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LABORATORY PERFORMANCE ASSESSMENT OF CONSOLIDATED CRUSHED SALT FOR BACKFILL MATERIAL IN POTASH MINE OPENINGS

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ABSTRACT

The objective of this study is to experimentally determine the strength and deformability of crushed salt as affected by applied stresses and consolidation period. The crushed salt has grain sizes ranging from 0.075 to 4.76 mm. The optimum brine content is determined as 5% by weight. The consolidation tests are performed by applying constant axial stresses to the crushed salt samples installed in the 54 mm diameter steel cylinders. The axial stresses are 2.5, 5, 7.5 and 10 MPa. The uniaxial compressive strengths are measured after the samples have been consolidated for 3, 5, 7, 10 and 15 days. The axial strains are monitored and used to calculate the magnitude of the consolidation for each specimen. The consolidation magnitude and density of the crushed salt samples increases with the applied stresses. The uniaxial compressive strength increases with the consolidation. The porosity decreases as the consolidation increases. The test results are used to develop a set of empirical equations to design the initial installation parameters in terms of the physical and mechanical properties of the crushed salt as backfill material in potash mine openings.

KEYWORDS: Crushed Salt, Backfill, Consolidation, Strength, Sealing

1. Introduction

The function of the crushed salt backfill is to act as a geotechnical long-term barrier against inflowing brine or water. Crushed salt has been widely recognized as the most suitable backfill material [1-2]. Crushed salt can be compacted and its initial porosity and permeability will decrease. Over long periods, the crushed salt is expected to gradually reconsolidate into a material comparable to intact rock salt [1]. For crushed salt emplaced in an opening in a rock salt formation, the consolidation is driven by the creep closure of the adjacent rock. The primary advantages of crushed salt are availability, low cost and obvious compatibility with host rock [3].

Miao et al. [4] and Kelsall et al. [5] suggest that the range of grain size for the consolidated crushed salt is 0.3 mm to 4.76 mm and 75 mm to about 0.05 mm, respectively. Wang et al. [6] conducted several series of densification tests on crushed rock salt with water contents varying from 0.12% to 4.72%. The compaction of crushed salt increase with increasing brine content until the optimum brine content is reached, and decreases with further brine content increases. Brodsky et al. [7] conducted hydrostatic and triaxial compression tests with brine content of 2.5% to 3% by weight. The results indicate that the permeability decreases approximately 2.1 orders of magnitude as fractional density increases from 0.9 to 1. The unconfined compressive strength and Young's modulus of crushed rock salt also increase with respect to densification time [4] and decreases with porosity [5]. The relationship between void ratio and time are found to be exponential equations [8]. The initial porosity and permeability decrease with increasing density [2,9,10,11,12]. Commonly employed theories on modeling creep of rock salt are rheological theories including empirical creep laws, viscoelasticity, elastic viscoplasticity theories, damage mechanics, hot-pressing theories and pressure solution theories [4,8,13,14]. The understanding of the consolidation behavior of crushed salt is an important precondition for repository design and for long-term safety assessment. Nevertheless, correlations between the physical (bulk density) and mechanical (strength and elasticity) properties of crushed salt after installation have rarely been established. Therefore, this study is conducted to establish a simple mathematical relationship. Only substituting time and consolidation stress values in the empirical equations, the physical and mechanical parameters can be obtained. Even though relatively extensive laboratory test results have been obtained for crushed salt behavior under consolidation, they can not readily be applied to the actual in-situ conditions. Most of the previous researchers have been concentrated on waste repository sealing. Their results may not be applicable to the salt and potash mine industry. The objectives of this study are to experimentally determine the mechanical properties of crushed salt as affected by consolidation pressure and period. Empirical relations will be derived to predict the mechanical properties of crushed salt as their density and porosity are reduced by consolidation. The results can also be used to define the initial installation parameters of the crushed salt to be used as backfill material in potash mine openings.

2. Crushed Salt Specimens

Crushed salt used in this study is prepared from the Middle member of the Maha Sarakham Formation in the Khorat basin, northeastern Thailand. The salts are crushed by hammer mill until has grain size ranging from 0.075 to 4.75 mm. This size range is equivalent to those expected to obtain as waste product from the potash mines. Saturated brine is prepared by mixing pure salt with distilled water in plastic tank. The proportion of salt to water is about 39% by weight. Specific gravity of the saturated brine ($S.G._B$) can be calculated by $S.G._B = \gamma_{Brine}/\gamma_{H2O}$, where γ_{Brine} is density of saturated brine (measured with a hydrometer, kg/m^3) and γ_{H2O} is density of water equal 1,000 kg/m^3. The specific gravity of the saturated brine in this study is 1.211 at 21°C. The optimum brine content are performed by applying axial stresses on loading steel piston to the crushed salt mixed with 0, 5 and 10% of saturated brine. The axial stresses are varied from 5, 10, 15 to 20 MPa. All tests are conducted under ambient temperature for 96 hours at the 5% and 10% of brine contents. The density of the consolidation specimens are similar. The proportion of saturated brine to crushed salt in this study is therefore determined as 5% by weight.

3. Consolidation Testing

The consolidation tests are performed by applying constant axial stresses on loading steel pistons to the crushed salt samples installed in the 54 mm diameter steel cylinders (Figure 1). The constant axial stresses are 2.5, 5, 7.5 and 10 MPa. All tests are conducted under ambient temperature for 3, 5, 7, 10 and 15 days, for each condition. The axial displacements are continuously measured as a function of time by dial gages to calculate the changes of axial strain, density, and void ratio. The uniaxial compressive strength test procedure follows the ASTM standard practice [15]. The compressive strength of the consolidated crushed salts samples is determined by axially loading the crushed salt cylinder (after removing from the steel tube) with a nominal diameter of 54 mm and L/D ranging from 2 to 3. Uniaxial compressive strength measurements are made after 3, 5, 7, 10 and 15 days of consolidation. Results indicate that the consolidation magnitude and density of the crushed salt samples increase with applied axial stresses and consolidation time (Figure 2). The uniaxial compressive strengths are determined after 3, 5, 7, 10 and 15 days of consolidation, after removing from the steel tube. The results indicate that the uniaxial compressive strength, elastic modulus, increase with the axial stress and consolidation duration. The Poisson's ratio decreases as the axial stresses and consolidation increases. The results are shown in Figures 3 and 4.

The test results are calculated based on the uniaxial strain condition ($\varepsilon_1 \neq 0$, $\varepsilon_2 = \varepsilon_3 = 0$, $\sigma_2 = \sigma_3 \neq 0$). The axial strains from the measurement results represent the volumetric strain of crushed salt specimens. Poisson's ratio is calculated from the uniaxial strain and the lateral stresses (σ_3) as follows [16]

$$\sigma_2 = \sigma_3 = [\nu/(1-\nu)]\sigma_1 \tag{1}$$

where σ_2 and σ_3, are lateral stresses, ν, is Poisson's ratio and σ_1 is consolidation stress (σ_{ax}). The mean stresses (σ_m) are also determined using the following relations [16]:

$$\sigma_m = (\sigma_{ax} + 2\sigma_3)/3 \tag{2}$$

where σ_m is mean stress, σ_3 is consolidation stress, and σ_3 is lateral stress. Mean stresses are found to decrease with the increase of axial stresses and time.

4. Predications

The results above are used to develop a set of empirical equation as a function of mean stress and time. The relationships between density and mean stress are non-linear which can be represented by a power equation:

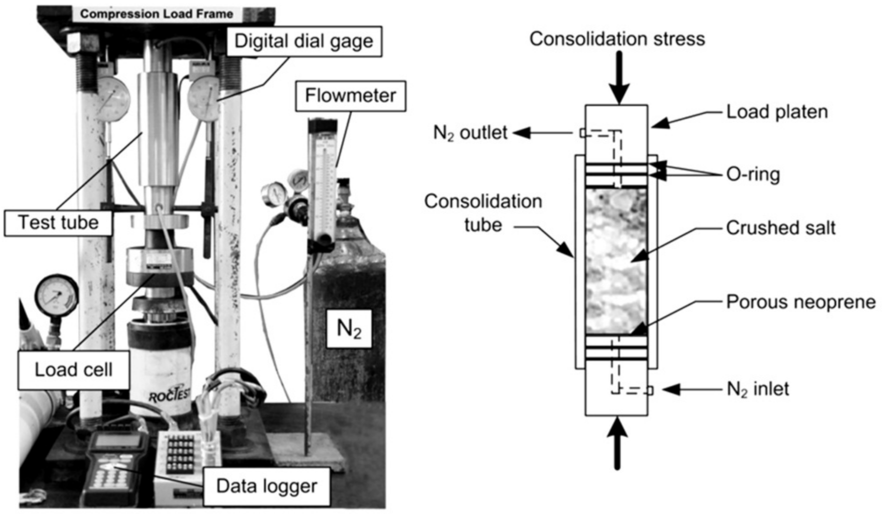

Figure 1 Test arrangement for consolidation testing

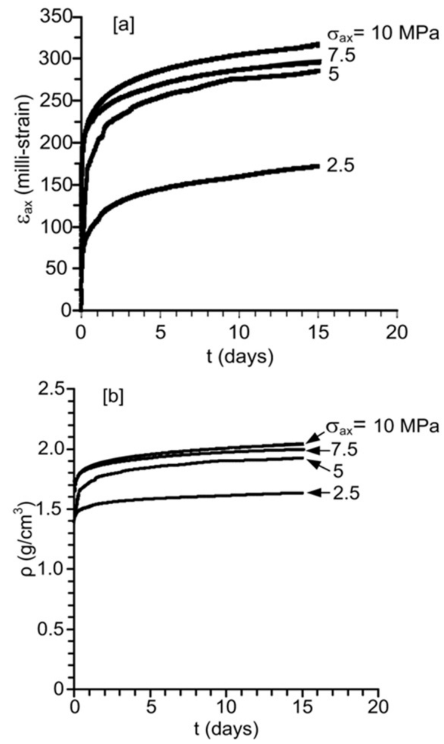

Figure 2 Axial strain (ε_{ax}) [a] and density (ρ) [b] as a function of time (t) for different axial stresses (σ_{ax})

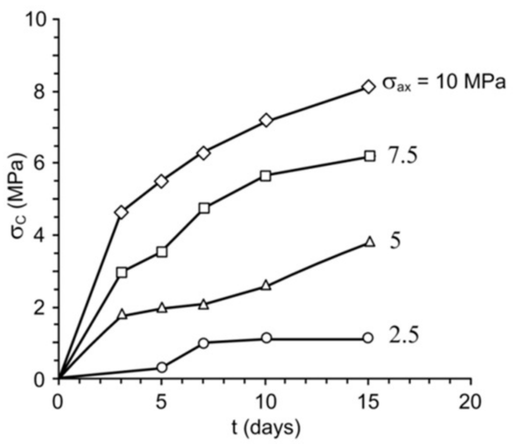

Figure 3 Uniaxial compressive strength (σ_c) as a function of consolidation time (t) for different consolidation stresses (σ_{ax})

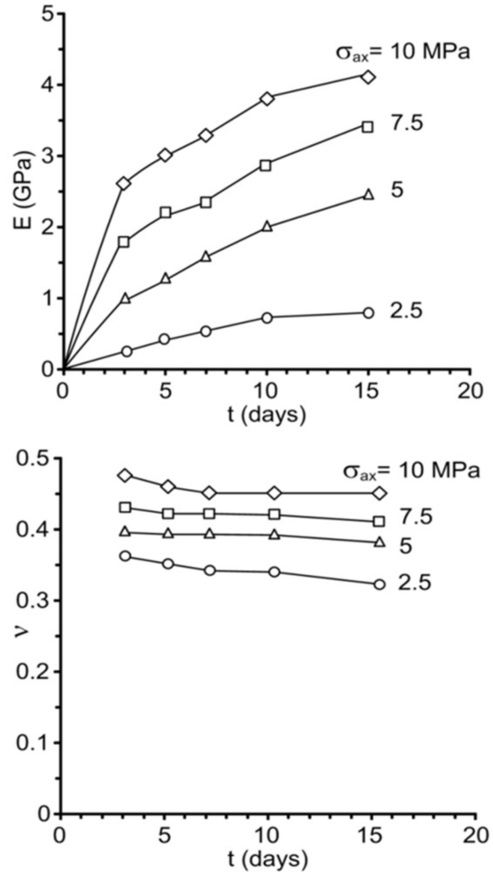

Figure 4 Elastic modulus (E) and Poisson's ratio (ν) as a function of time (t) for different consolidation stresses (σ_{ax})

$$\rho = \rho_0 + (D \cdot \sigma_m^E \cdot t^F) \tag{3}$$

where ρ is density at over time, ρ_0 is initial density (g/cm^3), σ_m is mean stress (MPa), t is time for consolidation (days), and D, E and F are empirical constants. Regression analysis on the test data using SPSS statistical software can determine these constants: D = 0.088, E = 0.833 and F = 0.176. Good correlation (R^2 0.915) between the constitutive equation and the test data is obtained. The equation can be used to predict density at any consolidation period and mean stress. The predictions of density under varied mean stresses ranging from 1 to 4 MPa and consolidation time for 12 months are shown in Figure 5. The uniaxial compressive strength results can also be predicted by a set of empirical equation as a function of mean stress and time. The relationship is non-linear which can be represented by a power equation:

$$\sigma_c = \varphi \cdot \sigma_m^{\delta} t^{\eta} \tag{4}$$

where σ_c is uniaxial compressive strength of crushed salt specimen (MPa), σ_m is mean stress (MPa), t is consolidation time (days), and φ, δ, and η are empirical constants. Regression analysis on the test data using SPSS statistical software can determine these constants : φ = 0.075, δ = 1.821, η = 0.479. Good correlation (R^2 = 0.998) is obtained. The equation can be used to predict the uniaxial compressive strength at any consolidation period and mean stress. Figure 6 shows the estimation of the uniaxial compressive strength under varied mean stresses ranging from 1 to 4 MPa with consolidation time for 12 months.

5. Discussion and Conclusions

The consolidation of crushed salt increases with increasing brine content until the optimum brine content is reached, which is 5% by weight. The volumetric strain and density increase with consolidation stresses and time. These findings agree well with those from other researchers [9-12]. The highest density observed at 10 MPa consolidation stress for 15 days, which equal to 2.04 g/cm^3. The proposed empirical equations can be used to predict the volumetric strain and density under any mean stresses. The predictions indicate that the density of consolidated crushed salt will be close to the intact salt (2.2 g/cm^3) after 12 months under mean stress equal to 4 MPa. The void ratio decreases as the consolidation increases. The uniaxial compressive strength and elastic modulus increase with the consolidation magnitude and period. The lowest compressive strength is observed for 2.5 MPa consolidation stress at 3 days. The highest compressive strength is observed for 10 MPa consolidation stresses which is about 8.1 MPa. The elastic modulus is 4.10 GPa after 15 days of consolidation. The proposed empirical equations can be used to predict the mechanical properties of crushed salt after installation as backfill material in the mine openings. Such application however requires that the volumetric closure and the stressed at the contact between the opening wall and the backfill material are known. As a result numerical simulation may be performed to provide the closure strains and contact stresses at the mine opening and backfill interface.

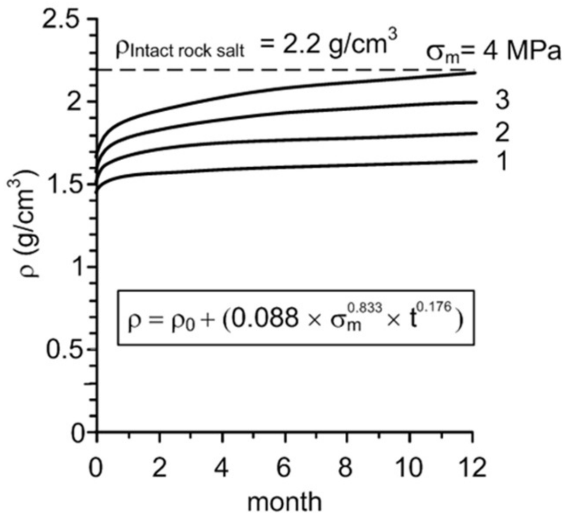

Figure 5 Predicted density (ρ) time curves for different mean stress (σ_m)

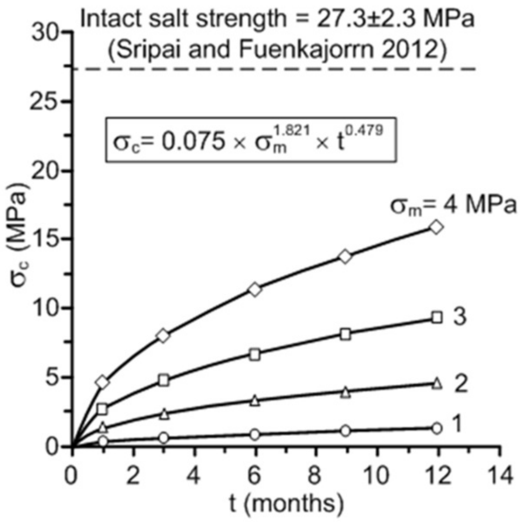

Figure 6 Predicted uniaxial compressive strength (σ_c) as a function of time (t) for different mean stress (σ_m)

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