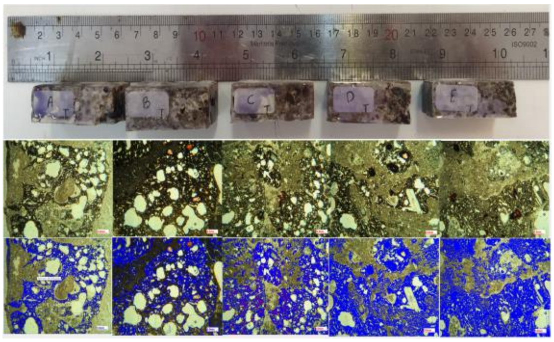

Fig. 3. Thin sections taken from the samples included in 5 groups and their review images.

In order to investigate the effect of porosity on the mechanical parameters of 3 groups of samples, tests were carried out, which are described below.

2.3. Uniaxial Compression Test

The uniaxial compressive test, also known as the unconfined compressive test, is employed to assess parameters such as the uniaxial compressive strength, Poisson's ratio, and Young's modulus of a material. This test involves the application of compression along the longitudinal axis of circular rock samples in the form of cylinders. It is considered the oldest and simplest test method, yet it remains one of the most convenient and effective approaches for determining the properties of rocks [27]. Based on the existing standards, samples of 5 porosity groups were prepared and ready for testing. Fig. 4 shows the sample preparation steps.

Fig. 4. Sample preparation steps: 1: Preparation of samples with different porosities 2: Preparation of core with standard diameter 3: Cut the sample to the desired dimensions 4: Initial grinding of the sample 5: Final grinding of the sample 6: Sample preparation for testing.

After preparing the standard samples, a uniaxial testing machine with suitable toughness was used to perform the test it should be mentioned that the cut samples had a diameter of 54 mm and a height of about 140 mm. As shown in Fig. 5. The load should be applied to the test specimen continuously without impact and at a constant rate rather than a more or less rate 1 loading constant or obtained deformation and failure Samples occur within 5 to 10 minutes. Instead, it is possible to select a loading rate between 0.5 and 0.1 MPa/s [27]. A high sensitivity data logger was considered to measure horizontal and vertical displacements.

Fig. 5. Uniaxial testing machine with a displacement data logger.

After performing the uniaxial test, different resistance parameters were obtained for the samples. This parameter includes:

1. Uniaxial compressive strength.
2. Elastic modulus.
3. Poisson's ratio.
4. Brazilian indirect tensile test.

2.3.1. Uniaxial compression strength

The uniaxial strength, also referred to as the unconfined compressive strength, of a rock can be defined as the maximum stress that a cylindrical rock specimen can withstand when subjected to a unidirectional stress applied along its axial direction. It is determined by dividing the maximum load sustained by the specimen during the test by its cross-sectional area. While its applicability is restricted, the uniaxial compressive strength enables comparisons between different rocks and provides some insight into their behavior under more intricate stress conditions [25]. The results obtained from the uniaxial test show that the resistance of the sample decreases with the increase in porosity this relationship is shown in Fig. 6.

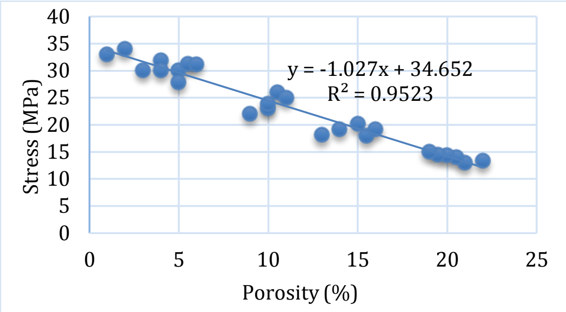

Fig. 6. Relationship between porosity and uniaxial compression strength.

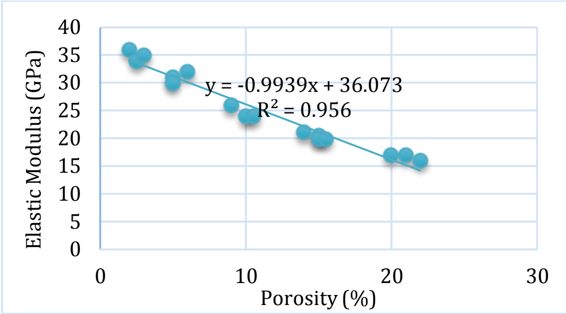

Fig. 7. The relationship between porosity and elastic modulus.

2.3.2. Elastic modulus.

The majority of materials possess the capacity to withstand and rebound from deformations caused by applied forces. This capability is known as elasticity and serves as the fundamental principle in rock mechanics. The simplest form of this response occurs when there is a linear relationship between the external forces and the resulting deformations. As long as the changes in forces remain sufficiently small, the response tends to be (almost always) linear [28]. After performing calculations and measurements, acceptable results were obtained that show the relationship between porosity and elastic modulus .As shown in Fig. 7, with the increase of porosity, the elastic modulus decreases and they have the reverse relationship.

2.3.3. Poisson's ratio.

In engineering analysis, Poisson's ratio is an essential parameter used to determine the stress and deflection characteristics of materials. (plastics, metals, etc.) [29]. This parameter is often used to describe the elastic properties of a material. When a longitudinal compressive force is applied to a solid, the solid begins to compress. During this compression, in most cases, the cross-sectional area of the material Increases. Poisson's ratio shows how deformable the cross-section of an object is It changes under longitudinal tension (or compression) [30]. This parameter is defined as the ratio of the lateral strain to the axial strain exhibited by a deformed object. Fig. 8 shown the diagram of axial strain stress and lateral strain stress of the samples.

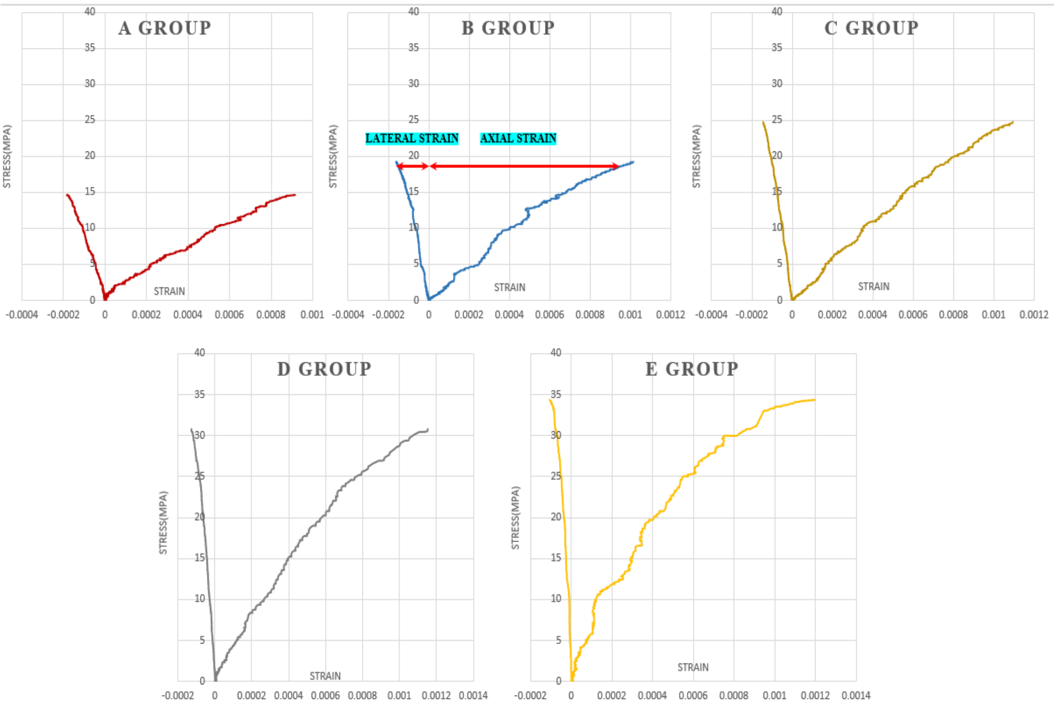

Fig. 8. Strain stress diagram used to calculate Poisson's ratio of samples with different porosity.

After performing the relevant calculations, the obtained data were analyzed. The results show that Poisson's ratio increases with the increase in the porosity of the samples, so Poisson's ratio and porosity have a direct relationship with each other. Fig. 9 shows this relationship.

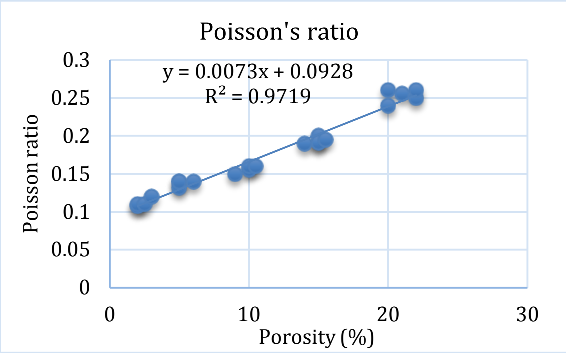

Fig. 9. Relationship between Poisson's ratio and porosity.

2.3. Brazilian Indirect Tensile Strength Test

On average, the tensile strength of rock is approximately 10% of its compressive strength value [31]. The direct tensile strength of a rock can be obtained by affixing metal end caps to the specimen using epoxy resin, which is then subjected to tension through the use of wires. In direct tensile tests, it is recommended that cylindrical specimens have a slenderness ratio between 2.5 and 3.0, and the diameter should preferably not be less than 54 mm. To ensure accurate results, the ratio of the specimen's diameter to the size of the largest crystal or grain in the rock should be at least 10:1. However, determining the direct tensile strength often presents challenges due to the lack of a satisfactory method for gripping the specimen without introducing bending stresses. As a result, most tensile tests have been conducted using indirect methods [25]. The Brazilian test is a method used indirectly to evaluate the tensile strength of rocks. It relies on the observation that when rocks are subjected to biaxial stress fields and one principal stress is compressive, they tend to fail in tension. In this test, a cylindrical rock specimen is loaded along its axis in a diametrical plane [25]. The samples made in this research have standard dimensions, i.e. diameter of 54 mm and a thickness of about 40 mm [32]. Fig. 10 shows the mudded Brazilian samples with different porosity.

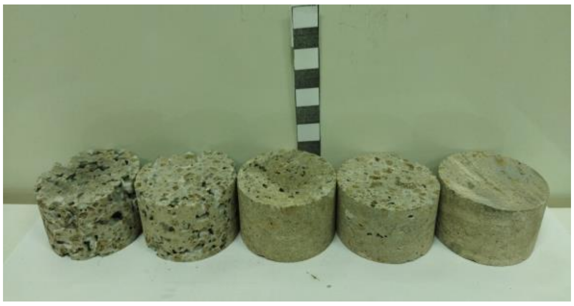

Fig. 10. Sample preparation for Brazilian test.

After preparing the standard samples, the samples were subjected to loading. Usually, there are two types of methods for loading in the indirect fatigue tensile test including linear loading and curved loading. In the case of line load, the upper and lower compression machine platens (jaws) make contact with the test sample along a line, tracing the circumferential area. On the other hand, in curved loading, a portion of the sample is in contact with both the upper and lower loading jaws, allowing the force to enter the sample with greater contact [31] . Fig. 11 shows the types of loadings in the Brazilian test and the curved loading used in this research.

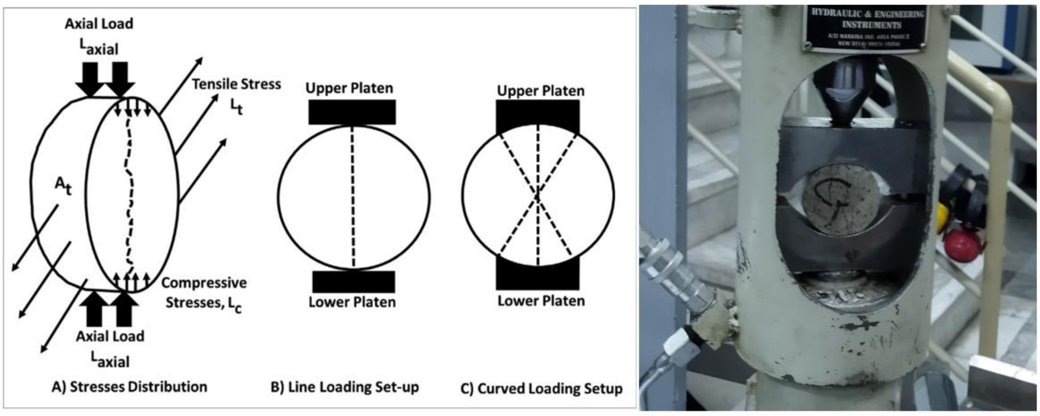

Fig. 11. Types of loadings in the Brazilian test [31]. And the path loading used.

After performing the relevant calculations of the Brazilian test, specific results and the tensile strength of the samples were obtained. As it is clear from the results, with the increase in the porosity of the samples, the tensile strength decreased, which indicates the reverse relationship. The results are shown in Fig. 12.

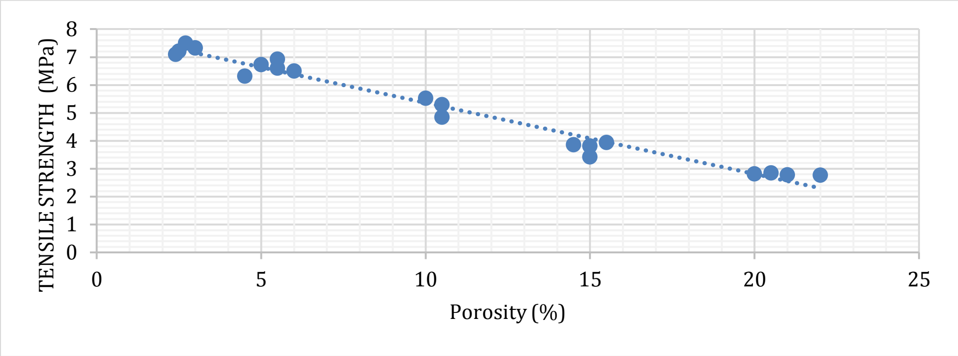

Fig. 12. Correlation between porosity and tensile strength of the samples.

The results of various tests on porous samples were obtained and the relationship between porosity and parameters was determined. In the following, the obtained results have been analyzed.

3. DISCUSSION

Porosity is a fundamental property that influences the behavior, performance, and applications of various materials. Its accurate characterization and understanding are essential for a wide range of disciplines and material science. Understanding the porosity of rocks is crucial for various applications, including mine engineering petroleum engineering, civil engineering, and environmental studies. Accurate characterization of porosity helps in resource assessment, rock strength analysis, and predicting the behavior of rocks under different conditions. This study undertook an examination of the impact of porosity on mechanical and resistance parameters, resulting in distinct findings derived from the conducted tests.

According to Fig. 6, as the porosity of the samples increases, the uniaxial strength decreases. This relationship suggests that there is an inverse correlation between porosity and uniaxial strength. In other words, as the amount of empty space or voids within the samples (porosity) increases, the strength to applied force in uniaxial strength decreases [33], [34]. When a material has a higher porosity, it means there are more empty spaces within its structure. These voids can act as stress concentrators and weaken the material's overall strength. As the applied force is transmitted through the material, it encounters these voids, causing localized stress concentrations and potential failure points. This leads to a decrease in the material's strength to uniaxial forces.

As shown in Fig. 7 as porosity increases, the elastic modulus of a material decreases. The presence of voids reduces the effective contact area between the solid components of the material, limiting the load transfer and causing a decrease in the overall stiffness. The voids also introduce stress concentration points, leading to localized deformation and a reduction in the effective elastic modulus [35]. According to Fig. 9 As porosity increases, Poisson's ratio increases with higher porosity, the material exhibits greater flexibility and is more prone to lateral deformation. The voids allow for more lateral expansion or contraction when the material is subject to axial loading, increasing Poisson's ratio. The increased porosity reduces the effective contact area between the solid components of the material, leading to less resistance to transverse deformation. This behavior causes a higher ratio of lateral strain to axial strain, indicating an increased Poisson's ratio. As shown in Fig. -12 with increasing porosity tensile stress decreases Tensile stress is the stress experienced by a material when it is subjected to a pulling or stretching force. It is calculated by dividing the applied force by the cross-sectional area of the material. With increased porosity, the effective cross-sectional area is reduced due to the presence of voids. Consequently, the material's ability to distribute and withstand tensile forces is diminished, leading to a decrease in tensile stress [36].

Based on the analysis presented, a 20% decrease in porosity significantly affects the mechanical properties of the material. The results suggest that reducing porosity can lead to substantial improvements in uniaxial strength, elastic modulus, tensile strength, and reduce Poisson's ratio. The study indicates that reducing porosity by 20% leads to a significant increase in uniaxial strength (260%), elastic modulus (225%), and tensile strength (270%), while decreasing Poisson's ratio by 40%. Therefore, it can be concluded that porosity primarily affects the material's ability to withstand tensile forces.

The relationship between mechanical properties and porosity in materials can be both linear and non-linear, depending on the specific material and the range of porosity being considered. In some cases, the relationship between mechanical properties and porosity can exhibit a linear trend. For example, when the porosity of a material is relatively low, the mechanical properties such as strength and stiffness may decrease linearly with increasing porosity. In such cases, the presence of porosity acts as a stress concentrator, leading to reduced load-bearing capacity. However, in other cases, the relationship between mechanical properties and porosity is non-linear. As porosity increases beyond a certain threshold, the reduction in mechanical properties becomes more significant. This non-linear relationship is often attributed to the interactions between the pores and the material matrix. When the porosity is high, the material may undergo significant deformation or failure due to the presence of large voids. This can lead to a sudden drop in mechanical properties, such as a decrease in strength, ductility, or fracture toughness. It's important to note that the specific nature of the non-linearity can vary depending on the material and the porosity range. For example, in some materials, the mechanical properties may decrease gradually at low porosities, followed by a more rapid drop at higher porosities. In other cases, the mechanical properties may exhibit a more complex non-linear relationship, with multiple threshold values. Additionally, the relationship between mechanical properties and porosity can also be influenced by other factors, such as the shape, size, and distribution of the pores, as well as the material's microstructure and composition. These factors can introduce further complexities and variations to the relationship. The research results indicate that the relationship between porosity and Poisson's ratio is linear. However, considering the non-linear relationship between other parameters can improve the accuracy of estimation.

The test results were scrutinized and evaluated, and the summarized outcomes are presented below.

4. CONCLUSION

Porosity is an inherent characteristic of all materials, indicating the quantity of vacant space present within a given material. In a soil or rock the porosity (empty space) exists between the grains of minerals. Most of the existing research on porosity has mainly focused on metals. In the rare cases that studies have investigated porosity in rock, it has usually been done as a sub-component of an investigation. In this research, the porosity of the specimens was investigated and the created porosity was created in the form of empty space throughout the sample in a uniform manner which is one of the distinctions of this research. according to this, five porosity groups with different porosity included 20%, 15%, 10%, 5%, 2-3% porosity were selected and classified in 5 groups of A, B, C, D, and E. A variety of tests were conducted on the samples to examine and assess their strength and mechanical characteristics.

The results show a significant correlation between porosity and other parameters which is described below.

- The results of uniaxial test show that E group with lowest percent of porosity (2-3%) have the maximum strength it means the uniaxial strength of the sample decreases with the increase in porosity.
- with increasing porosity, the elastic modulus decreases and the sample shows less resistance to deformation.
- Poisson's ratio increases with the increase of porosity and the samples with more porosity have a higher Poisson's ratio.
- The results obtained from the Brazilian test show that the tensile strength decreases as the porosity of the samples increases. One of the most important reasons can be expressed by increasing the amount of porosity,
- The amount of cohesion and resistance that exists in the solid texture has decreased, which has caused a decrease in the tensile strength of the samples.

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