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Numerical modeling of crack propagation process in brittle coal sample containing pre-existing crack under compressive load

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Abstract

In the brittle coal sample containing pre-existing cracks under compressive load, the first crack created is a wing crack that is formed under tensile force. After that, coplanar and oblique cracks are formed, respectively, which is the result of shear force. In this study, a discrete element method based on linear parallel bond model (LPBM) has been used to investigate the growth path of cracks and the amount of force required to create it. The formation of cracks in this method is due to the breaking of the bond between the particles, which forms macro cracks by joining the microcracks. It was found that the average normal forces for breaking the bond in wing crack are about 11 and 30% in oblique and coplanar cracks by investigate the load on the coal sample containing pre-existing cracks, therefore, the growth of wing tensile cracks in the sample is due to the low value of normal forces. The value of shear force required to overcome the parallel bond of particles in oblique and coplanar cracks is about 7.5 and 3.5 times in wing crack, respectively, in order for crack propagation, it is necessary to break the shear bond between the particles in the oblique and coplanar crack path. The average shear force required to break a bond in the coplanar crack path is about 47% in the oblique crack path, which makes the coplanar crack faster than the oblique crack. The wing crack has the highest value in terms of length compared to other secondary (induced) cracks before the peak point (in stress-strain curve), and this causes the pre-existing cracks in the coal seams to be joined using wing cracks. In this study, the propagation path of all three types of secondary (induced) cracks in the brittle coal sample has been investigated, which is consistent with previous research.

Keywords: *Brittle coal, Secondary (induced) cracks, Crack growth, Linear Parallel Bond Model (LPBM)*

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Extended Abstract:

1. Introduction

One of the important parameters to stability analyse of coal extraction by various methods and specially to investigate the cavity growth rate in the underground coal gasification (UCG) method from the viewpoint of fracture mechanics is to know and understand the mechanism of crack propagation under load applied. The process of crack growth or propagation in coal must be carefully investigated to determine the behaviour and type of created crack due to the load applied. In general, investigating the mechanism of crack propagation has a direct effect in increasing gas production in CBM (coalbed methane), increasing production and quality of synthetic gas in UCG method (underground coal gasification), panel stability, etc. Past research on the crack propagation in coal on a micro or macro scale using CT scanning, scanning electronic microscope, acoustic emission method, optical microscope and high-definition camera has been done.

In this paper, the types of created cracks by the compressive load applied on the coal sample have been investigated. Therefore, a distinct element method based on the linear parallel bond model (LPBM) has been used to investigate the amount of required normal and shear force to overcome the parallel bond between particles. This research can help to analyze the behavior of types of cracks under different types of loads and stress applied, heat and gas and the mechanism of required force for crack propagation in future research and create the necessary knowledge and understanding to investigate the issues of damage and failure or fracture in open and underground excavations of brittle coal.

2. Materials and methods

Generally, the relationship between particles or pieces and walls is expressed by the force-displacement law in the PFC software. When a parallel bond is formed through the bond method, an interface is formed between two notional surfaces, and the parallel bond force and moment are equal to zero. A parallel bond creates an elastic corresponding effect between these two notional surfaces, and this interaction is removed as soon as the bond breaks. The relation between maximum normal and shear stress around the parallel bond is expressed as the following equations:

$$\bar{\sigma} = \frac{\bar{F}_n}{\bar{A}} + \bar{\beta}\frac{\|\bar{M}_b\|\bar{R}}{\bar{I}} \tag{1}$$

$$\bar{\tau} = \frac{\|\bar{F}_s\|}{\bar{A}} + \begin{cases} 0, & 2D \\ \bar{\beta}\frac{|\bar{M}_t|\bar{R}}{\bar{J}}, & 3D \end{cases} \tag{2}$$

where $\bar{F}_n$ and $\bar{F}_s$ are the normal and shear forces from the force, $\bar{A}$, $\bar{I}$, and $\bar{J}$ are the cross-sectional area, the moment of inertia, and pole moment of inertia of parallel bond the cross-section, respectively, and $\bar{R}$ is equal to the particle radius, and $\bar{\beta}$ is the moment share ratio and a number between 0 to 1. If the values of the applied normal and shear stress to the bond between particles were more than the above equations, the bond would break, and a macro-crack would be formed by linkage of tension, shea, or hybrid micro-cracks. In this research, a type of bituminous coal with elasto-brittle behavior has been used.

3. Results

In this research, in order to investigate the type of created cracks result from the pre-existing cleat in the coal sample, this sample is subjected to a compressive load and the type of created cracks has been investigated. pre-existing cleat is 15 mm in length and 45 degrees incline. To investigate the type of crack, the required normal and shear force to overcome the parallel bond between the particles has been obtained. For this purpose, nine control points have been placed in the sample and the amount of normal and shear force to overcome the parallel bond at these points has been measured during software analysis. The types of created cracks in the brittle coal sample containing pre-existing crack after loading are shown in Figure 1.

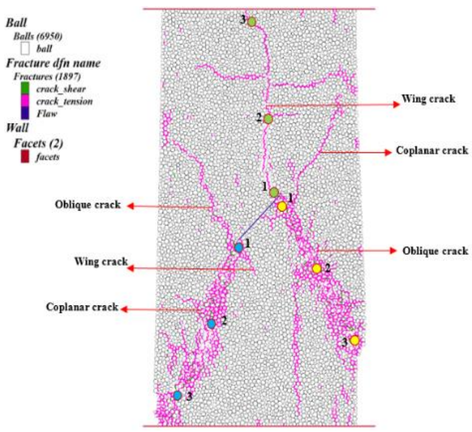

Fig 1. types of created cracks in the brittle coal sample

4. Conclusion

The results of this research are as follows:

- The linear parallel bond model is the best method for investigation the crack growth of brittle rock.
- The created secondary cracks by the compressive load in the brittle coal sample are wing, coplanar and oblique cracks respectively.
- The average of normal forces to break the bond in the wing crack is lower than the oblique and coplanar crack.
- The amount of required shear force to overcome the parallel bond of particles in oblique and coplanar cracks is about 7.5 and 3.5 times in wing cracks, respectively.

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