# ASSESSMENT OF COAL DYNAMIC DESTRUCTION INTENSITY FROM THE ENERGY VIEWPOINT

by

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*In order to effectively assess the intensity of coal destruction under impact disturbance, the Split Hopkinson Pressure Bar tests at different impact velocities were carried out. The coal destruction intensity was explored in terms of both the degree of specimen fragmentation and the degree broken pieces ejection. Quantitative criteria for comprehensively assessing and predicting the coal destruction intensities were further proposed. Combined with the test results and the change rule of destruction intensity energy indexes, the degree of coal crushing can be divided into three grades: light, medium and heavy, and the degree of coal ejection can be divided into four grades: no ejection phenomenon, slight ejection, medium ejection and violent ejection. The research results of this paper provide new ideas and scientific guidance for the comprehensive evaluation of dynamic disasters intensity.*

Key words: *dynamic disasters, energy indexes, coal, destruction intensity*

## Introduction

Impact disturbance is one of the main factors triggering dynamic disasters [1-4]. How to effectively predict and evaluate the destruction intensity of power disasters caused by impact disturbances is of great significance for the efficient and safe utilization of energy [5]. Based on a huge amount of experimental analysis, many scholars have proposed a series of indicators to illustrate the rock destruction intensity from different analytical perspectives. Common energy indicators include bursting liability indices [6], impact energy index [7] and residual elastic energy index [8]. In addition some of the energy indicators based on the stress-strain relationship, combined with the phenomenon of energy dissipation caused by rock failure, there are still many rockburst proneness assessment indicators based on electromagnetic and other characteristics [5, 9, 10]

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However, existing studies on the magnitude of dynamical hazards do not consider the effects of shock perturbations. Therefore, in this paper, firstly, the energy indexes reacting to the degree of specimen crushing and the degree of specimen fragment ejection are proposed. Then, a series of the split hopkinson pressure bar (SHPB) tests were conducted to explore the destruction intensity of coal under different impact disturbances. Quantitative criteria for comprehensively assessing and predicting the intensity of coal dynamic destruction are further proposed. The research results are intended to contribute to the promotion of safer and more sustainable energy utilization.

## Material preparation and methods

Coal samples from both Ulanqab and Yulin cities in China were selected in this study. In order to ensure the homogeneity of the samples, samples with similar wave speed and mass were censored as test objects, as illustrated in fig. 1. The specimens were tested in compression at five impact strengths using the SHPB test system. In order to avoid the dispersion of test results, the test was repeated three times under the same impact conditions and the optimal test results were selected. During the impact process, the degree of ejection of the dynamic destruction was recorded in real time using high speed photographic equipment. In order to make the ejection phenomenon of high speed photography more obvious, the sample was sprayed with white paint in the circumferential direction. Finally, the specimen fragments were sieved using a standard sieve to record the degree of fragmentation of the coal after dynamic destruction.

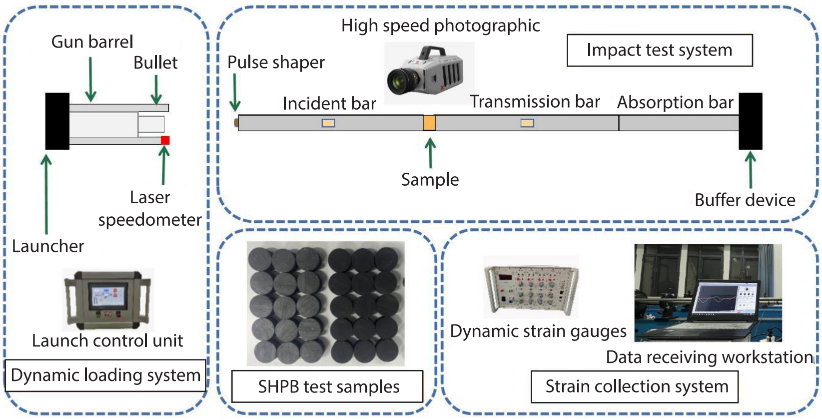


**Figure 1. Test samples and the SHPB experimental equipment**

## Dynamic destruction intensity indices

There are two energy mechanisms that drive rock destruction. One is that the growth of dissipated energy reduces the energy storage limit, the other is that the increase of elastic energy storage increases the power source that drives rock failure [11]. The degree of rock fragmentation is related to energy accumulation and energy dissipation. The prediction and assessment of the degree of rock fragmentation lies in capturing the distribution of energy within the rock as it approaches destruction. Therefore, the energy index of the degree of rock fragmentation is proposed:

$$C_f = \frac{U_D}{U_E} \tag{1}$$

where $U_D$ and $U_E$ represent the dissipated and elastic energy densities at the peak load, respectively, which can be obtained by integrating the stress-strain curves and $C_f$ is the energy distribution ratio, the physical meaning of which is the ratio of elastic and dissipated energy at the peak load.

The ejection phenomenon of dynamic disaster refers to the sudden release of elastic strain energy, which leads to the rapid outward ejection of rock [8]. The strength of the ejection degree is mainly related to the energy storage performance of the rock. The energy release rate characterizes the elastic energy density absorbed by the rock under unit strain, and the energy dissipation rate represents the energy dissipation density caused by unit strain [12]. The instantaneous state of the aforementioned two energy parameters can effectively characterize the energy storage performance of rock mass. Therefore, the energy index of the ejection degree of rock fragments is given:

$$C_e = G_E - G_D \tag{2}$$

where $G_E$ and $G_D$ are energy release rate and energy dissipation rate, respectively. The $G_E$ and $G_E$ can be obtained by the differential of elastic energy density and dissipation energy density to strain, respectively. Here, $C_e$ is the energy rate difference.

### Evaluation of coal crushing degree under impact disturbance

Under different impact disturbances, the average fragmentation size, fragmentation fractal dimension and energy distribution ratio of the two kinds of coal are shown in fig. 2. The magnitude of the shock perturbation strength is expressed by the loaded strain rate. The growth of impact disturbance intensity leads to the rise of energy distribution ratio, and the decrease of average fragmentation and fractal dimension of crushing. It shows that the proportion of energy dissipation for sample crushing is increasing. The proportion of large-scale fragments in the total mass decreases, and the fragmentation degree becomes smaller and smaller. Combined with the change of energy distribution ratio, the fragmentation degree can be divided into three grades. Light, moderate and severe fragmentation degree correspond to $C_f$ < 0.25, 0.25 ≤ $C_f$ < 0.4 and $C_f$ ≥ 0.40, respectively.

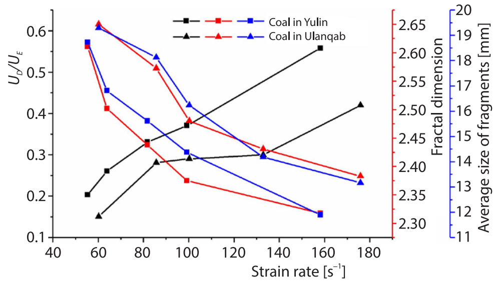


**Figure 2. Test samples and experimental equipment**

### Evaluation of coal ejection degree under impact disturbance

Under the impact load, the variation trend of the energy rate difference of the two coal samples with strain is shown in fig. 3. As the sample deformation grows, there is a tendency for the energy rate difference of both types of coals firstly to rise to the peak and then begin to decrease gradually. Combined with the record of the ejection process of the sample by high speed photography, five pictures with obvious change characteristics were selected to characterize the ejection process of the sample failure. The degree of ejection of the sample under different impact strengths is shown in fig. 4. The destruction of the specimen without ejection phenomenon occurs when the impact strength is small. However, as the impact intensity grows, the maximum value of the energy rate difference gradually increases, and the instantaneous energy storage performance of the coal specimen is enhanced. The specimens exhibit increasingly pronounced ejection phenomena with more and more violent ejection. Combined with the variation of the extremes of the energy rate difference, the degree of ejection can be categorized into four criteria. The levels of no ejection, slight, moderate and severe ejection correspond to $C_e < 14.5$ MJ/m$^3$, 14.5 MJ/m$^3 \leq C_e < 22$ MJ/m$^3$, 22 MJ/m$^3 \leq C_e < 28$ MJ/m$^3$, and $C_e \geq 28$ MJ/m$^3$, respectively.

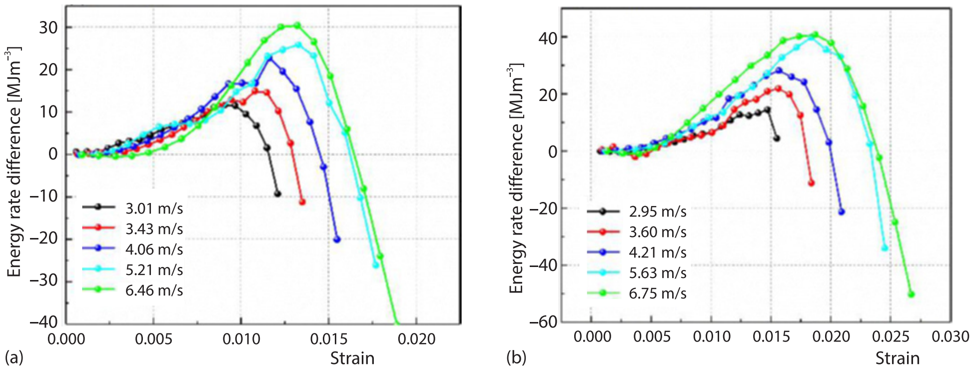


**Figure 3. Variation trend of the energy rate difference of the two kinds of coal samples; (a) coal in Yulin and (b) coal in Ulanqab**

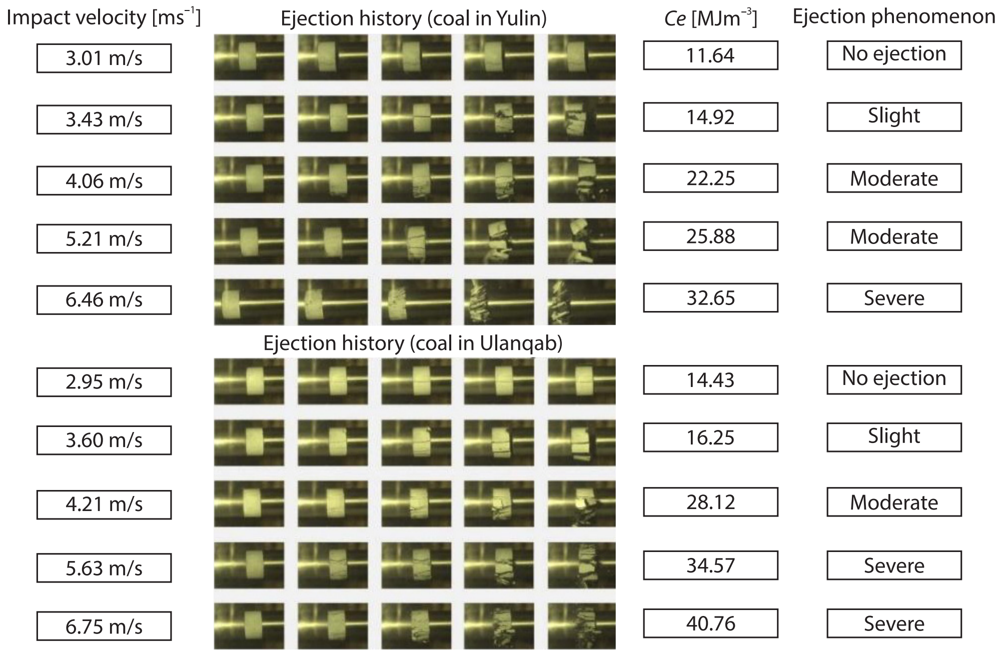


**Figure 4. The degree of ejection of the coal samples**

## Evaluation of dynamic destruction intensity under impact disturbance

Combined with the test results, the dynamic destruction intensity of coal can be quantitatively evaluated by the energy index, $C_f$, of sample crushing degree and the energy index, $C_e$, of fragment ejection degree. The specific assessment criteria for the overall destruction intensity is shown in fig. 5.

Evaluation of coal dynamic destruction intensity

Evaluation of fragmentation degree: $C_f = \frac{U_D}{U_E}$

Criteria for classification of fragmentational degree:

| | |
|---|---|
| $C_f < 0.25$ | Light |
| $0.25 \le C_f < 0.40$ | Moderate |
| $C_f \ge 0.40$ | Severe |

Evaluation of ejection degree: $C_e = G_E - G_D$

Criteria for classification of ejection degree:

| | |
|---|---|
| $C_e \le< 14.5$ | No ejection |
| $14.5 \le C_e < 22$ | Slight |
| $22 \le C_e < 28$ | Moderate |
| $C_e \ge 28$ | Severe |

**Figure 5. The specific assessment criteria for the overall destruction intensity**

## Conclusion

In this paper, the intensity of coal damage can be characterized by the combination of the fragmentation degree and the ejection degree. With the growth of impact disturbance strength, the coal fragmentation degree gradually increases, the proportion of fine fragments gradually rises, and the ejection degree of fragments becomes more and more violent. Under different impact disturbance strengths, the fragmentation degree can be classified into three grades: mild, moderate and violent, and the degree of coal ejection can be classified into four grades: no ejection, mild, moderate and violent ejection.

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## Nomenclature

$G_D$ – energy dissipation rate, [MPam$^{-3}$]
$U_D$ – dissipated energy, [MPam$^{-3}$]
$C_e$ – energy rate difference, [MPam$^{-3}$]
$G_E$ – energy release rate, [MPam$^{-3}$]
$U_E$ – elastic energy density, [MPam$^{-3}$]
$C_f$ – energy distribution ratio, [–]

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