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THE CORRELATION OF EXPOSURE TIME AND CLAYSTONE PROPERTIES AT THE WARUKIN FORMATION INDONESIA

*Supandi[1,4,5], Zufialdi Zakaria[2], Emi Sukiyah[3] and Adjat Sudradjat[1,4]

[1]Post Graduate Program of Geological Engineering, Universitas Padjadjaran, Indonesia; [2]Department of Applied Geology, Universitas Padjadjaran; Indonesia; [3]Department of Geological Sciences, Universitas Padjadjaran, Indonesia; [4]STTNAS Yogyakarta, Indonesia; [5]PT Borneo Indobara, Indonesia

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ABSTRACT: The deterioration of claystone material was studied by observing a mine slope after digging. An understanding of the degradation of material properties based on field characteristics was required for a detailed slope stability analysis. Experiments were carried out to investigate the correlation of exposure time and the degradation of the mechanical properties of claystone. The methods used in this research include direct field observation and measurements taken from samples of claystone. Claystone samples with different exposure times were obtained from the mine slope face. The exposure time was calculated from the time the slope was dug (when mining started). Determination of the mechanical properties was conducted using undrained, unconsolidated triaxial testing and uniaxial testing. Statistical analysis was carried out to determine the mineralogical homogeneity of the claystone. An empirical analysis was carried out by plotting the exposure time against the mechanical properties on a scatter diagram. The degree of correlation was one parameter used to determine the relationship between the exposure time and material behavior. Based on the results of the research, it is known that the time span of exposure correlates strongly with material properties due to weathering and degradation. The decline in strength was accelerated after the material is exposed. Strength gradually decreased to moderate after 200 days of exposure. Furthermore, the mechanical properties of claystone material will be stabilizing after 400 days. The results of the analysis were very important in predicting the behavior of claystone with exposure time on a slope.

Keywords: Exposure Time, Degradation, Loss on Ignition, Claystone

1. INTRODUCTION

Rock engineering properties are considered to be among the most important parameters for mine slope design. Many researchers have discussed the degradation of minerals in clastic rocks due to exposure. Exposure time is defined as the duration of time that a rock has been exposed in a new environment, with exposure time calculated after digging is started or the slope is established. Time of exposure impacts the degree of weathering and degradation of material physical properties.

Changes in exposure time impact the rate of weathering and changes in physical properties that ultimately affect the mechanical properties and slope stability. Water flow, pore pressure and shear, the moisture content and rock porosity have a very strong association with increasing water levels. Exposed material has greater potential to change if material porosity is also higher [1]. Deterioration of the mechanical properties on hard clay is strongly influenced by the increase in void ratio. The increase in void ratio is influenced by stress changes and rock strains in combination with increasing mixture content [2]. Strength is a main parameter in slope stability. Degradation occurs throughout exposure time until the time it stabilizes.

Exposure time and weathering have a strong relationship, which is expressed by changed material properties. The longer the weathering process is, the greater the impact on changes in the rock mechanical properties. The process occurs due to exposure of the rocks. When rocks are exposed, weathering occurs, encouraging the material structure to be porous, which affects the void ratio. Although the void ratio is related to depth, changes in air void ratio (matric suction) and groundwater pressure can still interfere and induce changes in mechanical properties [3].

Rahardjo *et al.* performed a calculation of the infiltration value of the rock with time [3]. In Fig. 1 below, it appears that infiltration is very fast when the rock is first exposed and then gradually decreases until it reaches a constant value [4]. Therefore, the degradation process of clastic sedimentary rock occurs intensively when the rocks begin to be exposed. The increased infiltration of water into clastic sedimentary rocks can affect the degradation acceleration of the mechanical properties of the rocks.

Grain size, mineralogy and porosity influence mechanical properties [5]. Changes in the physical properties of rock affect changes in the mechanical properties of rock; importantly, this correlation can provide an estimation of the lower limit of these properties and can be used in slope stability analysis

[6]. Rock degradation after exposure is affected by several factors; the main factors driving the degradation of rocks are the processes of weathering and slaking. Excavation of mine slopes causes depressed pore water pressure in the rock mass and, as time passes, a steady state is reached. Therefore, rock degradation is controlled by changes in moisture content and rock weathering [7]. The increase in soil shear strength due to the increase in negative air pressure could be described with the following equation [8]:

$c = c' + (\mu_a - \mu_w) \tan \varphi$, where $(\mu_a - \mu_w)$ is matric suction. (1)

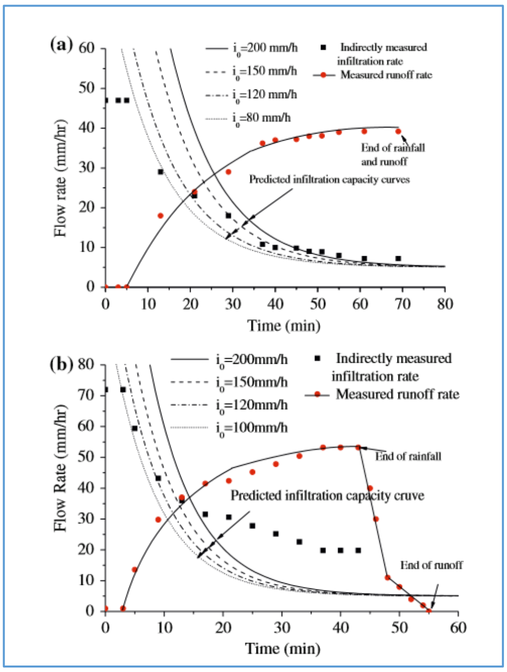

Fig.1 Predicted infiltration decay curve of silty clay slopes [3]

When the rocks are exposed, a change in equilibrium pressure and water pressure occurs, and changes in cohesion due to changes in the void ratio consequently impact the changes in rock properties [8]. Research on the changes in moisture content due to exposed material has been widely conducted, and this process has been shown to impact the evolution of rock mechanical properties. As a result of these changes, rock mechanical properties encounter changes that cause a decrease in slope stability [9].

The degradation of clastic sedimentary rock mechanical properties is influenced by 7 factors; the increase in moisture content is one of the main factors affecting the decrease in rock mechanical properties [10]. Water infiltration into sandstone material should be minimized to maintain the mechanical properties of sandstone [11]. From the research results, it is clear that the increase in water level can impact slope stability. Increasing moisture content triggers an increase in pore pressure and reduces the rock mechanical properties. In clastic sedimentary rocks, fine grains absorb water more easily, causing liquefaction if the water supply is continuously increased [12]. The rate of rock infiltration has been studied [13]. The increase in moisture content affects the liquefaction process, which can impact the cohesion and friction angle [14]. An increase in clastic sedimentary rock exposure time changes the rock mechanical properties; the longer the rocks are exposed, the greater the moisture content, reducing the degradation of the rock mechanical properties [15]. When the rock is exposed to air, the weathering process can occur intensively, and weathering can change the rock structure, which in turn can lower the values of certain rock properties [16]. The friction angle of claystone material under wet conditions is lower than that under dry conditions [17]. The physical properties of clastic sedimentary rocks have a strong correlation with their mechanical properties [18]. Therefore, the moisture contents of claystone and sandstone increase rapidly at the beginning of exposure. The mechanical properties decrease with increasing moisture content. The friction angle, cohesion and strength decrease significantly [19]. These trends are supported by research results [20], showing that the moisture content has a great influence on the rock mechanical properties. Hydraulic conductivity shows strong agreement with the void ratio. An increasing void ratio is followed by increasing hydraulic conductivity [21]. Coefficient deterioration of sandstones moderates as pH decreases from 7 to 4. Deterioration occurred as determined by the cohesion, internal friction angle, and strength [22]. The strength of claystone shows deterioration of approximately 43% after 3 weeks with number D50 decreasing [23]. Degradation of claystone increases while moisture content increases and many microstructures of fissuring are noted [24]. Kaolinite is determined to be a non-swelling type [25]. The strength of claystone increases by approximately 40%, while temperature increases up to 450°C [26]. Mechanical properties decrease after weathering has occurred at the slope [27]. Effective stress increases, while the void ratio decreases [28]. Claystone with residual strength tends toward damage intensity and confining pressure [29]

Based on the above explanation, weathering and the change in physical properties can alter the mechanical properties of clastic sedimentary rocks, so a detailed analysis is needed to determine the correlation of these factors for claystone in the Kusan Block. Tests were conducted based on rock exposure time, as referring to the mining sequences, and sampling was conducted in the claystone slopes with similar mineralogy.

The exposure time correlation and mechanical properties can be determined and used to optimize the mining activities. To identify the correlation of several factors, correlation tests were conducted following [30], and details are provided in Table 1.

Table 1 Guidelines for the degree of correlation

Interval Coefficient	Relationship Degree
0.00 – 0.19	Very low
0.20 – 0.39	Low
0.40 – 0.59	Medium
0.60 – 0.79	Strong
0.80 – 1.00	Very strong

Source: [30]

2. MATERIAL AND METHODS

The studies were conducted at the Kusan Block, Tanah Bumbu, South Kalimantan, Indonesia (Fig. 2). The Kusan Block is composed of sandstone and claystone with low harnesses that are less than 1 MPa. The ground water level is relatively high, ranging from 5 to 10 m from the surface, with a nearly invisible seepage surface in the mine slope. The pattern of the local geological structures is difficult to detect because of the fragile nature of the material and the relatively well-arranged stratigraphic pattern, with the material dominated by claystone in the lower section and sandstone at the top; the claystone is grayish, and the sandstone is gray (Fig. 3).

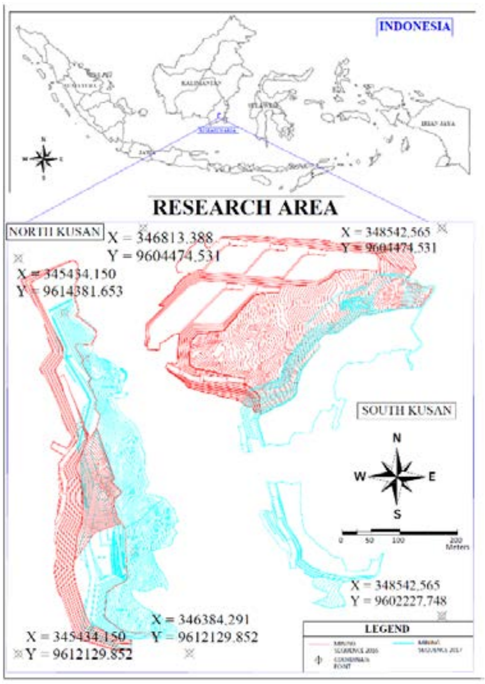

Fig.2 Research area in the Kusan Block, Tanah Bumbu Regency, South Kalimantan Province, Indonesia

The research was divided into 4 stages. The first stage was field observation and sample collection. At this phase, the researcher made observations by describing the existing slope face on the slope mine. The researcher also noted the exposure time of each slope formed by mining activity to obtain the time span for exposure to claystone material on the slope. Samples of claystone were selected based on visual descriptions. Samples of claystone were taken from several slopes with different exposure times, and the exposure times were recorded from when digging started to when sampling was completed. Mining sequences caused some slopes to have different durations of exposure time, which will be studied to identify the effect of exposure time on the mechanical properties of claystone. The exposure time at the upper part of the slope is longer than that at the bottom, causing the same claystone material to have a variety of mechanical properties. Fig. 4 shows that the top excavation was completed in 2015, while the bottom excavation was completed at the end of 2016; therefore, when sampling was performed along the slope surface, different rock exposure times were represented, which affected the rock mechanical properties.

Fig.3 Slope conditions due to mining activities in the Kusan Block

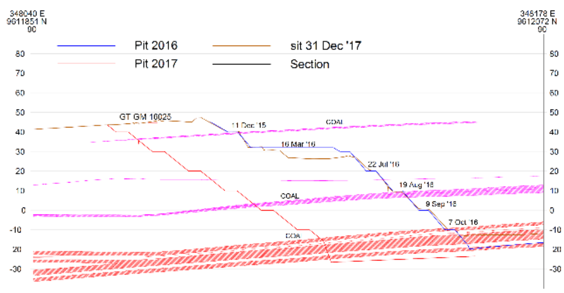

Fig.4 Cross section of the Kusan Block and overview of the sampling location

Samples were collected from each claystone on the slope face, at different elevations. Different exposure times influence the mechanical properties of the claystone. The samples had approximately 70 mm diameters and 50 cm lengths. The samples were wrapped in plastic to maintain their basic material properties. A total of 35 rock samples were used in this study, and they were all claystone. Sample preparation was done by conforming to the ASTM (American Society for Testing and Materials) standards [31].

The second stage involved laboratory analysis. The researcher analyzed mechanical properties of the claystone to determine basic and mechanical properties using a triaxial test and a uniaxial test. Determination of the material properties is carried out using triaxial testing under undrained and unconsolidated conditions, which refer to [28]. Cohesion and friction angle can be determined from this test. This resulted in the data related to moisture content, wet density, void ratio, strength, cohesion, friction angle, and Loss on Ignition (LoI). Mineralogical laboratory analysis was carried out to determine specific compositions of the minerals. X-ray diffraction analysis is an analytical technique in which a prepared sample is bombarded with an X-ray beam at varying rates to determine its mineralogy. The various mineral phase components of the claystone sample were determined from carefully prepared powder samples (325 mesh). A polarizing microscope was used to visually inspect and petrographically describe the powdered samples. Diffractograms of the claystone are shown in Fig. 5, and an overview of the condition of the sample under a microscope can be found in Fig. 6. X-ray diffraction was conducted to determine the degree of weathering of the claystone. The LoI indicates the weathering degree of each sample. An increase in the exposure time affects the weathering degree.

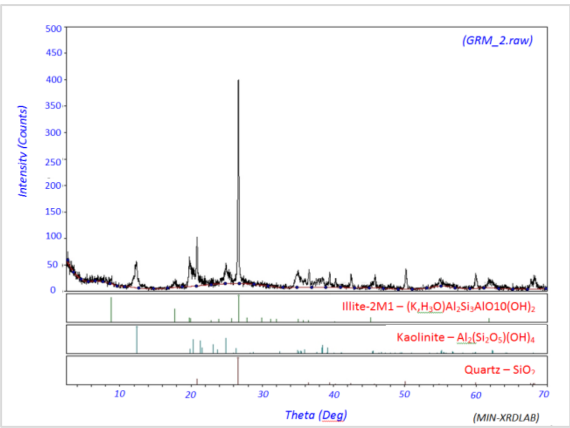

Fig.5 XRD spectrograph of the analytical pattern of claystone

The third stage involved a statistical analysis of the mineralogy of the claystone in this area carried out in order to determine the claystone homogeneity. An analysis of the influence of the exposure time on the material can be conducted if the claystone is supported by a homogeneous mineralogy, so samples collected from several locations with different exposure times are acceptable.

The fourth stage was studio processing. This stage aimed to correlate certain variables based on field observation and other variables resulting from the laboratory tests.

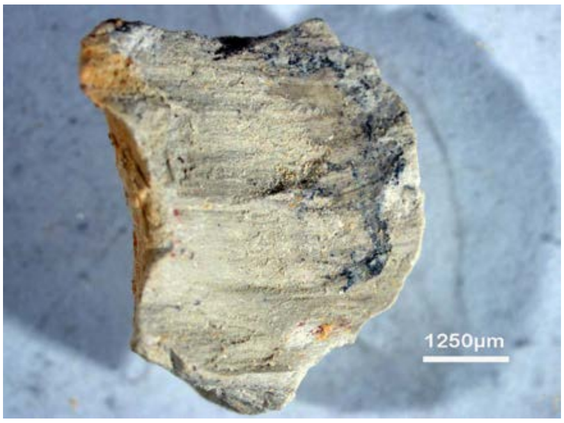

Fig.6 Close-up of the claystone sample under a microscope. Based on the result of XRD analysis, it is known that the content of quartz (59%), Kaolinite (27%) and illite (14%).

3. RESULTS AND DISCUSSION

The average rainfall intensity in the Kusan Block is a 20 mm/day, and rainfall occurred every day from January to April 2017. Sampling was carried out from February to March 2017 during the rainy season (Fig. 7). Greater rainfall intensity will trigger an increase in moisture content of the claystone, especially the claystone at the surface. Changing between dry and wet seasons influences the mechanical properties of claystone. This condition is common in clastic sedimentary rock; while the moisture content increases, the mechanical properties decrease. With more rainfall, more water enters the rock pores, affecting the changes in moisture content and pore pressure.
Claystone in the Kusan Block is composed of illite and kaolinite with minor very fine-grained quartz. Based on a statistical analysis of the material homogeneity, sample collection of claystone with different exposure times is acceptable for further analysis. A homogeneous mineralogy of the claystone is very important to ensure that the testing is conducted on samples with originally similar characteristics. Normality testing also shows that the homogeneity based on a calculation is lower than that from a table.

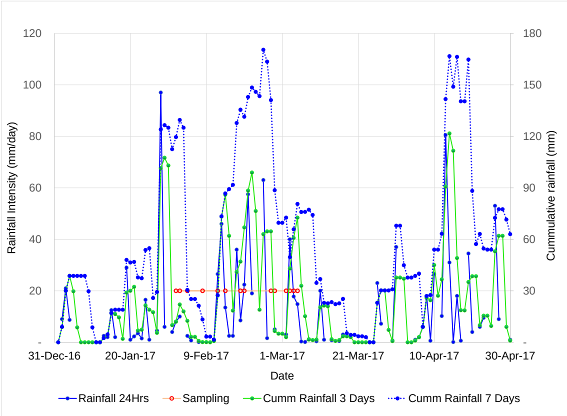

Fig.7 Rainfall intensity from January to April 2017; sampling was done during the rainy season

To obtain a relationship between exposure time and several other variables, a scatter diagram was used to determine the correlation between several factors. A regression line with a degree of correlation was obtained from this work; the most dominant factor correlated with exposure time can be found.

Determination of the effect of exposure time on the mechanical properties was performed by plotting the exposure time with cohesion and the friction angle. The results are shown in Fig. 8. Fig. 8 shows that as the exposure time increases, the mechanical properties of cohesion and the friction angle both decrease.

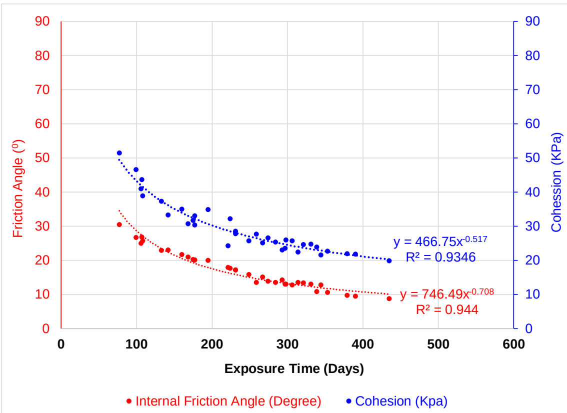

Fig.8 The relationships between exposure time and internal friction angle – cohesion of claystone

In these claystones, the exposure time and mechanical properties show a very strong relationship, as indicated by a degree of correlation above 0.8. Cohesion and the friction angle have relatively similar relationships with exposure time; at the beginning of exposure, cohesion and the friction angle decreased significantly, with the rate of decrease gradually reduced. In this study, exposure time at the mine wall was up to 450 days.

At the exposure time of 0-200 days, the claystone properties decreased considerably; cohesion and the friction angle decreased by approximately 20 KPa and 20 degrees. After 200 days, cohesion and the friction angle decreased more, by approximately 10 KPa and 10 degrees. The decrease in cohesion and the friction angle was almost 50% from the previous period, indicating that either the claystone did not change or the properties reached the optimum values after more than 400 days. At exposure times longer than 400 days, the properties showed a relatively flat curve, where almost no change was observed in the claystone mechanical properties of cohesion and friction angle. The regression equation for the relationships between the exposure time and the cohesion and friction angle of the claystone are as follows:

Cohesion= $746.49x^{-.0708}$ $R^2 = 0.944$ (1)

Friction angle = $466.75x^{-0.517}$ $R^2 = 0.934$ (2)

Decreasing properties of cohesion and the friction angle with increasing exposure time are also predicted to be influenced by several factors, both internal and external. Internal factors that can reduce the cohesion and friction angle of claystone material are weathering and deterioration in rock strength. Due to these factors, correlations between the exposure time and the LoI and strength are determined. The test results are plotted in a scatter diagram, as in Fig. 9. The figure shows that the exposure time has a very strong correlation to the LoI and strength; the degrees of correlation are 0.9346 and 0.9146, respectively. The LoI increased with exposure time. Every year, there is a 4% increase in the LoI, so it has an impact on the changes in the mechanical properties of rocks, especially the strength.

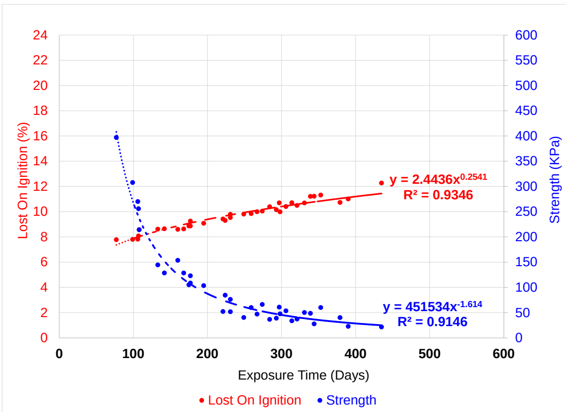

Fig.9 The relationships of exposure time with loss on ignition and strength

The strength of claystone decreased significantly by 300 KPa during the first 200 days and tended to decrease by 75 KPa between 200 and 400 days of exposure time. After 400 days, the rocks tend to reach a stable point of approximately 25 KPa. This value tends to be approximately the same as the laterite soil hardness that exists in the Kusan Block. Both factors form an atypical pattern, so it can be concluded that the rapid decline in strength is influenced not only by the LoI but also by other factors. The regression equation for the relationship between the exposure time and the LoI and strength are:

$$LoI = 2.4436\ x0.2541^{-.0708} \quad R^2 = 0.9346 \qquad (3)$$

$$Strength = 451534x^{-1.614} \quad R^2 = 0.9146 \qquad (4)$$

Several previous studies have suggested that rock mechanical properties change depending on changes in the physical properties. Two of the factors that influence the changes in mechanical properties of claystone are the porosity and moisture content. Both factors are highly influenced by the exposure time. The scatter diagrams between the exposure time and the void ratio and moisture content are shown in Fig. 10.

The regression patterns between the exposure time and the void ratio and moisture content have a relatively uniform pattern, with a very strong degree of correlation above 0.878 for the void ratio and 0.8469 for the moisture content. Every 100 days, there is an increase of 5% and a small relative decrease (<1%). The moisture content changed after the claystone was exposed due to some internal factors, one of which is a change in the grain structure; this change is detected from the change in the number of pores. The void ratio increased with the exposure time. The moisture content pattern followed that of the void ratio; this pattern will cause the moisture content to interact with the physical properties of the rock and affect its mechanical properties. The longer the exposure time is, the greater the moisture content. From the regression pattern correlation, the following equations were :

$$Void\ Ratio = 2.5773x^{0.4076} \quad R^2 = 0.8789 \qquad (5)$$

$$Moisture\ Content = 0.2234x^{0.1879}\ R^2 = 0.8469 \qquad (6)$$

The regression correlations for the cohesion and the void ratio and moisture content are as follows:

$$LOI = 45.706x^{-0.464} \quad R^2 = 0.8894 \qquad (7)$$

$$Moisture\ Content = 299.5x^{-0.76}\ R^2 = 0.8746 \qquad (8)$$

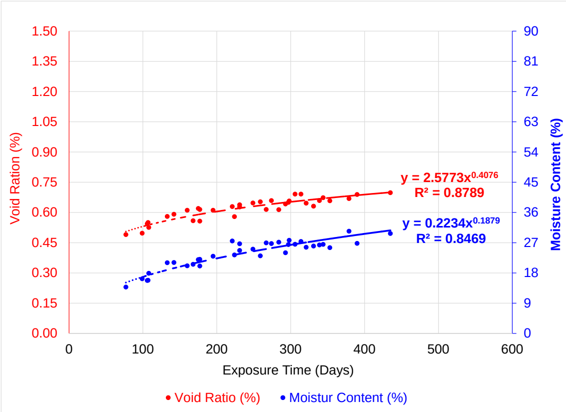

Fig.10 The relationships of exposure time with void ratio and moisture content

The shear strength formulation is based on the Mohr-Coulomb law, $\tau = c + (\sigma - \mu) \tan \varphi$, where cohesion is the main component of stability. Therefore, an analysis of the correlation of cohesion to LoI and moisture content was applied. Cohesion has a very strong relationship with exposure time; the LoI and moisture content are indicated by the correlation degree values of 0.8894 and 0.8469, respectively. From Fig. 11, it can be obtained that the increase in LoI induces a 20 KPa decrease in cohesion. An increase in moisture content of 12% will decrease the cohesion by 20 KPa. A decrease in the cohesion of 20 KPa will occur in approximately 300 days.

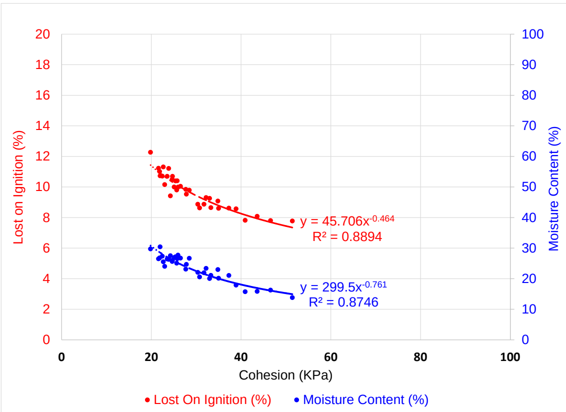

Fig.11 The relationships of exposure time with loss on ignition and moisture content

Based on this work, long-term slope stability analyses can consider the degradation processes in the claystone that reduce its mechanical properties, possibly ultimately disrupting slope stability. For a slope with an age of 1 year, one may consider the value of degradation in the chart or draw a regression line to consider the properties based on the correlation results. Knowing the degradation process and calculating the magnitude of degradation are critical for designing a mine slope and associated mine life. If the resource retrieval activity is shorter, then the slope can be optimized, and if the life of the slope reaches a longer period, the degradation process can be calculated. It is important to optimize reserves, which in turn can determine the optimal balance between reserves and slope stability.

4. CONCLUSION

This paper presented the influence of exposure time on material properties related to the degradation of claystone. Geomechanical laboratory tests and X-ray diffraction tests were carried out to determine the mechanical properties and mineralogy of claystone. The analysis was carried out by plotting exposure time against several mechanical properties. The exposure time has a very strong correlation with cohesion, friction angle, strength, moisture content, void ratio and LoI. The cohesion, friction angle and strength of the claystone decrease significantly after the material is exposed and slowly degrades after 200 days. This claystone is stable after 400 days, as indicated by a relatively flat curve. Cohesion and strength decreased by 20 KPa and 300 KPa for every 300 days of exposure time. Moisture content and LoI increased gradually, encouraging a decrease in the mechanical properties of claystone. The void ratio also increased, thereby increasing the moisture content, which can affect the mechanical properties of rocks. The rate of degradation of these rocks can be utilized in the determination of the mine design and mining sequences by adjusting for the age and slope stability. It is expected that by knowing the degradation conditions, the mining process can be optimized to increase reserves.

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