The Experimental Research of the Effect of Heating Temperature and Heating Time for Oil Shale Crack

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Summary: The oil shale from open-pit oil shale mine of Fushun, Liaoning province was chosen as our study objective, the effect of the time and temperature on oil shale crack was studied. The results showed that with the temperature increasing, crack width, length and quantity increased. When temperature was greater than 300 ℃, the length and quantity increased rapidly, so, the threshold temperature was 300 ℃; with the heating time increasing, the crack width and quantity increased first, then decreased, while the length presented an increase. The crack quantity reached the maximum for heating 8 h and crack width reached the broadest at 6 h. So the optimum heating time is 6-8 h.

Keywords: Oil shale, Crack, Thermal cracking, Heating time, Temperature.

Introduction

The conventional energy including oil, coal and natural gas is gradually reducing, so it is urgent to search alternative energy [1]. Oil shale is an ideal alternative energy for its rich resource and easy to be large-scale exploit. Oil shale deposits in the most parts of the earth, and the reserve is up to 475 billion tons, about 5.4 times of oil recoverable reserves [2].

Due to high efficiency and low pollution, oil shale in-situ mining technology attracts people attention. In-situ mining technology refers to that heating oil shale in-situ to produce the shale oil and gas. In the in-situ oil shale exploitation, the main method is that by injecting heat into the underground, thermal cracking in oil shale occurs and then cracks generate, which can induce industrial oil and gas flows. Since the 1980s, in-situ heating technology mature gradually, and more than ten new technologies have appeared, that are represented by Shell's ICP technology, Exxon-Mobil's Electrofrac TM technology and EGL's in-situ mining technology [3, 4].

Crack structure has great influence on oil shale permeability. Crack is the main channel of seepage, connecting with the surrounding pores. Those cracks will be the natural seepage channel for oil and gas, so as to enhance oil and gas recovery. Now it has been confirmed that the exploitation of oil shale in-situ on a large scale is feasible in business [5, 6]. So it is imperative to study the effect of heating time and temperature on the crack, which can provide the reference to the in-suit technology application [7].

Although there are lots of studies on oil shale in-situ mining technology, that mainly focus on pyrolysis characteristics and carbonization law of granular oil shale. Zhang etc. [8] reported that threshold temperature of fine sand is 150-210 ℃. E. Eseme etc. [9] reported that temperature is the main factor controlling the thermo-mechanical deformation of oil shale. Kang etc. [10] researched the effect of temperature on oil shale using small size oil shale rock. However, studies on thermal cracking of massive oil shale under high temperature are very few. In this paper, the experiments was conducted to study the effect of time and temperature on the oil shale crack using the oil shale from the open-pit oil shale mine of Fushun, Liaoning province, China.

Experiment

Equipment

Muffle furnace (type: KSZN-k8), digital camera, electron microscope（500 times definition）, boiler dry, pliers and steel rule were used.

Samples

Samples (Fig. 1) belong to Cenozoic tertiary and exist in coal-bearing strata, which were from open-pit oil shale mine of Fushun, Liaoning province, China, The sample is dark brown with simple luster. Structure of the sample rock grain is compact with microscopic primary stratification and the oil ratio is 4% to-10%.

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Fig. 1: The sample of oil shale.

Process

In the experiment, the oil shale was processed to approximate cuboids, in order to observe expediently the crack. Then the oil shale rocks were marked with number using marker pen as samples. The samples were heated using muffle furnace at different temperature (100, 200, 300, 400, 500, 600 ℃) and for different time (2, 4, 6, 8, 10 h). After heating, the samples were cooled to room temperature and the length, width and quantity of crack was recorded by digital camera and high magnifications electron microscope.

Parameter Measurement

More 10 measuring points were selected from one crack to measure using ruler to calculate the average width. The measurement of the crack length was repeated 3 times to get the average length. Only visible crack was chosen to calculate the quantity of crack. And cracks are dividing into different grades (grading standard is shown in Table-1).

Table-1: The grading standard for cracks.

Grade	The crack length
Short crack	1-5 mm
Medium crack	5-10 mm
Long crack	>10 mm

Results and Discussion

The Effect of Heating Temperature on the Crack of Shale

Set the heating time constant (2h), the samples was heated at a range of temperature (100, 300, 400, 500, 600 ℃)

The Effect of Temperature on the Crack Width

As shown in Fig. 2, the crack width and shape were different at different temperature, and more than 10 points were selected to measure the width. The crack width was shown in Fig. 3. The results showed that with heating temperature rising, the main crack width of the sample presented a rising tendency as a whole. The main crack width increases sharply with the temperature increasing when the temperature is lower than 300 ℃. This is probably consequence of improvement of internal thermal stress. These findings are consistent with literature that has been reported [10]. However, the increase of width turned gentle when the temperature varied between 400 ℃ and 600 ℃, and lots of micro cracks generated around the main crack. Then the micro crack and main crack connected each other, so good oil and gas seepage channel was formed. This may be because that organics in the shale began to thermal-crack and to blow out at high temperature.

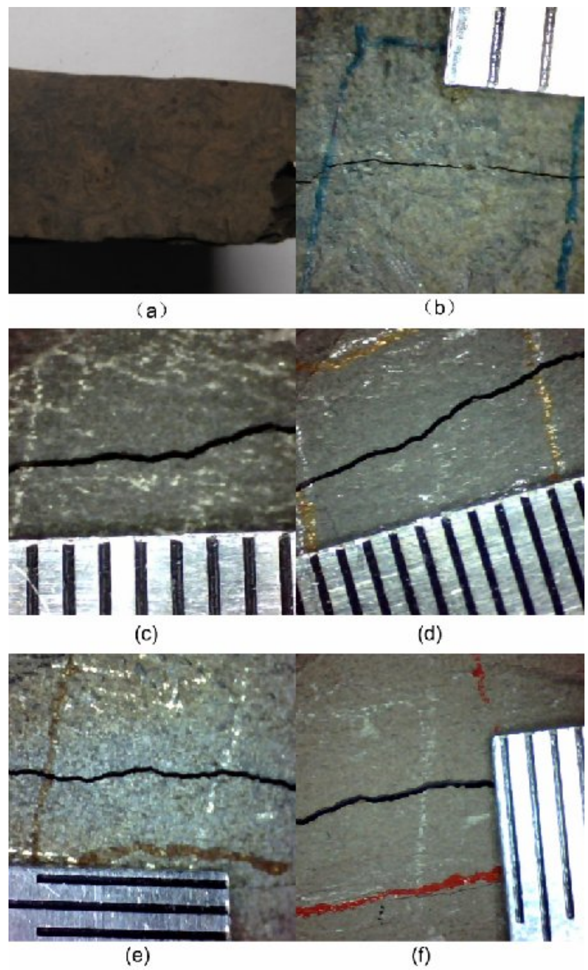

Fig. 2: The oil shale crack width at different temperature, (a) room temperature, (b) 100 ℃ (c) 300 ℃ (d) 400 ℃ (e) 500 ℃ (f) 600℃.

The Effect of Temperature on the Crack Length

As shown in Fig. 4, the main crack length increased slightly when the temperature raised from room temperature to 300 ℃.When the temperature was greater than 300 ℃, the crack length increased sharply. Compared with the width, high temperature contributed more than low temperature to the length increase.

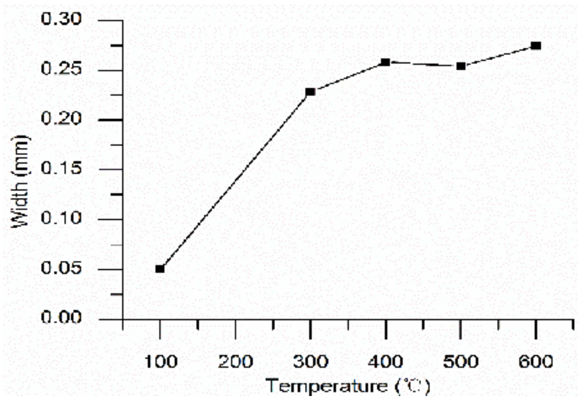

Fig. 3: The effect of temperature on crack width.

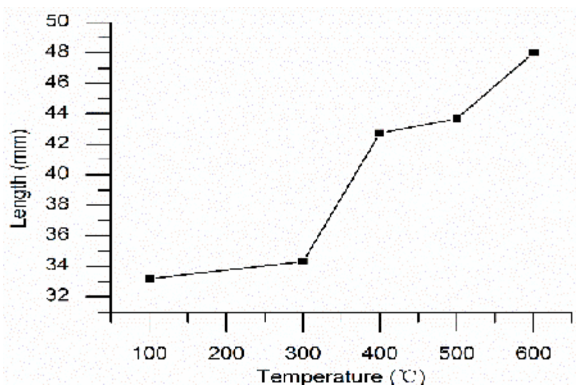

Fig. 4: The effect of temperature on crack length.

The Effect of Temperature on Crack Quantity and Shape

As shown in Fig. 4, at 100 ℃ only one line-shape crack in the middle of the sample was observed. With temperature increasing, the crack extends and broadens quickly, and became a long crack through the whole sample surface. At the same time, lots of different length and width cracks on the both of the cracks appeared that parallel to stratification.

When temperature raised from room temperature to 600 ℃, width, length and quantity of crack presented an increase. The crack quantity of different level was counted, and the crack quantity and proportion were shown in Fig. 6 and Fig.7, respectively. Based on temperature change, the process could be divided into two stages. In the first stage (room temperature to 300 ℃), the crack quantity with different length increased steadily, and the crack mostly extended at the edge of the sample. There are two reasons for the phenomenon. First, this may be because that crack lacks of limitation at edge of the oil shale rock. Second, this also may be because that the thermal decomposition mainly caused the crazing and extending of original bedding stratification .Quantity of short crack increased most quickly and held the dominant position gradually. The proportion of short crack raised from 0 to 31%, and the proportion of medium cracks, has raised from 0 to 8%, while the long proportion decreased. In the second stage (300 to 600 ℃), the quantity of all cracks increased simultaneously and sharply. That may be attributed to the thermal-cracking of organics in the oil shale rock. Proportion of short crack reached the maximum at 300 ℃, and then decreased slightly, and the proportion of medium crack increased significantly (0 to 33%). The crack quantity presented a sharp increase at 300 ℃. We believe that 300 ℃ is the threshold temperature for open-pit oil shale mine of Fushun. When the temperature was greater than 500 ℃, crack quantity, width and length increased significantly, showing "extensively developed and concentrated outbreak" characteristics. The result indicates that the heating temperature should be more than 500 ℃ to achieve a good crack net.

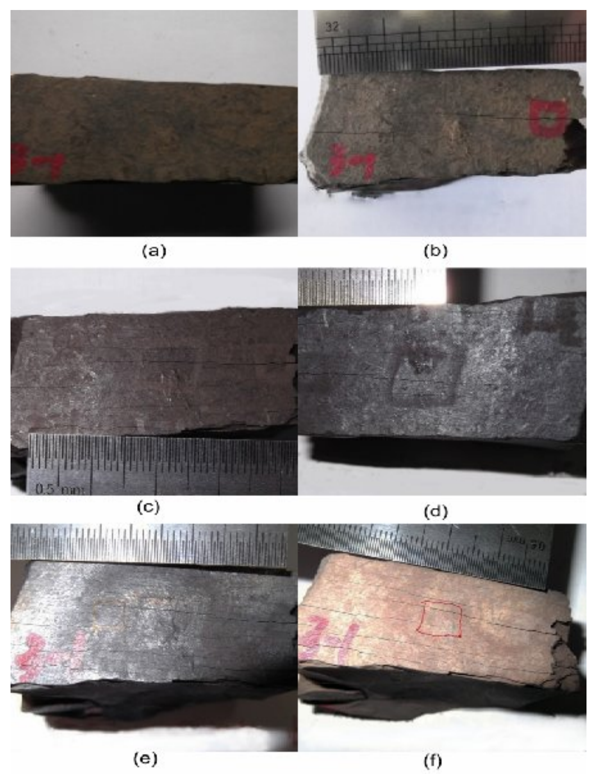

Fig. 5: The oil shale crack quantity and shape at different temperature, (a) room temperature, (b) 100 ℃ (c) 300 ℃ (d) 400 ℃ (e) 500 ℃ (f) 600 ℃.

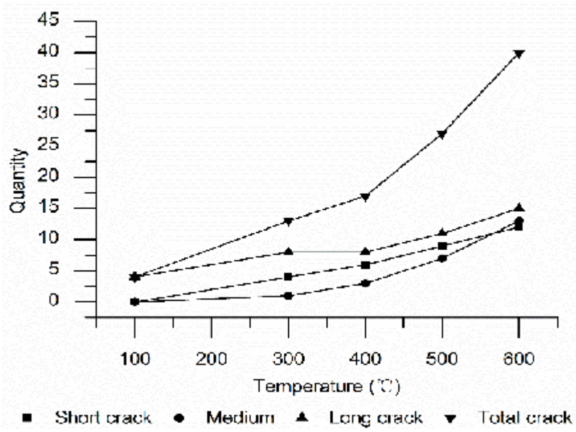

Fig. 6: The effect of temperature on crack quantity.

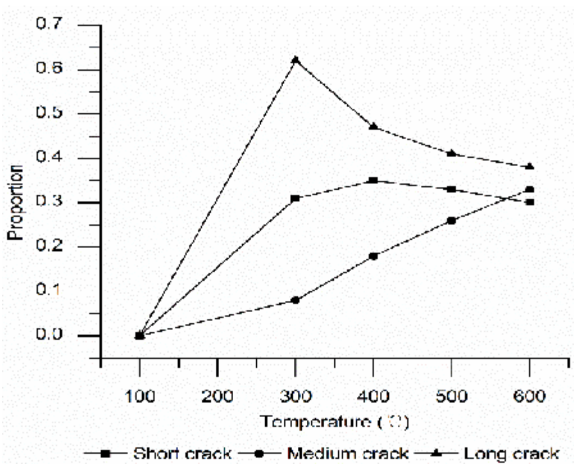

Fig. 7: The effect of temperature on crack proportion.

The Effect of Heating Time on the Crack of Shale

Set the heating temperature constant (500 ℃), the samples were heated at a range of time (2, 4, 6, 8, and 10 h).

The Effect of Time on the Crack Width

As shown in Fig. 8, as heating time increased, the crack width changed significantly, and the crack shapes were also becoming more complexity. The effect of heating on crack width was shown in Fig. 9, the result showed that the crack width increased when the heating time raised from 2 to 6 h while decreased when the heating time raised from 6 to 10 h.

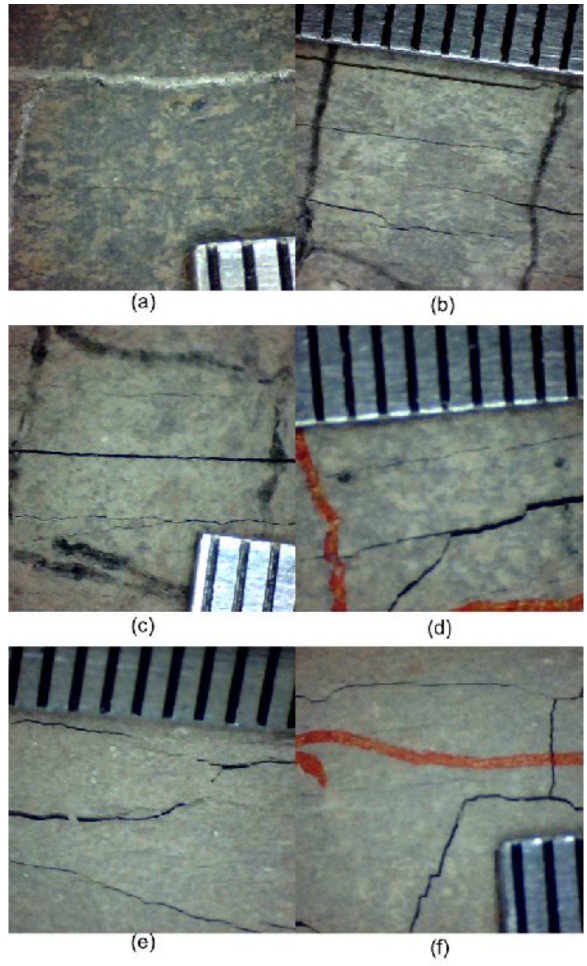

Fig. 8: The oil shale crack width at different heating time, (a) 0 h, (b) 2 h (c) 4 h (d) 6 h (e) 8 h.

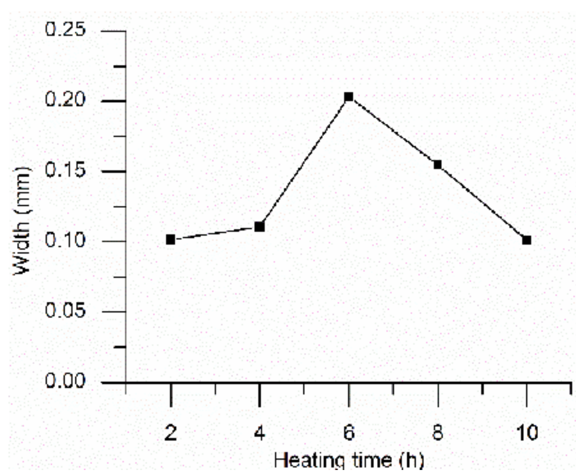

Fig. 9: The effect of heating time on crack width.

The Effect of Time on the Crack Length

As shown in Fig. 10, the main crack length increased slightly when the heating time raised from 2 to 10 h. Compared with the temperature, heating time has weaker influence on crack length.

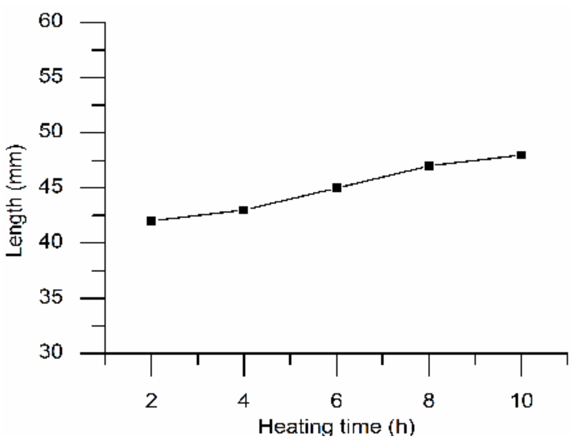

Fig. 10: The effect of heating time on crack width.

The Effect of Time on Crack Quantity and Shape

As shown in Fig. 11, with heating time increased, the crack shape and length changed significantly. In the early heating period, the cracks on sample surface were less with "simple" shape. In the later heating period, the cracks on sample surface were more with cured shape. And many bifurcations occurred, lots of micro cracks caused on both sides of original crack in different degree.

The crack quantity and proportion were shown in Fig. 12 and 13. The result showed that when heating time increased from 2 to 10 h, the changes of crack quantity and proportion experienced three stages. In the first stage (2 to 4 h), the proportion and quantity of short and medium crack reduced, and the quantity and proportion of long crack increased. In the second stage (4 to 8 h), the proportion of short and medium crack increased, while proportion of long crack reduced sharply. It may be because that the heat transferred into the interior of oil shale, and thermal cracking happened violently. Moreover, the crack caused by thermal stress did not changed obviously. In the third stage (8 to 10 h), the proportion of short and medium crack presented an increase, while long crack decreased. This is may be because many short and medium cracks have developed into long cracks due to thermal-cracking. Furthermore, it may be due to the reason that organic volatile components have volatile completely, so the little new short and medium cracks appeared.

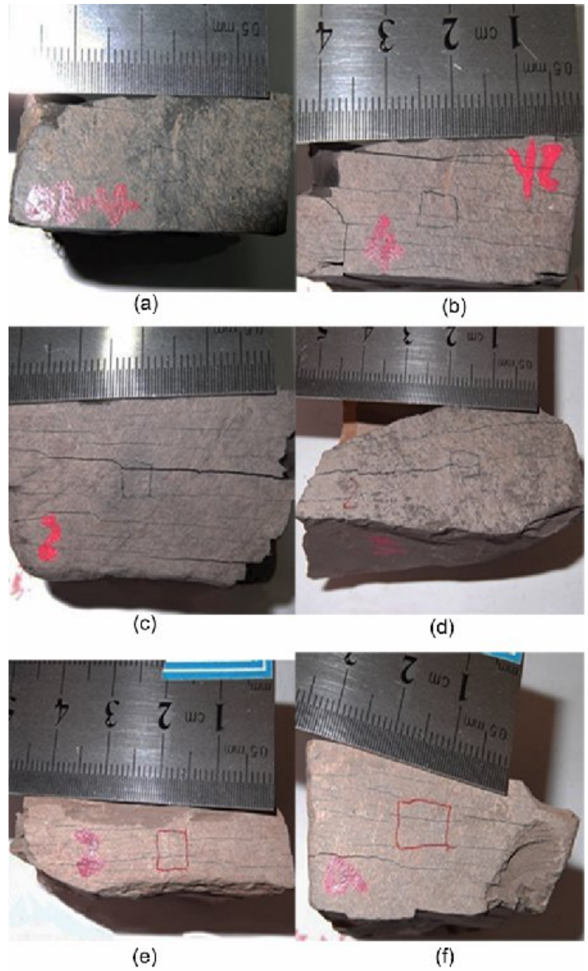

Fig. 11: The oil shale crack width at heating time, (a) 0 h, (b) 2 h (c) 4 h (d) 6 h (e) 8 h.

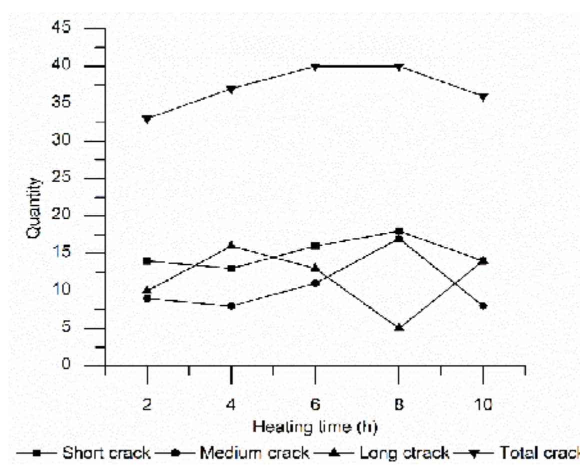

Fig. 12: The effect of heating time on crack quantity.

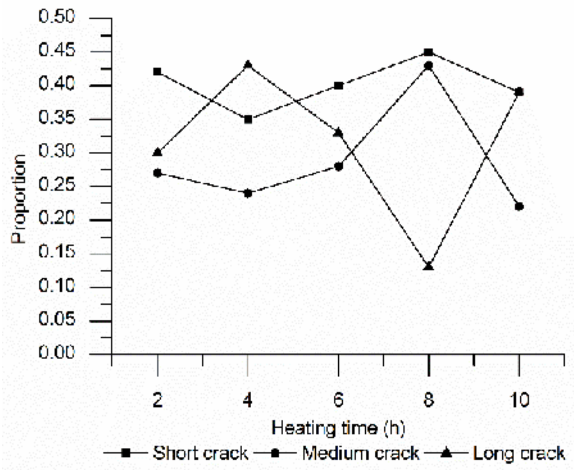

Fig. 13: The effect of heating time on crack proportion.

Conclusion

The effect of the heating time and temperature on oil shale crack were studied that were from open-pit oil shale mine of Fushun, Liaoning province, China. The results showed that with the temperature increasing, crack width, length and quantity increased. When temperature was greater than 300 ºC, the length and quantity increased rapidly, so, the threshold temperature was 300 ºC. In contrast, the width increased sharply when the temperature is lower than 300ºC. With the heating time increasing, the crack width and quantity increased first, and then decreased, while the length presented an increase. The quantity reached the maximum for heating 8 h and width reached at 6 h. So the optimum heating time is 6-8 h.

Some limitations of this study are that the pressure was not considered and the samples were only from open-pit oil shale mine of Fushun, Liaoning province, China. We only concentrated on the oil shale that is heated by electricity and heat air. More experiments should be conducted considering the effect of pressure and more samples from different places should be studied.

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