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Estimation of creep parameters of rock salt from uniaxial compression tests

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ABSTRACT

This paper discusses an approach to predict the creep behaviour of rock salt using uniaxial compression testing machine, as the conventional creep testing equipments are expensive and scarcely available. As commonly observed in brittle rock, a distinct Kaiser effect is not found during pre-peak loading path, but after unloading a distinct Kaiser effect is observed in rock salt. In the present study, Acoustic Emissions (AE) technique is used to infer the rock salt behaviour under uniaxial compression. The AE technique used in the present study to explain the rock salt behaviour is based on a combination of Maxwell and Hooke models. Using these models, elastic and viscous parameters are calculated. The proposed model is able to predict the stress-strain response of rock salt with a fair accuracy in both loading and unloading conditions. It is observed that the viscosity has negative correlation with the strain rate and hence the calculated viscous parameters are then extrapolated. The extrapolated results of viscosity for different strain rate in the range of $10^{-6.5}$–10^{-10} s^{-1} are very close with reported values from the literature and for the strain rate below 10^{-10} s^{-1}, the predictions are higher than the values reported in literature. This is due the fact that below 10^{-12} s^{-1} strain rate, the viscosity becomes independent of the strain rate and its value becomes almost constant for 3–5 mm grain size rock salt. Hence a cutoff viscosity is proposed at a value of 10^{18} Pa.sec.

1. Introduction

An important property of rock salt is its time-dependent deformation behaviour or creep, which is typically captured by performing creep tests in uniaxial or triaxial conditions at constant values of stress or strain at a particular temperature. The stress and temperature can be changed stepwise during the test in order to create phases with constant condition[1]. An idealized one-dimensional creep plot is commonly represented by the instantaneous elastic deformation followed by the sequence of specific time-dependent deformations i.e. the primary transient phase where the strain rate decreases with time and the steady-state creep where the strain rate remains constant followed by tertiary creep characterized by a rapidly accelerating strain rate to ultimate fracture failure[2].

A number of widely differing intuitive creep models such as classical Norton's power law which is an approximation of the actual creep behaviour to LUBBY2 model which is additive superposition of the transient creep rate with time and a constant secondary creep rate[3] are available. These creep models are essentially based on out of a fit to the creep testing data and some of the well-known models are compiled by Cristescu and Hunsche[4]. Comparison of creep rheological model such as Hookean model, Newtonian model, St. Venant model, Maxwell model, Maxwell and Kelvin-Voigt model, Standard model, Burger's model with experimental response has been made by Aydan et al.[5] with discussing their merits and demerits. which led to considerable differences in the prediction obtained owing to the merits and demerits of each model described by Cristescu and Hunsche[4]. In laboratory creep tests are conducted by the use of two type of apparatus: one, the conventional cantilever type apparatus wherein the load level can easily be manually kept constant with time and the other, the load/displacement-controlled apparatus capable of applying constant load by a servo-controlled machine. Cantilever type apparatus has the restriction of the level of applicable load which depends on the length of cantilever arm as well as oscillation during the change in load step while the servo-controlled testing machine requires continuous monitoring of load and its automatic adjustment. In additional to the fact that a dedicated creep testing machine fully equipped is expensive, these creep tests involves each loading step ranging from few days to several months or even years. This may lead to delay in characterization of creep parameters and thus the design and execution of projects involving creep related stability issues. Hence, there is great demand for assessment/estimation of creep parameters of rocks using simple routine tests either through simple models or empirical equations. It is reported that the creep behaviour can very well be related even through simple quasi-

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static deformation tests in addition to creep tests and relaxation tests[4]. In the present study, an approach has been proposed to determine the time-dependent creep behaviour of rock salt by performing simple uniaxial compression tests at different strain rates.

In the 1940's, the Acoustic Emissions (AE) technique was introduced in rock mechanics and is commonly used to study the failure in rocks. AE is defined as the transient elastic wave generated by the rapid release of energy from a source within a material[6]. Due to its high sensitivity to crack initiation, propagation, and coalescence in rocks under loading, AE monitoring provides a powerful tool for investigating rock failure and this technique has been widely used in rock mechanics studies and several other engineering applications[7–12]. Hence, the AE technique is used in the present study for understanding rock salt behaviour under uniaxial compression. Time effects in uniaxial test are evident from the loading rates that changes the whole stress-strain curve from the beginning and also the failure is time-dependent[4]. The characterization of mechanical properties of rock salt using AE source was attempted by[13–15]. Nevertheless, the AE technique has not been used to study the rheology behaviour of rock salt. The creep behaviour of rack salt is rarely evaluated from the conventional uniaxial compression tests at strain rates: $10^{-3} - 10^{-5}\,s^{-1}$. For predicting the creep behaviour of rock salt, AE signatures along with the stress-strain response obtained from uniaxial compression are analyzed using simple classical models i.e. Hooke and Maxwell. Using these models viscous response is quantified, which is an important factor for substantiating the rheology of rock salt. Calculated viscosities are then extrapolated to determine the secondary creep rate by considering the creep behaviour of rock salt in longer time as independent phenomenon from the initial transient creep. In the present study, the rock salt from the Khewra mines of Pakistan, which belongs to the extensive bedded formation of marine evaporates aged 650 million years old from early Cambrian era is considered. Khewra mine rock salt contains 96–98% of halite[15,16] (NaCl). The salt bed deposits in India are around 500–700 m deep and no extraction is going on presently. Nagaur-Ganganagar Basin in India is interpreted to be connected to the evaporite sequences of the Salt Range in Punjab platform of Pakistan in the northwest[17] and hence rock salt from Khewra is taken for this study.

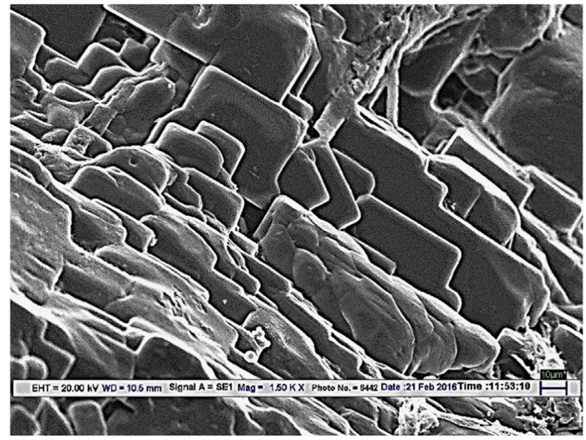

Fig. 1. SEM Image of Khewra Rock Salt (Magnification 1500 X).

2. Physical properties of test specimens

Cylindrical specimens of 38 mm diameter in the ratio of 2:1 length to diameter were prepared the top and bottom surfaces of the specimens were smoothened to parallelism using dry cut from lathe machine. The specimens were made to meet the tolerance criteria as specified in IS 9179 (1979)[18]. Physical properties of these specimens are given in Table 1. Density was calculated as per IS 13030 (1991)[19] and its values are in the range of 2.10–2.14 g/cc. The obtained values of density are comparable with the reported density of rock salts in literature[20]. The specific gravity test was conducted as per IS 2720 (PartIII-1980)[21], and kerosene was used as it is a non-polar fluid since halite mineral is not soluble in non-polar fluid. Using the density and specific gravity values,

Table 1
Physical Properties of Rock Salt Specimens.

Rock Salt Specimen No.	Bulk Density (g/cc)	L/D	Specific Gravity	P-Wave Velocity (m/s)	Dynamic Modulus (GPa)	Porosity (%)
B9	2.13	2	2.20	4001	34	3.14
B20	2.14			4186	37	2.5
B6	2.12			4029	34	2.5
B5	2.13			4040	35	3.4
B36	2.10			3776	30	3.7
B40	2.14			3629	28	3.64

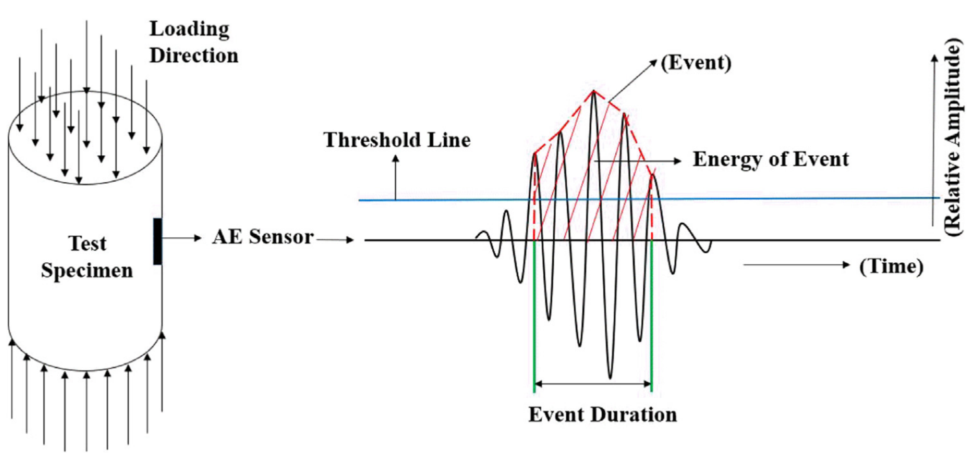

Fig. 2. AE Signal Processing Detail.