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Effect of temperature on mode I and mode II fracture toughness of Lushan sandstone

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Abstract

Rock is a brittle naturally substance that is subjected to a variety of environmental impacts, such as temperature, confining pressure, humidity and water erosion. Among the different parameters, the effect of temperature on rock fracture in most engineering fields has been considered. These include the determination of the resistance of rock structures to accumulate atomic waste in underground reservoirs, the hydraulic fracture process for extraction of oil and gas from different layers of the earth and analysis of the structures of underground mines. In this paper, we investigate the effect of temperature on mode I and mode II fracture toughness of Lushan sandstone. For this, we used the Cracked Chevron Notched Brazilian Disc. In this study, the specimens were subjected to a temperature of 20, 60, 100 and 150 ℃. The results show that, with increasing temperature up to 150℃, mode I and II fracture toughness of sandstone increases.

Keywords: *Temperature, Sandstone, Fracture Toughness, Mode I and Mode II.*

Extended Abstract:

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1. Introduction

Since rocks in a natural environment are generally jointed and cracked and are affected by temperature under the surface of the earth, it is necessary to study the rock behavior in the laboratory under different temperatures and how they affect crack propagation to determine the actual behavior of the structure when constructing various structures on rocks. Many researchers have examined the effect of temperature on the fracture toughness, some of which are mentioned here. Al Shayea et al. (2000) have investigated the effect of temperature on the mode I fracture toughness of limestone. According to this study, the fracture toughness increases from 0.42 MPa√m at ambient temperature to 0.52 MPa√m at a temperature of 116 °C. Funtasu et al. (2004) studied the effect of temperature on the mode I fracture toughness Kimachi and Tuff sandstones. The mode I fracture toughness of the sandstone to 125° C does not show much variation and is approximately constant. With increasing temperature (above 125 °C), the fracture toughness also increased so that, it shows an increase of 30 % at 150° C and an increase of at 40 % at 200 °C. The I mode fracture toughness of Tuff is reduced by increasing the temperature up to 75 °C, and it rises by increasing the temperature up to 100° C and 125 ° C (Funatsu et al., 2004). Meredith and Atkinson have investigated the effect of temperature on the mode I fracture toughness of two blocks of Gabrro. The fracture toughness of both Gabrro blocks increased by raising the temperature to 100° C and then decreased by changing the temperature of 100° to 400° C (Meredith & Atkinson, 1985). Feng et al. heated the specimens at nine different temperatures of 20 (ambient temperature), 100, 200, 300, 400, 400, 600, 700, and 800° C to examine the effects of temperature on mode I fracture toughness of sandstone (Feng et al., 2017). SCB specimen was used to conduct this experiment. The results of this study showed that at 20 - 100° C, the mode I fracture toughness of sandstone is raised due to the evaporation of water in the rock and the initial micro-cracks closing down in the rock. At a temperature of 100 – 500 °C, the mode I fracture toughness of sandstone is reduced due to the propagation of the thermal cracking caused by the application of heat to the specimen. At 500 - 800° C, the mode I fracture toughness is substantially reduced due to the quartz phase transition and the development of cracks caused by heating of the specimen. Feng et al., also examined the effect of temperature on the mode II fracture toughness of sandstone at temperatures of 20 (ambient temperature), 100, 200, 300, 400, 400, 500 and 600 °C using SCB specimen. The results of this study showed that with the increase in temperature from 20 (ambient temperature) to 500° C, the mode II fracture toughness almost remains constant and does not change significantly. When the temperature exceeds 500 °C, the mode II fracture toughness decreases substantially (42.55 %) (Feng et al., 2018). Meier used PTS experiment to investigate the effect of temperature on the mode II fracture toughness. In this experiment, thirty granite specimens were selected and heated from 25° (ambient temperature) to 250 °C. The results showed that by increasing the temperature from 25° (ambient temperature) to 150 °C, the mode II fracture toughness remains approximately constant. When the temperature exceeds 150 °C, the fracture toughness increases (approx. 10 %) (Meier, 2009). Generally, in previous research, the effect of temperature on the mode I fracture toughness was investigated. And studies using mode II were conducted using specimens other than the Brazilian disk, except for Al-Shayea et al. research was done on the cracked straight through Brazilian disc (CSTBD). However, in this study, in addition to mode I, the transitions of mode II fracture toughness have been examined under the temperature by preparing cracked chevron notched Brazilian disc (CCNBD). In this study, the aim is to investigate the effect of temperature on

the mode I-II fracture toughness of sandstone up to 150 °C. This is the maximum recorded temperature in petroleum wells.

2. The specimen of the experiment

In this study, sandstone was used due to its abundance in most formations of Iran. The physical and mechanical properties of the specimen are shown in Table 1.

Table 1. The physical and mechanical properties of sandstone

UCS(MPa)	σ_t (MPa)	E(GPa)	Poisson's ratio	V_p (m/s)	effective porosity (%)	dry unit weight (KN/m3)
58.8	5.4	14.67	0.26	3494	13.31	21.63

3. The process of the experiment

The experiment is performed at four temperatures of 20 (ambient temperature), 60, 100, and 150 °C to investigate the effect of temperature on the fracture toughness. After the furnace reached the desired temperature, it takes a while for the specimen in the container that is positioned in the furnace to reach the desired temperature. This period is obtained by placing a thermometer in the vicinity of the specimen and putting the container inside the furnace. For a temperature of 60° C, it is 5.8 h, 14 h for 100° C, and 16 h for 150 °C. The container is then taken out of the furnace and is placed under the axial loading machine to determine the fracture load of the specimen.

4. Results

The specimens were tested at four temperatures of 20 (ambient temperature), 60, 100, and 150 °C to investigate the effect of temperature on the mode I and mode II fracture toughness. Three specimens were used to ensure the test result in each temperature. Then the fracture toughness in each temperature was determined through calculation of the mean of the obtained numbers. In figure (1) and (2) the mode I and II fracture toughness of chevron cracked sandstone specimens at resulting temperatures from the calculation of the mean at each temperature are shown.

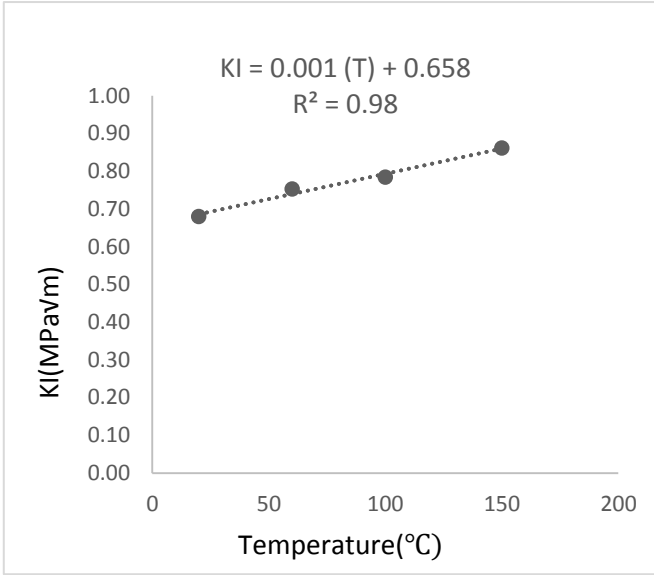

Fig. 1. The effect of temperature on the mode I fracture toughness.

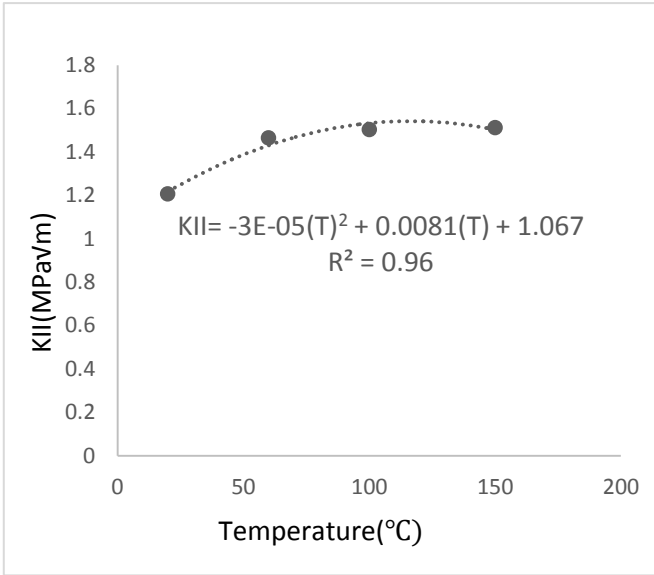

Fig. 2. The effect of temperature on the mode II fracture toughness.

As noted, the variation of the mode ii fracture toughness under the heat is similar to that of the mode I fracture toughness. The fracture toughness increased by increasing the temperature from 20 (ambient temperature) up to 150°. To analyse the effect of temperature on the mode I fracture toughness, strain variations of sandstone is measured at temperatures mentioned by installing an electrical strain gauge (Fig. 3). As can be seen, with the increase in temperature, sandstone particles are compressed. By considering the increase in fracture toughness, it can be concluded that the thermal expansion led to the closing of micro-cracks in the sandstone specimen.

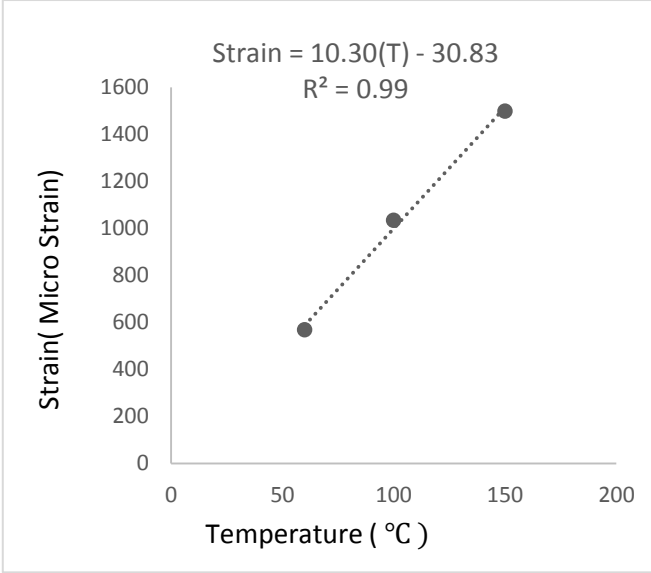

Fig. 3. strain variations against sandstone temperature.

5. Conclusion

In this study, the effect of temperature on the mode I and II fracture toughness was investigated. Experiments were conducted on cracked chevron-notched Brazilian disc samples.
Based on the experiments, the following results were obtained:
The mode I fracture toughness of sandstone increased linearly with the temperature increased from 20° (ambient temperature) up to 150 °C (26.47 % increase).
The mode II fracture toughness of sandstone increased with the temperature increasing from 20 (ambient temperature) up to 60 °C (21.66 % increase) and then with the increase in temperature from 60° to 150 °C, the fracture toughness increased to a slight degree.
The strain variation of sandstone at mentioned temperatures showed that with the increase in temperature, it could be concluded that sandstone particles are compressed and considering the increase in fracture toughness, the thermal expansion is caused the micro-cracks in sandstone specimen to close down.

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