Uniaxial Mechanical Pressure Effect To The Pore Structure Deformation of an Altered Breccia Rock

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Abstract. To investigate the pore evolution, a series of uniaxial compression test was conducted on an altered breccia rock was taken from Kadidia-Sigi, Sulawesi Tengah. The treatments of uniaxial compression started from natural pressure 986553.4 N/m2 then, 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2. The digital image processing method was applied to record and analyze the deformation of pore and crack structure. Physical parameters of rocks are investigated to understand the fact that porous rocks are fluid storage media. The amount of fluid contained can be estimated in an outline by analyzing the pore fraction of rocks. The results are qualitative data in the form of 2D and 3D images that the pore intensity decreases and the fractures intensity increases while quantitative data in the form of physical pore parameters [porosity {ϕ(P)} is linear negatively correlated and specific surface area {SsA(P)} is polynomial negatively correlated].

Keywords: Uniaxial Mechanical, Altered Breccia Rock, Uniaxial Compression

1 Introduction

A geothermal potential area at Kadidia is one of the geothermal potential areas in Sulawesi Tengah. This area is associated with the structure that developed in the Kadidia area, which is the Naik Poso fault that extends from the east outside the research area and the Palu Koro fault which is west of the research area. The Naik Poso fault is a fault that controls the emergence of the geothermal manifestations of the Kadidia area [1]. Kadidia geothermal rocks were altered which are characterized by alteration minerals in rock pores which are the result of sedimentation or transportation of origin rocks that fill the depression zone of Kadidia. The fracturing hydraulic has succeeded in increasing geothermal productivity because it creates a new fracture on a rock [2].

Basically, all physical properties of rocks are influenced by the pore structure. Pore structure can be used to estimate the permeability value, in this case, porosity and pore distribution [3]. Porosity and specific surface area are some of the main petrophysical parameters for managing subsurface energy resources including hydrocarbons and geothermal reservoirs and aquifers. Porosity is determined as a porous fraction that is occupied by pore spaces $(0 < \phi < 1)$ which is often expressed as a percentage. Whereas the specific surface area is the pore surface area of each solid volume unit [4]. In general, the specific surface area of rock is formed by the total surface of all pores in a rock.

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This study is a development from previous works that aim to analyze pore space deformation on geothermal rock conducted by fracturing hydraulic on an altered andesite breccia rock at Candi Telomoyo potential geothermal area and at Sumani geothermal area which has a result that the porosity and specific surface area increased with increasing the pressure [5,6]. We take advantage of the digital image analysis from digital rock physics (DRP), such as the three-dimension digital data that can be used to visualize the structure of the rock: the pore structures and both the matrix structure. DRP has advantages such as faster, more accurate, and lower cost analysis [7]. In addition, DRP is an application of upscaling techniques, that is, techniques to determine the nature of macroscopic material only from microscopic information [4].

2 Method

The rock sample is an altered breccia rock was taken from KDD-01 thermal gradient well at the potential geothermal area at Kadidia village, Nokilalaki sub-district, Sigi regency, Sulawesi Tengah. The rock sample was taken from 697 m depth from a well with total depth 703.85 m of clay cap. The sample rock reconstructed with a cylinder shape with a diameter of 4.5 cm and length 4.5 cm (see **Figure 1**).

This rock sample has a natural pressure of 69.7 kg or 986553.4 N/m2. This is known because rock samples were obtained from wells with a depth of 697 m. Giving pressure treatment on rock samples carried out at 5 times applying different pressure and carried out on rocks until it broke. Giving pressure treatment on rock samples in 5 different conditions carried out at pressures of 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2. Giving pressure treatment was carried out using a uniaxial compressive strength testing tool (see **Figure 2**).

Fig. 1. Geothermal sample rock.

Fig. 2. Uniaxial strength testing tool.

The digital images of the rock were produced by using a SkyScan 1173 micro-CT scan (see **Figure 3**). By using a micro-CT scan device, the digital data from the rock was obtained by generating a three-dimensional image of the rock itself. This device is specialized to produce high energy of X-ray which is able to scan such high-density rock. The scanning parameters are listed in Table 1.

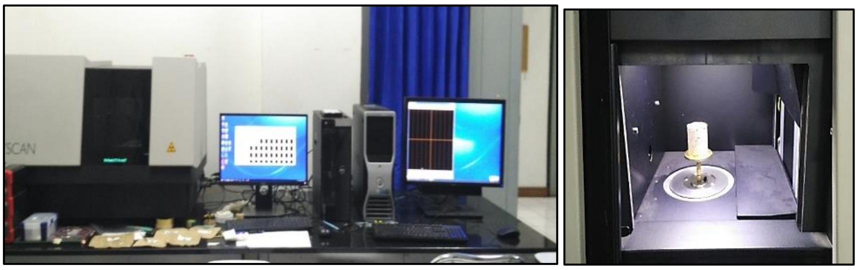

Fig. 3. Left-Right: SkyScan 1173 micro-CT scan device and preparation of sample scanning.

Table 1. Scanning parameter for rock's sample [8].

Scanner	SkyScan 1173
Sample spatial dimension	4.5 cm × 4.5 cm
Voltage	125 kV
Rotation step	0.04°
Filter	0.25 mm brass
Exposure time	450 ms
Object-source distance	182.000 mm
Camera-source distance	364.000 mm
Image pixel size	49.875 pixel
Scanning interval	1 hour 49 min 51 sec
Number of raw projection images	1200 (TIFF images)
VOI	300×300×300

3 Result and Discussion

3.1 Qualitative changes in the pore structure

Visualization is an important thing in analyzing the sample qualitatively. Cross-sectional images are produced by Nrecon software which reconstructs the images based on the Feldkamp algorithm (see **Figure 4**) and we can enhance the visibility of the pore and crack space. From **Figure 4** we can see that at natural pressure, 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, and 9907997 N/m2 of the connected fractures are on the z-axis and y-axis compared to the x-axis which only has fractures but they are not connected whereas. At pressure 11323425 N/m2 of the connected fractures are found on all axes. Small branches of fracture are visible, however, it cannot yet be concluded how significantly these branches of fracture contribute to the fluid flow [9].

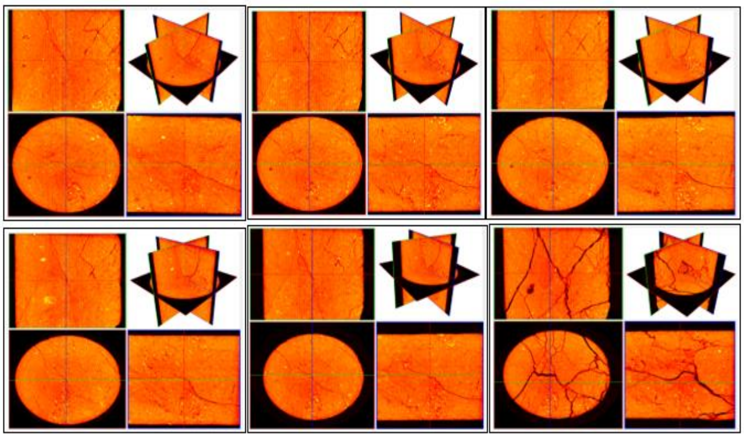

Fig. 4. Color-coded pseudo-density 2D slice view. Top row : at pressure 986553.4 N/m2, 1415428 N/m2, and 4246285 N/m2. Bottom row : at pressure 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2. (Top left-bottom left: Coronal image at x = 478 - Transaxial image at z = 478; top right-bottom right: Sagittal image at y = 559 - visualize ortho-slice).

The three-dimensional visualization of the digitalized sample shows a more enhanced performance (see **Figure 5**). The color of certain can be further modified by modifying the RGB transfer function but we cannot more observe the crack connectivity properties from the orthogonal view from **Figure 5**.

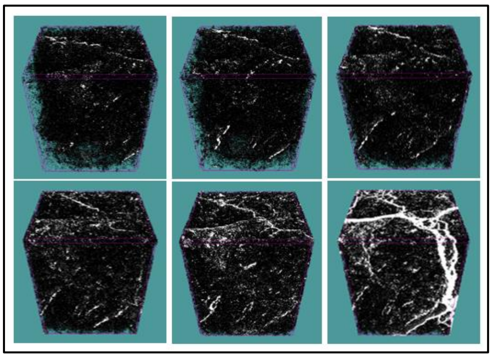

Fig. 5. 3D visual of the digitized sample with white color is a pore and black color is a matrix. Top row : at pressure 986553.4 N/m2, 1415428 N/m2, and 4246285 N/m2. Bottom row : at pressure 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2.

Figure 5 shows the pore structure for natural pressure, 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2 shown by the white color, while the black one shows the rock matrix. The 3D visualization at natural pressure shows the rock voids in the sample which are still small. There is a little visible fracture on the surface of the sample whereas. The 3D visualizations at pressure 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, 9907997 N/m2, and 11323425 N/m2 show that the pore intensity has decreased while the fracturing intensity increases. This is indicated by the white dots that previously stood alone but then joined with others to form a line called a fracture Or in the other words, the connected pore.

3.2 Quantitative changes in the porse structure

From rock samples at a depth of 679 m, it has a porosity value of 0.948%. This value represents 16.6% of the sample porosity value from the core porosity of 697 m rock depth which is valued at 5.69% [1]. The relationship of porosity to pressure changes is presented in **Figure 6** below.

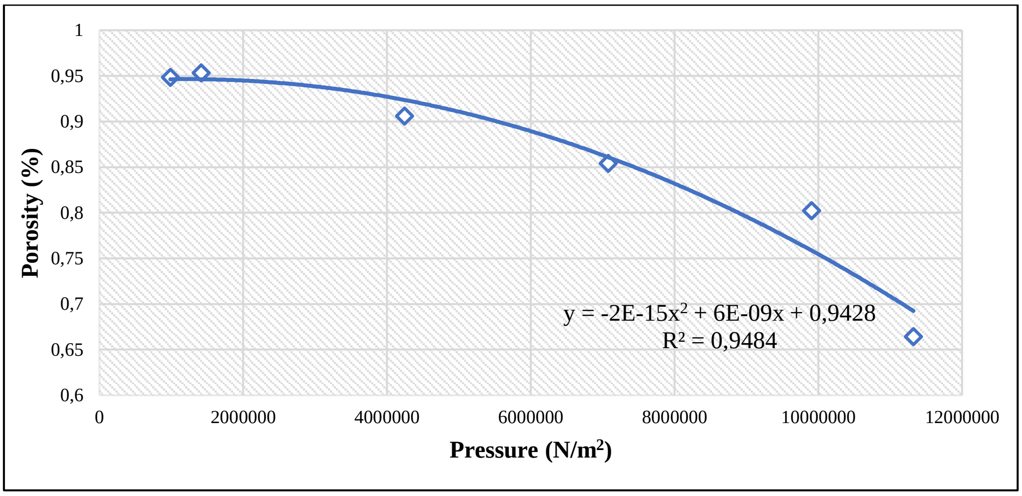

Fig. 6. The relationship of porosity to pressure changes.

Mathematically, the porosity relationship between a rock sample and pressure can be written in Equation (1):

$$\phi(P) = -2 \times 10^{-15} P^2 + 6 \times 10^{-9} + 0.9428 \tag{1}$$

From Equation (1) can conclude that the effect of pressure on porosity obtained has a polynomial relationship and is negatively correlated, the greater the pressure, the smaller the porosity value.

Meanwhile, the change in pore distribution in rocks with increasing pressure can be seen in **Figure 7** which explains that at the natural pressure of 986553.4 N/m2 it shows that the pore size distribution is mostly dominated by pore size with an average pore size of 2 pixels which is equal to 83.6324% and 0.1235% for the largest average pore size of 12 pixels. At pressures of 1415428 N/m2, 4246285 N/m2, 7077141 N/m2, and 9907997 N/m2the pore size distribution are still dominated by pore size with an average of 2 pixels with a range of 75.3757% - 84.7697% and the largest average pore size being 14 pixels. Meanwhile, at 11323425 N/m2 pressure, the number of pores with an average size of 2 pixels decreased to 42.0319% and the average size of the largest pore increased from the average size of the previous largest pore of 24 pixels.

This happens because the sample is dominated by clay minerals which are characterized as having many pores so that when under pressure there will be compression / compacting. In addition, the sample is also composed of quartz which is known to have fragile tenacity so that when pressed it will turn into the powder then the quartz powder fills the pores that were previously present. Then, there is a glass mineral as a sample compiler that has a very small size and fine texture and its presence along with clay minerals so that it fills the gap between minerals in the sample.

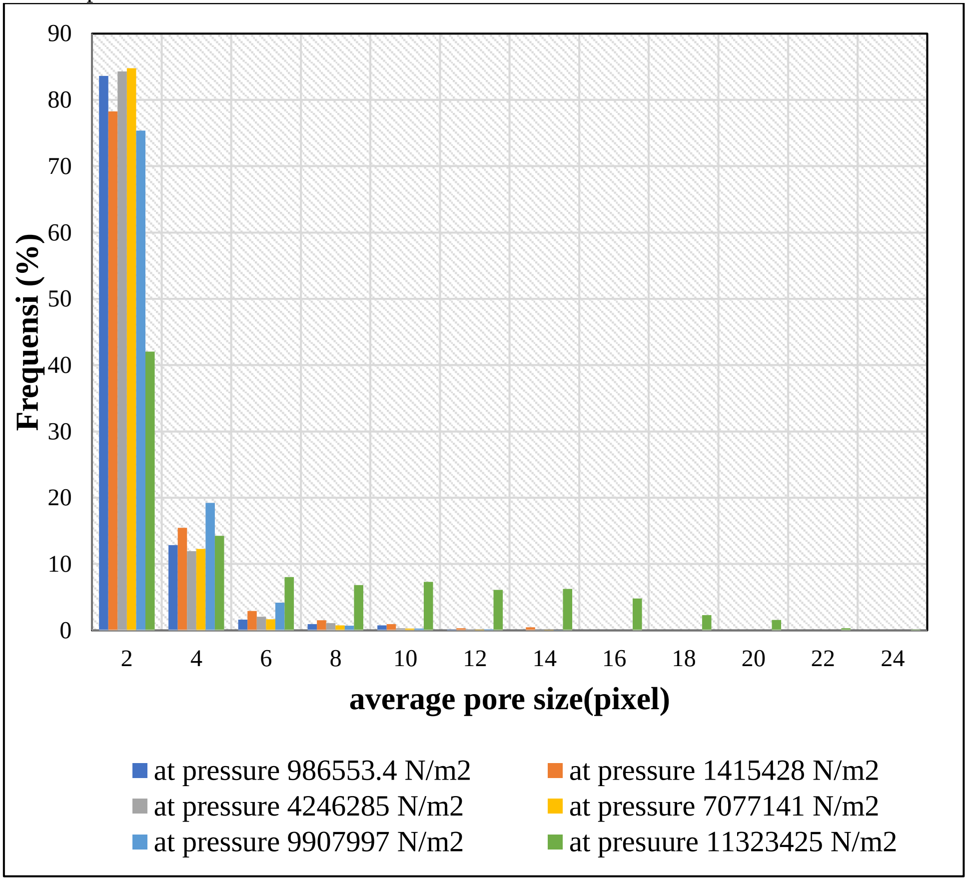

Fig. 7. Graph of the relationship of pore size-frequency to average pore size.

The specific surface area is the area of the pore in the rock matrix volume. The relationship of the specific surface area of the rock sample to the increase in pressure is presented in **Figure 8** which shows that the specific surface area increases polynomially to the increase in pressure. This makes it clear that the increase in pressure received by the sample causes an increase in the size of the pore volume in the sample. The relationship of pore volume to pressure is presented in **Figure 9**.

From **Figure 8** and **Figure 9** it can be seen that there is a decrease in the specific surface area at a pressure of 1415428 N/m2 as well as the volume of its portion. At pressures of 4246285 N/m2 to 9907997 N/m2, the specific surface area has increased as well as the volume of its portion although the increase is not as significant as the specific surface area of the pressure. But unlike the case at 11323425 N/m2pressure, the sample experienced a decrease in the specific surface area from the previous while, the volume of the pile increased significantly.

The decrease in specific surface area at a pressure of 11323425 N/m2 and an increase in pore volume at that pressure is due to the compacted rock and the relatively small pore frequency distribution from an average pore size of 2 pixels to 24 pixels later, the presence of actinolite minerals as rock constituents which have grain form so that when the sample is given a pressure of 11323425 N/m2, the mineral actinolite is compressed and its shape changes.

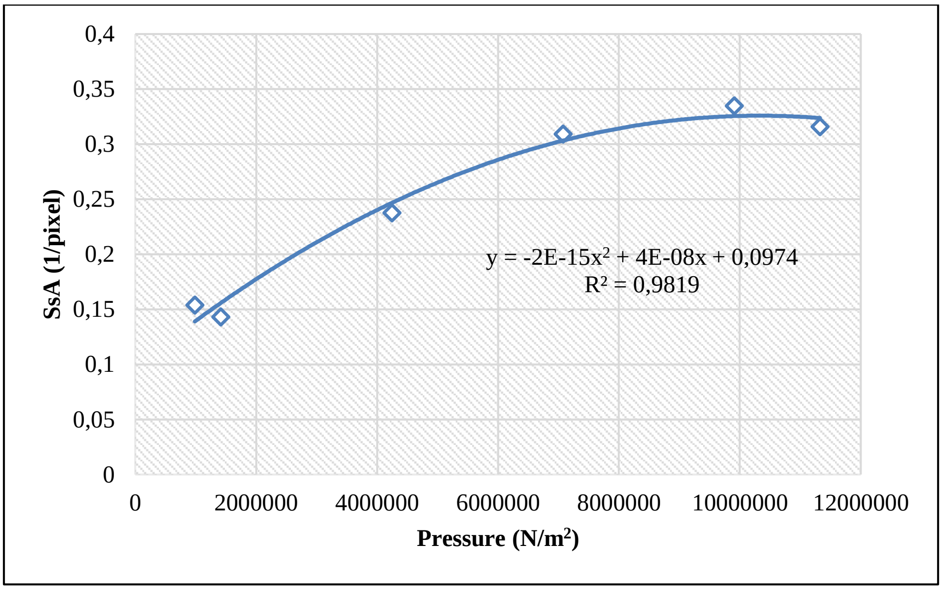

Fig. 8. The relationship of the specific surface area of the rock sample to the increase in pressure.

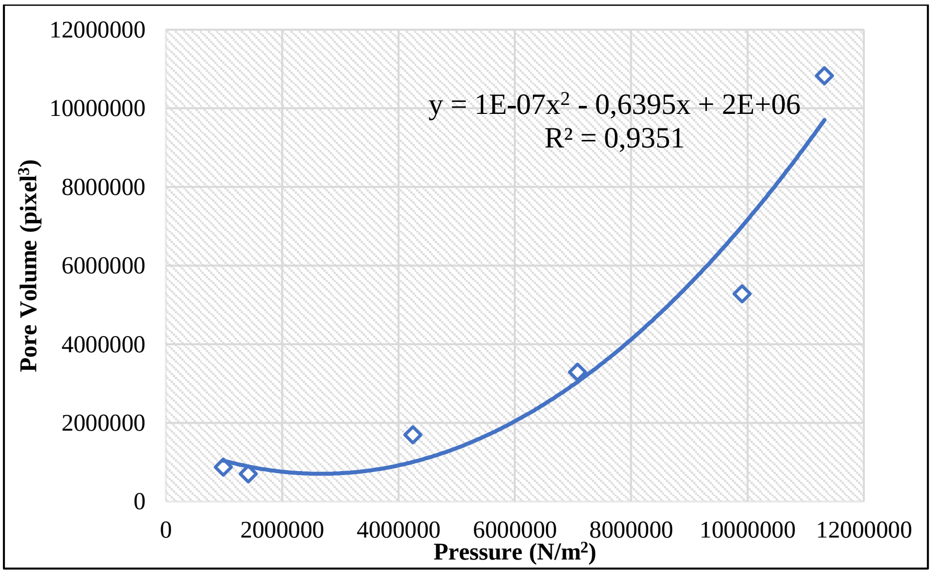

Fig. 9. Graph of the relationship between pore volume and pressure.

4 Conclusion

Deformations in the physical parameters of rocks in terms of their porous structure have decreased due to the uniaxial mechanical pressure treatment. The porosity value decreases by increasing the pressure. The value of the surface area only increases up to 9907997 N/m^2pressure.

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