Study on impact crushing work of coal based on impact crushing experiment

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Abstract. As a porous medium, coal contains gas in the form of surface adsorption. High gas content indicates that coal has high adsorption potential. After the adsorbed gas is transformed into free state, the energy of crushing and throwing out coal can be released. Therefore, the gas desorption process plays an important role in coal and gas outburst. From the perspective of energy, based on the impact crushing experiment of coal samples, this paper obtains a new mathematical model of coal crushing work, which has important theoretical value for the prediction and prevention of coal and gas outburst.

1. Introduction
Coal and gas outburst is a serious power disaster in coal mine. Many scholars [1, 2] believe that coal and gas outburst occurs under many factors, such as gas occurrence, in-situ stress of coal and rock, physical and mechanical properties of coal and rock, etc. Hu qianting [3] and others believe that the weak plane of coal and rock mass structure, fault, external disturbance and brittle failure of coal and rock mass will lead to the instability of coal mass, and the unstable coal mass will be broken and thrown out by the elastic potential of coal and rock volume accumulation, the gravitational potential energy of unstable coal and rock mass and the internal energy of gas. A new mathematical model of crushing work is established through the crushing experiment.

2. Coal outburst crushing work
Wen Guangcai [4] used the converted radius and new surface area of coal particles after coal crushing to characterize the degree of coal crushing, and established the relationship between crushing work and crushing degree within a certain range.

In order to better popularize the experimental research, considering that there is a fracture surface in the coal body before outburst, the new surface area is difficult to measure, and the particle size analysis of pulverized coal with a more expensive particle size analyzer is cumbersome and economical, so it is better to use the percentage of crushed pulverized coal mass with particle size less than 0.2mm to approximate the relative crushing degree of coal. According to the impact crushing test of coal samples from 21 outburst mines in China, the expression of crushing work is obtained [5].

\[ A = 46.91 f^{1.44} p_{1.68} B \]  

\( A \) — Coal crushing work.
$f$ — Firmness coefficient;  
$Y_{p1}$ — Percentage of coal sample with particle size less than 0.2mm in total coal sample mass,%;  
$B$ — Quality of outburst coal.

3. Coal impact crushing test
Formula (1) shows that the firmness coefficient of coal is the main influencing factor of crushing work. The author takes samples from 8#, 9#, 10# coal seams of Pinggou coal mine and 8# coal seams of Baode coal mine to determine the effect of firmness coefficient of coal on coal crushing work.

3.1. Determination of firmness coefficient of coal
(1) Experimental equipment
Tamping cylinder (see Fig. 1), metering cylinder (see Fig. 2), sample separation screen, balance, small hammer, funnel, etc.

![Fig. 1 Structure of tamping drum](image)

Figure 1 is the structural diagram of the tamping cylinder, in which 1 is the drop hammer, 2 is the cylinder body and 3 is the cylinder bottom; Figure 2 shows the structure of the measuring cylinder, 1 is the piston ruler and 2 is the measuring cylinder.
Fig. 2 Structure diagram of metering cylinder

(2) Analysis of experimental results

\[ f = \frac{20n}{L} \]  

where:
- \( f \) — Firmness coefficient;
- \( n \) — Sample impact times;
- \( L \) — Metering height of pulverized coal after impact.

The more times of impact, the smaller the value, and it can be seen from the above formula that the firmness coefficient of coal is greater. The number of impact times plays an important role in the experimental results.

3.2. Analysis of determination results of firmness coefficient of coal

The author measured the firmness coefficient of coal under different impact times on the coal samples of Baode and Pinggou coal 8# seams. The measurement results are shown in Table 1. In the table, \( n \) is the impact times of falling hammer, \( L \) is the height of pulverized coal with particle size less than 0.5mm after impact, and \( \Delta \frac{n}{L} \) is the firmness coefficient of coal.

| coal mine      | Number of impact(n) | Pulverized coal Metering height (L/mm) | \( \Delta \frac{n}{L} \) | Firmness coefficient |
|----------------|---------------------|----------------------------------------|--------------------------|---------------------|
| Baode mine     | 1                   | 71                                     | *                        | 0.28                |
|                | 2                   | 108                                    | 0.0045                   | 0.37                |
|                | 3                   | 136                                    | 0.0035                   | 0.44                |
|                | 4                   | 157                                    | 0.0035                   | 0.51                |
|                | 5                   | 169                                    | 0.0040                   | 0.59                |
|                | 6                   | 176                                    | 0.0045                   | 0.68                |
|                | 7                   | 179                                    | 0.0050                   | 0.78                |
|                | 1                   | 51                                     | *                        | 0.39                |
|                | 2                   | 81                                     | 0.0050                   | 0.49                |
|                | 3                   | 105                                    | 0.0040                   | 0.57                |
| Pinggou mine   | 4                   | 126                                    | 0.0030                   | 0.63                |
|                | 5                   | 147                                    | 0.0025                   | 0.68                |
|                | 6                   | 160                                    | 0.0035                   | 0.75                |
|                | 7                   | 166                                    | 0.0045                   | 0.84                |
Fig. 3 Relationship between impact times and firmness coefficient

The relationship curve between drop hammer times and firmness coefficient is shown in Figure 3. It can be seen from the figure that the firmness coefficient increases with the increase of impact times.

Fig. 4 Relationship between impact times and $\Delta n/L$

In order to measure the accuracy of the firmness coefficient of coal and better reflect the firmness of coal, it can be seen from formula (2) that the value is directly proportional to the ratio of $\Delta n / L$. The corresponding number of drop hammer impacts when $\Delta n / L$ tends to the minimum value. The optimum number of shocks shall be specified. It can be seen from figure 2.7 that the minimum value of $\Delta n / L$ of Baode coal mine is between 3 and 4 times. The minimum value of $\Delta n / L$ of Pinggou coal mine is 5 times. The experimental results of coal samples in other mining areas are similar. Based on this, in order to meet the comparability of firmness coefficient between coal samples, it is suggested that the optimal impact times should be selected from 3, 4 and 5. Considering saving time and cost, it is most reasonable to select 3 optimal drop hammer times.

4. Experimental study on coal crushing work

4.1. Impact crushing energy experiment

The crushing work of coal and gas outburst adopts formula (1), in which $A$ is the crushing work of coal body; $f$ is the firmness coefficient; $Y_p$ is percentage of coal sample with particle size less than 0.2mm in total coal sample mass; B is the quality of outburst coal. It can be seen that the crushing work is directly proportional to the firmness coefficient of coal.
The author took samples from 8#, 9#, 10# coal seams in Pinggou coal mine, measured the firmness coefficient of coal by three drop hammer experiments, and took the average value of three experiments. The measured values of coal samples from 8#, 9#, 10# coal seams in Pinggou coal mine were 0.45, 0.49 and 0.58 respectively. Based on the crushing work formula, I analyze the relationship between the crushing work per unit mass and (the percentage of coal sample mass with particle size less than 0.2mm in the total coal sample mass), as shown in Figure 5.

![Fig. 5](image)

**Fig. 5** Relationship between the crushing work per unit mass and (the percentage of coal sample mass with particle size less than 0.2mm in the total coal sample mass)

It can be seen from Figure 5 that the percentage of coal sample with particle size less than 0.2mm in the total coal sample has a great impact on the crushing work, that is, the coal crushing work increases with the increase of parameter $Y_{p1}$. In addition, the greater the firmness coefficient of coal, the greater the increase of crushing work per unit mass of coal. In other words, the harder the coal, the greater the work done for coal crushing.

### 4.2. A new mathematical model of coal crushing work

The crushing of outburst lump coal mainly uses the impact tamping method, and the falling hammer falls freely from a certain height to smash the coal. As the coal is subjected to the pressure of falling hammer and cylinder bottom, it belongs to double-sided crushing, and the cylinder is placed on a solid cement floor. The crushing work is determined by the drop weight, cylinder height and impact times. The standard of tamping equipment is: the drop weight is 2.4kg and the cylinder height is 0.6m.

$$A = nmgh$$  \hspace{1cm} (3)

- $A$—Impact crushing work;
- $n$—Drop times;
- $m$—Hammer mass;
- $h$—Drop height of hammer.

The crushing work formula is $A = 46.91 f^{1.44} Y_{p1}^{1.68} B$, where $A$ is the coal crushing work; $f$ is the firmness coefficient. $f = 20 n / L$; $L$ is the height of pulverized coal with coal particle diameter less than 0.5mm after impact. $Y_{p1}$ is the percentage of coal sample with particle size less than 0.2mm in the total coal sample. The formula can better determine the crushing work and the quantitative relationship between the two, but the author found that there is a certain difference between the formula and the crushing work calculated by formula (3). Although the falling weight gravitational potential energy will not be fully converted into the crushing work of coal, and some will be dissipated in the form of heat, after all, only a small part of the heat will be lost. In addition, from the perspective of experimental simplicity, the author believes that the crushing work formula needs to be modified.
Let $L_0$ be the percentage of the height of pulverized coal with particle size below 0.5mm in the total height of pulverized coal:

$$L_0 = \frac{L}{L_z}$$  \hspace{1cm} (4)

$L$ — Height of pulverized coal with particle size less than 0.5mm;
$L_z$ — Total height of pulverized coal.

After a lot of experimental research, based on the experimental data, considering the difference of changing the mass percentage into the height percentage, the author substituted the formula into the formula obtained by formula (1) for further processing to obtain a new crushing work formula:

$$A = 50 f^{1.44} L_0^{1.86} B$$  \hspace{1cm} (5)

$L_0$ — Percentage of pulverized coal with particle size less than 0.5mm in the total height of pulverized coal;
$B$ — Quality of outburst coal.

![Fig. 6 Relationship between crushing work per unit mass of coal and parameter $L_0$](image)

Similarly, taking the values of 8#, 9#, 10# coal seams in Pinggou coal mine as an example, Figure 6 shows the curve between the crushing work per unit mass obtained based on formula (5) and the percentage of the height of pulverized coal with particle size less than 0.5mm in the total height of pulverized coal. It can be seen from the figure that the greater the height ratio of pulverized coal with particle size less than 0.5mm, the greater the crushing work, and the greater the crushing work. With the increase of the $f$ value, the crushing work increases accordingly, which is in line with the actual situation, However, it is more simple and convenient to determine the crushing work by using this formula, which only needs to be sieved to 0.5mm. Moreover, when measuring the value, the pulverized coal height below 0.5mm has been measured. Only the total pulverized coal height needs to be measured, which saves the experimental time and is more efficient.

5. Conclusion

(1) Through the determination of the firmness coefficient of coal under different impact times for the coal samples of Baode and Pinggou coal 8# seams, the relationship between the increment of pulverized coal less than 0.5mm and the firmness coefficient of coal and the impact times of falling hammer is obtained. Through the coal sample of Hepinggou 8# coal seam in Baode The analysis of $\Delta n/L$ minimum value shows that the optimal drop hammer times is 3 times.

(2) The firmness coefficient of coal samples in 8#, 9#, 10# coal seams of Pinggou coal mine is measured. Based on the crushing work formula, the relationship between the crushing work per unit volume of coal and the parameter $Y_{p1}$ under different values is obtained. It is concluded that the coal
crushing work increases with the increase of the parameter $Y_0$; The greater the firmness coefficient of coal, the greater the increase of crushing work per unit mass of coal. Based on the experiment, a new mathematical model of coal crushing work is obtained: \[ A = 50 f^{1.44} L_1^{1.16} B \].

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