World Journal of Engineering and Technology, 2023, 11, 569-585
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Experimental Study on the Mechanical Parameters Relating to the Impact Tendency of Coal Sample

Diaka Cisse*, Hao Wang, Mingyang Wen, Zhanghao Liu

School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, China
Email: *diakacis746@icloud.com, hpuwanghao@hpu.edu.cn, wenmingyang1996@163.com, 1014845223@qq.com

How to cite this paper: Cisse, D., Wang, H., Wen, M.Y. and Liu, Z.H. (2023) Experimental Study on the Mechanical Parameters Relating to the Impact Tendency of Coal Sample. *World Journal of Engineering and Technology*, **11**, 569-585.
https://doi.org/10.4236/wjet.2023.113040

Received: July 6, 2023
Accepted: August 26, 2023
Published: August 29, 2023

Copyright © 2023 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

Coal burst remains one of the gravest safety risks that will be encountered in mining in the future, because the stress conditions will become more complex as mining depths increase. Various influencing elements exist, and varied geological and mining circumstances might result in diverse coal burst phenomena. The impact propensity of coal has variations as a result of the distinct physical and mechanical qualities of each. To identify the impact propensity of coal and then understand the rules of coal burst occurrence, laboratory tests can be conducted to identify the physical and mechanical parameters affecting coal samples. The mechanical properties, energy absorption, and energy dissipation characteristics of coal samples were examined experimentally in this paper using coal samples that were taken from the mine. On the basis of the evaluation of the impact inclination parameters for four fundamental coal samples, novel impact inclination indicators and the relationship between the fractures in the coal sample and the impact inclination parameters were discussed. The following are the key conclusions: 1) On-site samples of No. 15 coal from the Qi yuan Coal Mine were taken (15 s) and processed in accordance with the guidelines for the coal specimen impact inclination test. The accuracy of the specimen was sufficient for the test. 2) Analysis is done on the mechanical relevance and calculation techniques of the four fundamental coal sample impact tendency characteristics, dynamic failure time (DT), elastic strain energy index (W_{ET}), impact energy index (K_E), as well as uniaxial compressive strength (R_C). 3) Regarding the rock burst danger of rock samples, the potential use of the ratio of pre-peak and post-peak deformation modulus to $K\lambda$ and the residual elastic strain energy index C_{EF} as the impact propensity indices of coal samples are discussed. It is possible to utilize two new impact propensity indices to evaluate the impact propensity of coal samples, according to test results that reveal a linear correlation between two new impact inclination indexes and four fundamental impact tendency indexes. 4) The statistical analysis of the crack ratio with the four impact propensity indicators after coal specimen failure, and the correlation among the crack ratio with the indicators, are both done. The findings indicate that the four impact propensity indicators have a linear relationship with the crack ratio of the coal sample surface cracks.

Keywords

Coal Burst, Coal Impact Trend Parameter, Elastic Modulus Index, Residual Elastic Strain Energy Index

1. Introduction

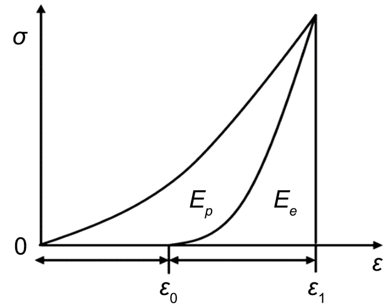
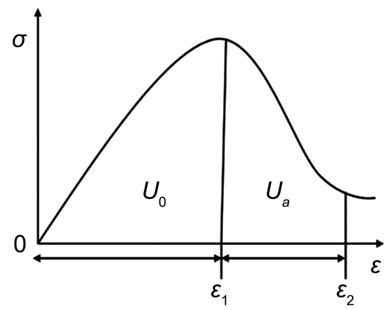
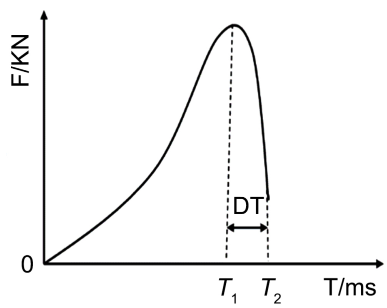
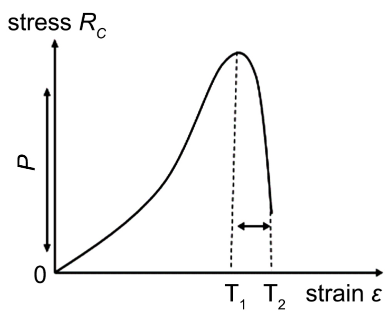
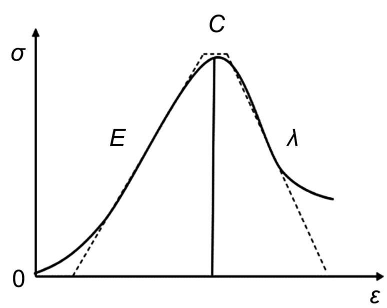
Coal burst, also known as the abrupt and disastrous failure of coal, is a severe safety risk for underground coal mines and has generated a great deal of academic interest from geology and mining scholars [1]. The first coal burst to be documented occurred in England in 1738 [2] [3]. Since that time, mining depth has increased both the intensity and frequency of coal bursts [2] [4] [5]. Because the propensity of coal to impact deeper seams of coal mining is a crucial factor in the incidence of rock fractures as well as a key indicator of coal failure. The propensity of coal to produce rockfall is an innate characteristic of coal. The major coal-mining nations in the world have faced hundreds of rock fissures. Boulder occurrence was first noted in China in 1933. It had happened more than 4000 times in the 60 years leading up to 1996, causing more than 400 fatalities as well as significant financial damage. China has determined that it will continue to rely on an energy plan that includes coal as the primary fuel, electricity as the hub, oil, and gas, and the development of a new, all-encompassing energy strategy. Although coal mining is China's primary industry, the nation's energy security depends significantly on its continued, healthy expansion. China's coal resources are being mined at a larger scale and to a deeper level each year with the goal to meet the country's growing economic needs. Mine disasters such as leaks of gas, gas explosions, water leaks, coal seam self-ignition, ceiling collapses, and rock cracks will always pose a threat to the safety of coal mines as mining conditions become more complex. The welfare and efficiency of the mining industry are seriously threatened by such failure characteristics [6] [7]. Maximum coal and rock pressures cause the rapid, abrupt, and violent release of elastic energy. Rock masses, coal, and supporting structures are frequently destabilized and damaged by rock formations inadvertently, leading to injuries, road damage, and malfunctioning equipment. High soil stresses, far-off mining stress disturbances, faults, and "coal seam ceilings and soil support structures" are major determinants of rock fracture behavior, and complicated mechanisms regulate bed motion. One of the most common risks in deep mines is rock failure. Studies have revealed that the tendency of coal to rock impact [8], the environment in which they occur, the structural characteristics of the coal characteristics of the rocks that surround them, engineering blasting, and mining faults are all directly related to the phenomenon of rock microtremors. Impact propensity is a mechanical feature that is intrinsic to impact fracture and is a need for rock rupture [9]. In the domains of engineering and rock mechanics, rock fracture is a hot topic. Different coal mines experience coal bursts in a variety of ways. As a result, there are various ideas about the development mechanism of rock bursts, each with a different set of formation circumstances and evaluation standards. Discover the power cause of coal cracks according to different rock fracture positions, understand the law of appearance, and discover the origins of coal cracks in the mining region or mine because the reasons, as well as features of rock fracture, differ in different mines. It is essential to implement specific anti-scour measures. The process of coal cracking is still being thoroughly researched. Through field observations and experimental research on coal fracture, relevant researchers have developed a number of theories on the mechanics behind rock fracture [10] [11]. From rigid testing equipment theory, which posits that unexpected instability failure happens when the testing machine's stiffness is less than the specimen's ultimate deformation stiffness, comes stiffness theory [12]. According to Zhang *et al.*, rockfall is a coal instability event. They contend that under the effect of stress, coal's local stress exceeds its peak strength and transforms it into a material that softens stress. They provide the unpredictability theory of rock fracture, which states that rock fracture happens once the rock is disturbed in a condition of instability [13] [14] [15]. Qi *et al.* conducted studies on coal impact and sliding, analyzing the friction and sliding characteristics of coal as well as the resilience of friction and sliding, and suggested that a rockfall is a type of friction and sliding destruction to the coal mass structure, manifesting as an immediately apparent sticking Slip instability procedure [16]. Li investigated the material properties and mechanical procedure the related to bituminous coal body mechanism from a state of equilibrium to the loss of equilibrium under immediate loading in accordance with the motion evolution properties of the structural and mechanical condition of the bituminous coal body structure through the mining process. They introduced the mineral's fracture classification criterion and had a fair amount of success with it in practice. An extensive theoretical debate is prompted by the instability theory, which demonstrates that the rock break is produced by the instabilities and degradation of the coal mass composition in the mining area. The limited role of government in the prevention and control of rockfall is due to the difficulty in establishing a feasible standard for rock crack hazards. Yin *et al.* formulated a catastrophic theoretical model and examined the spatial instabilities of the coal body system governed by horizontal pressure and vertical force, as well as the process of coal mass state mutation brought on by changes in these forces [17]. Theoretical research on rock fractures was first fractally analyzed by academician Xie, who employed fractal theory to describe the fractal characteristics of rock fractures. This theory states that a powerful rock fracture or rock seismic is comparable to a fractal break in the rock and that as the fractal dimension decreases, the energy dissipation needed for the fractal break increases exponentially. Rock shatter theory work has advanced significantly according to the theory of breaking mechanics. Zhang *et al.* [18] [19] [20] [21] conducted a preliminary investigation of the near-surface crack growth as well as the structural integrity of the nearby wall rock in light of the real circumstance [7] [22]-[27]. In the study of rock-crushing problems, many researchers have focused on the crushing susceptibility of rock materials. The elastic strain energy index [28], and the elastic strain's potential energy, the elastic strain energy index WET is defined as the percentage of the elastic strain energy density of the coal compared to the dissipative strain energy density at a stress point of 80% - 90% of the coal specimen's peak endurance. The equivalent unloading test also needs to be performed. (Note: For the sake of calculation simplicity, this article supposes elastic strain energy as the index instead of strain energy [28]. Even after decades of research, several areas still require improvement, and their management is still a key research area. Even after decades of research, several areas still require improvement, and their management is still a key research area [29]. Ma *et al.* [27] examined the coal-rock collision propensity's weakness component. Dou *et al.* [30] indicated that the Impact propensity Index may be affected by the percentage [ratio] of coal plus rock specimens. Using theoretical research and experimental data, Yao *et al.* [31] employing excess energy and the greatest harm as the foundation for evaluation, categorized impact development indices for coal specimens. Wang *et al.* [32] in order to categorize the effect tendency of coal specimens from various coal mines, constructed a Bayes discriminant model. As a result, this article introduces the main 4 indices of coal impact tendency and a new method of calculation of the surface area ratio of coal specimen cracks on the surface after coal specimen failure is also investigated, as well as the link involving the crack ratio as well as the four impact propensity indications after coal sample failure. The results indicate that the cracking ratio of surface cracks in coal samples is also linearly connected to the four impact trend indicators. Mechanical laboratory tests were utilized to estimate mechanical parameters and analyze the coal seam impact propensity.

2. Evaluation of the Impact Tendency of Coal

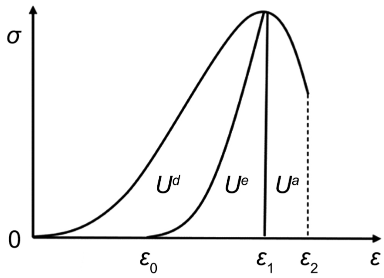
A Review and Analysis of the Available Burst Evaluation Indices

Scholars have developed a variety of indices or methodologies from various perspectives to accurately measure the bursting propensity of coal. The most often used burst evaluation indices are shown in **Table 1**. Based on the stress-strain curve, these burst assessment indexes investigated the procedure and estimation of the coal burst from several angles. The aforementioned indices, however, use coal as an investigation object. Although they are valuable for estimating bursting liability in underground coal mining, the effect of the roof must be overlooked. Even if we find that the exploding susceptibility of coal and roof is weak and powerful, respectively, determining the whole bursting hazard of coal and

Table 1. A list of burst rating indices.

Indices	Equation for evaluation	Determination graph	Bursting liability category
1) Elastic Strain energy index W_{ET} (Kidybinski 1981)	$W_{ET} = E_e/E_p$ where is E_e Elastic strain energy and E_p is plastic strain energy ε_1 and ε_0 are the strain at the equivalent unloading level, and the residual strain when the stress is unloaded to 0.		$W_{ET} < 2.0$ none $2.0 \le W_{ET} < 5$ Weak, $W_{ET} \ge 5$
2) Impact energy index or bursting index K_E (TAN Y A. 1992)	$K_E = U_o/U_a$ where U_o is the pre-peak and U_a is the post-peak, ε_1 is the strain at peak strength, and ε_2 is the maximum strain of the coal specimen during UCS tests		$K_E < 1.5$ none $1.5 \le K_E < 5$ Weak, $K_E \ge 5$
3) Dynamic Failure time DT (W.B. Zhang, S.K. Wang, Y.K. Wu, X.C. Qu 1986)	$DT = T_2 - T_1$ When T_1 is the duration from ultimate strength, T_2 is the duration to complete damage of coal specimens		$DT > 500$, none, $50 < DT \le 500$, Weak, $DT \le 50$, strong
4) Uniaxial Compressive Strength (R_C) (K. ZCzeczeńska D. K. Zuo 1986)	$R_C = P/A$ Where P is the maximum breaking load N, A is the cross-sectional area of the sample		$R_C < 7$, none, $7 \le R_C < 14$, weak, $R_C \ge 14$, strong
5) Modulus index $K\lambda$ (Dai *et al.* 2019)	$K\lambda = \lambda/E$, where λ is the softening modulus of stress-strain curve after peak stress, and E is the elastic modulus before peak stress		$K\lambda \ge 3.51$, strong, $1.11 < K\lambda < 3.51$, Weak, $K\lambda \le 1.11$, none

Continued

6) Residual elastic strain energy index C_{EF} (F. Gong, J. Yan, X. Li 2018)	$C_{EF} = U^e - U^a$ where C_{EF} is the residual elastic energy index, U^a is the failure energy density and U^e is elastic strain energy density, U^d is dissipated energy density (ε_1) is the axial strain at its maximum strength, and (ε_2) is the coal specimen's ultimate strain.		C_{EF} 1< 15 kJ/m^3 15 ≤ C_{EF} ≤ 30 kJ/m^3, weak, C_{EF} > 30 kJ/m^3

rock is challenging. In simpler terms, the probability of a coal burst is determined not only by the breaking liability of the coal seam but also by the structural qualities of the roof.

3. Assessment Methods and Results

In order to evaluate the coal impact propensity of coal specimens using the parameters mentioned above, various laboratory experiments must first be conducted. The test was conducted on fifteen samples of coal in order to acquire the assessment results of the requirements and evaluate the accuracy of the judgments made. The test's details are listed below.

3.1. Specimen Preparation

For the purpose to carry out the test, fifteen specimens of coal from the top coal seam were chosen (Category 15s) see **Figure 1**; the coal specimens were processed into rectangular shapes with three specifications). Dimensions: the coal must be at least 250 mm in length, width, and height. Before the test, all of the pieces were secured with plastic bands to maintain the coal's previous shape. Because there is no discernible geological structure in the initial mining zone, the coal samples that were gathered this time can more accurately represent the properties of the coal in the Qi yuan Mine.

3.2. Test Equipment and Procedure

Rectangular specimens were produced to systematically investigate coal's impact tendency and mechanical behavior. Uniaxial compression tests were performed on rectangular samples to measure Young's modulus. We used rectangular coal to test basic physical and mechanical parameters to simplify testing. The Wuhan Laboratory of Rocks and Soil Mechanics, Chinese Academy of Sciences, created this RMT-150B Rock Mechanics Servo Testing Machine, and an electronic balance with a maximum weight was used and weighed with an accuracy of 0.01 g, which was used for the test, see **Figure 2** and **Figure 3**. The primary control computer, digital controller, manual controller, hydraulic controller, hydraulic motor, triaxial pressure source, hydraulic origin, and numerous functional test accessories make up the majority of the test equipment. Apparent density was measured by the volumetric method.

Figure 1. Fifteen coal samples.

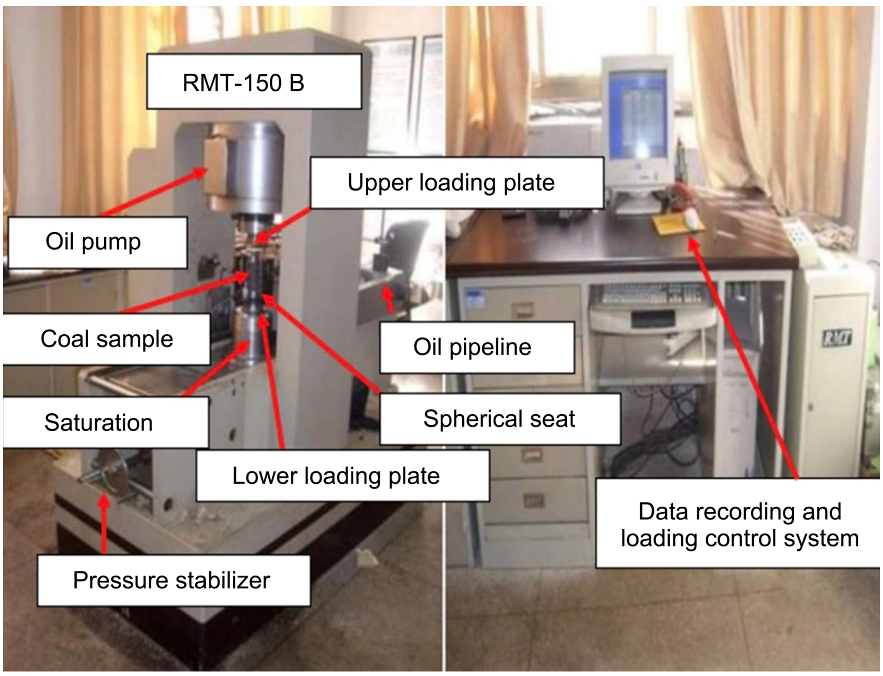


Figure 2. RMT-150 Rock Mechanics test system.

Figure 3. Electronic balance.

4. Results along with Evaluation

4.1. Stress-Strain Graphs and Failure Mechanisms

Figure 4 illustrates the stress-strain curves of the four (4) main coal impact tendency parameters of fifteen coal samples and Figure 5 gives the failure modes.

The schematic diagram of elastic strain energy index calculation is shown in Table 1.

As shown in Figure 4(a), the stress-strain curve is the elastic strain energy index W_{ET} of the coal samples.

Elastic strain energy index according to the formula (1)

$$W_{ET} = \frac{E_e}{E_p} \tag{1}$$

In the formula:

W_{ET}—elastic energy index;

E_e—elastic strain energy, its value is the area under the unloading curve;

E_p—plastic strain energy, its value is the area enclosed by the loading curve and unloading curve.

Calculation of the average elastic energy index of each group of specimens

For a group of specimens, the average elastic energy index is calculated according to formula (2):

$$W_{ETS} = \frac{1}{n}\sum_{i=1}^{n} W_{ETi} \tag{2}$$

In the formula:

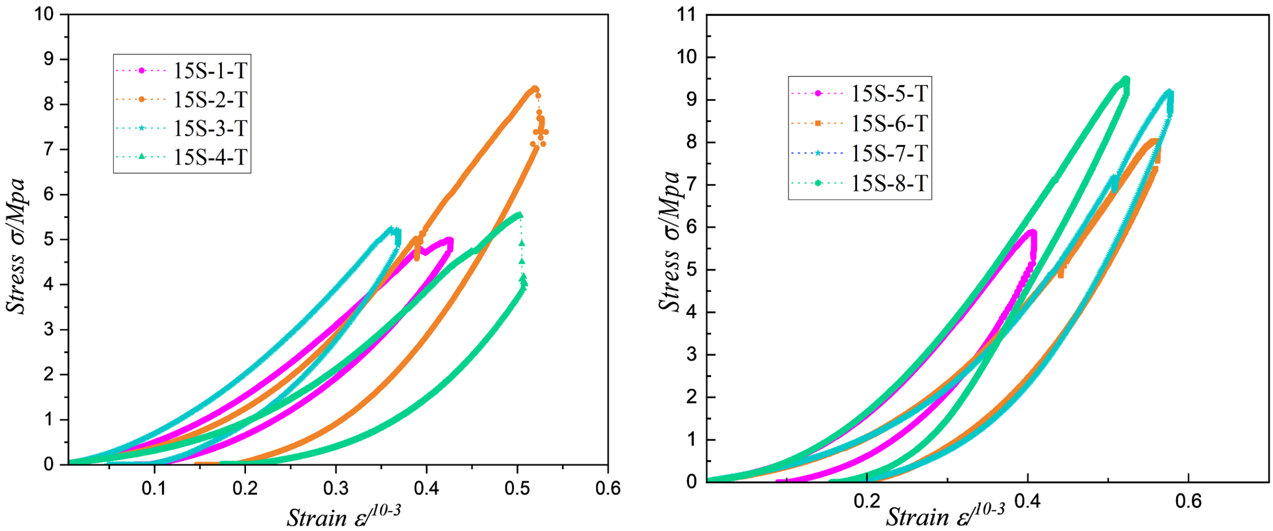
W_{ETS}—average value of elastic energy index;

W_{ETi}—elastic energy index of each specimen;

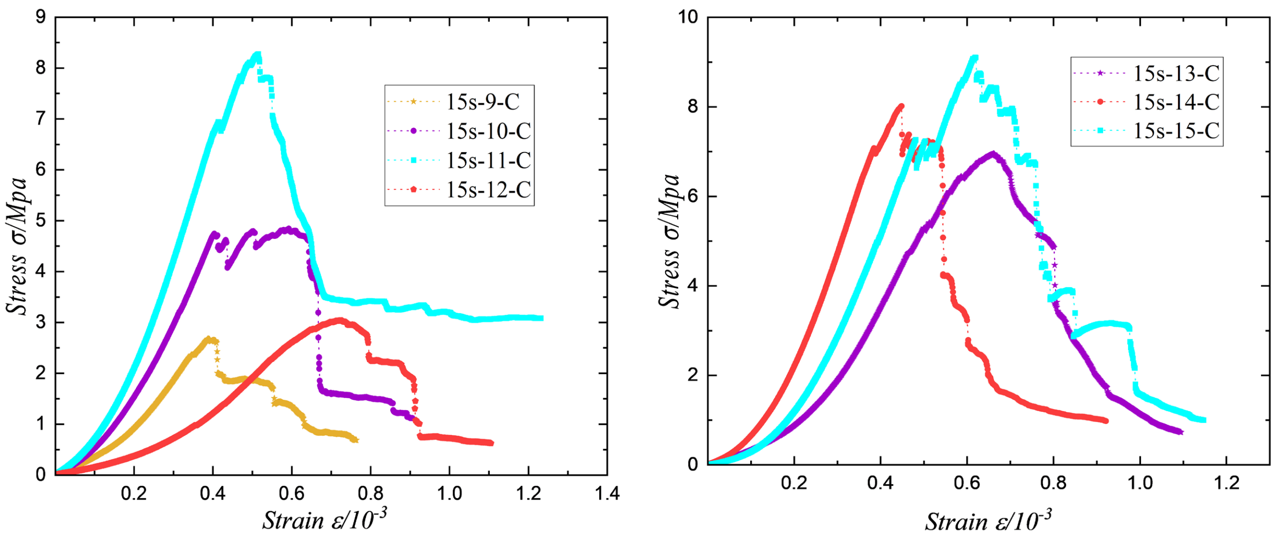
n—the number of specimens.

From Figure 4(b), the impact energy index K_E, is calculated according to the formula (3)

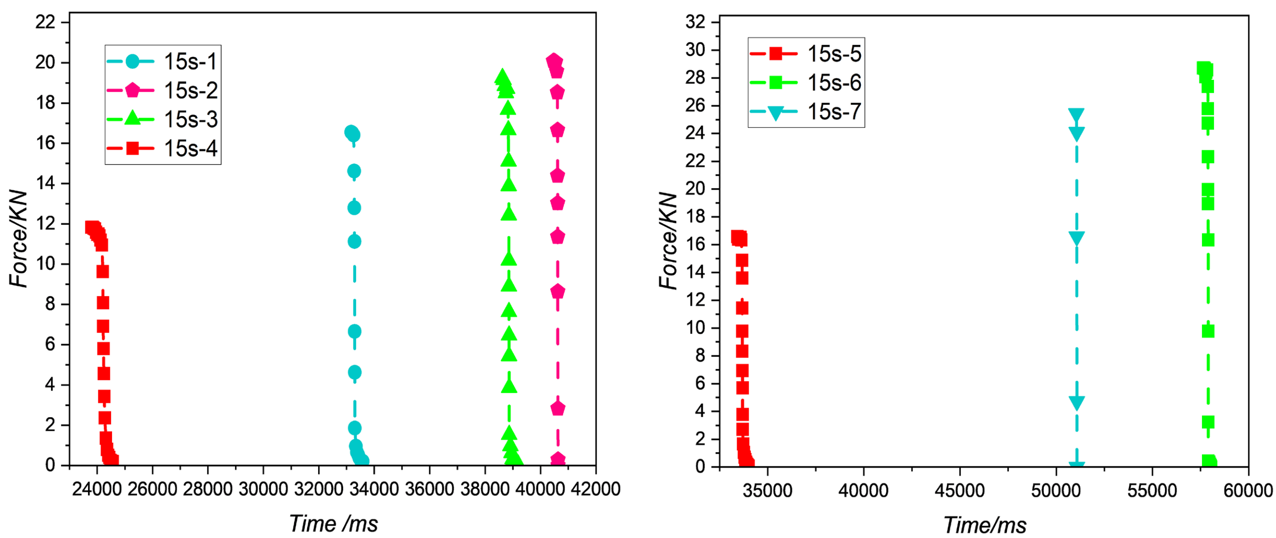
$$K_E = \frac{U_o}{U_a} \tag{3}$$



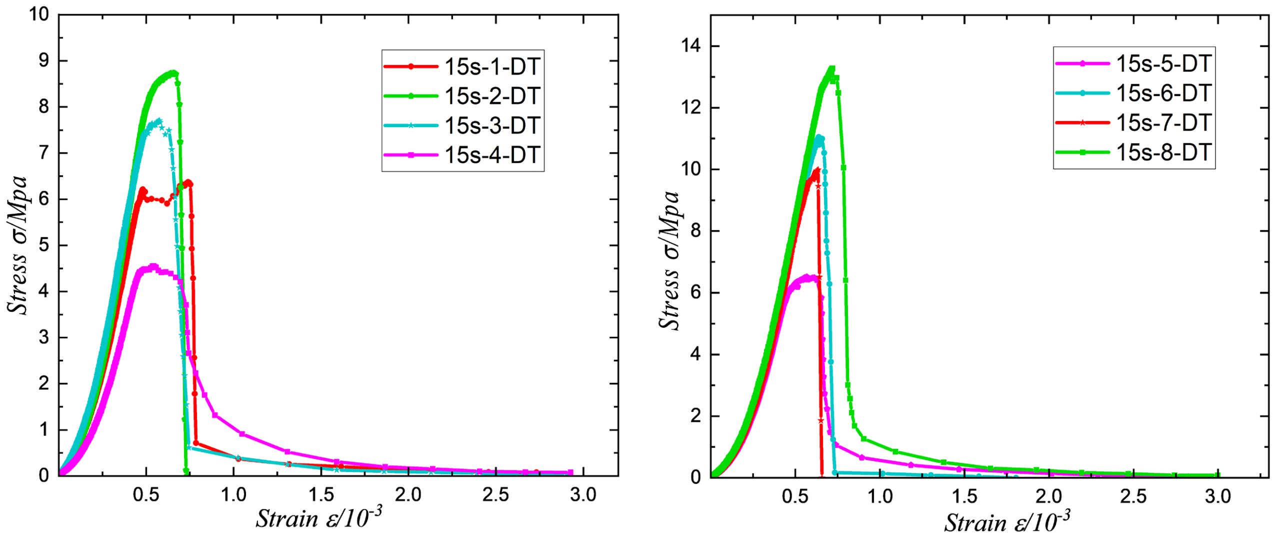
(a) Elastic strain energy index W_{ET}



(b) Impact energy index K_E



(c) Dynamic failure time DT



(d) Uniaxial compressive strength R_C

Figure 4. Stress-strain curves of the main coal burst propensity.

Figure 5. Failure mode of the fifteen coal samples.

In the formula:

U_o—the accumulated deformation energy before the peak value;

U_a—loss deformation energy after peak value;

K_E—impact energy index.

For a group of test pieces, the average impact energy index is calculated according to formula (4):

$$K_{ES} = \frac{1}{n}\sum_{i=1}^{n} K_{Ei} \tag{4}$$

In the formula:

K_{ES}—average value of impact energy index;

K_{Ei}—impact energy index of each specimen;

n—the number of specimens.

For **Figure 4(c)**, the dynamic failure time DT, Numerous research has demonstrated that the dynamic failure time is more useful as an indicator since it is sensitive to the impact tendency. The average dynamic failure time of the specimen (take an integer) according to the formula (5) Calculate:

$$DT_s = \frac{1}{n}\sum_{i=1}^{n} DT_i \tag{5}$$

In the formula:

DT_s—average dynamic failure time, in milliseconds (ms);

DT_i—the dynamic failure time of each specimen, in milliseconds (ms);

n—the number of specimens in each group.

The computer data acquisition and processing system should display the dynamic failure time curve of each coal sample according to the measured data, and determine the dynamic failure time (DT value) of each coal sample manually, and the system should use the formula (5).

For **Figure 4(d)** is the uniaxial compressive strength, the greatest stress that a coal sample is capable of withstanding when compressed in a single direction is referred to as the coal's uniaxial compressive strength. Equation (6) is used to determine the coal rock's uniaxial compressive strength:

$$R_c = \frac{p}{A} \tag{6}$$

In the formula:

R_c—compressive strength, MPa;

P—maximum breaking load, N;

A—The cross-sectional area.

4.2. Identification Results

The impact propensity of coal seams is classified into three categories: no effect (Class I), weak effect (Class II), and strong impact (Class III) in accordance with the coal industry regulations in the Chinese People's Republic test method GB/T25217.2-2010.

The average dynamic failure duration of the 15s coal specimen is 597 ms, the elastic energy indicator is 1.95, the impact energy indicator is 1.34, the uniaxial compressive force is 8.43 MPa, and the modulus index is 0.1, according to the test results of the coal samples' impact tendency index. In accordance with GB/T25217.2-2010, "Classification of Impact Propensity of Coal and Measurement Method of Index", the impact propensity classification, indicators, and full assessment criteria, the complete assessment of 15s impact propensity is Class I, no impact tendency (Table 2).

5. Verification with a Crack Expansion Schematic Diagram

5.1. Failure Characteristics for Variable Sizes under Uniaxial Compression

When the specimen's height is low during uniaxial compression, the end effect constricts the entire specimen, producing the end effect. The end impact is diminished as a result of the specimen's increased size, which brings the center stress zone very near to the single-dimensional stress state. The friction or fissures between the rock particles steadily widen as the loading step progresses. Additionally, when the weight increases, the cracks along the left bottom to the center progressively deepen, pierce, and break. The large specimens are associated with shear failure, whereas the small examples are primarily horizontal cracks and local shear failure.

The uniaxial compression failure characteristics of specimens with various sizes are shown in Figure 5.

5.2. Relationship between Cracks and the Coal Burst Propensity

The surface area ratio of coal sample surface cracks after coal sample failure is statistically analyzed, and the relationship between the crack ratio and the four impact tendency indicators after coal sample failure is also analyzed. The results show that the crack ratio of coal sample surface cracks is also linearly correlated with the four impact tendency indicators. Figure 6 demonstrates how the elastic strain energy index W_{ET} the impact energy index K_E, the dynamic failure time DT, and the uniaxial compression strength R_C relate to the crackers in the fifteen coal samples. The data gathered for the coal specimens were divided into different categories based on actual coal bursting vulnerability. Additionally, there were discernible variations in cracker percentages that corresponded to different coal bursting propensities (Figure 7).

Table 2. Test results of the fifteen coal specimens.

Indexes						Result	
Group	Dynamic failure time DT (ms)	Elastic strain energy index W_{ET}	Impact energy index K_E	Uniaxial compressive strength R_C	Modulus index $K\lambda$	Category	Attributes
15s	597	1.95	1.34	8.43	0.1	Class I	None

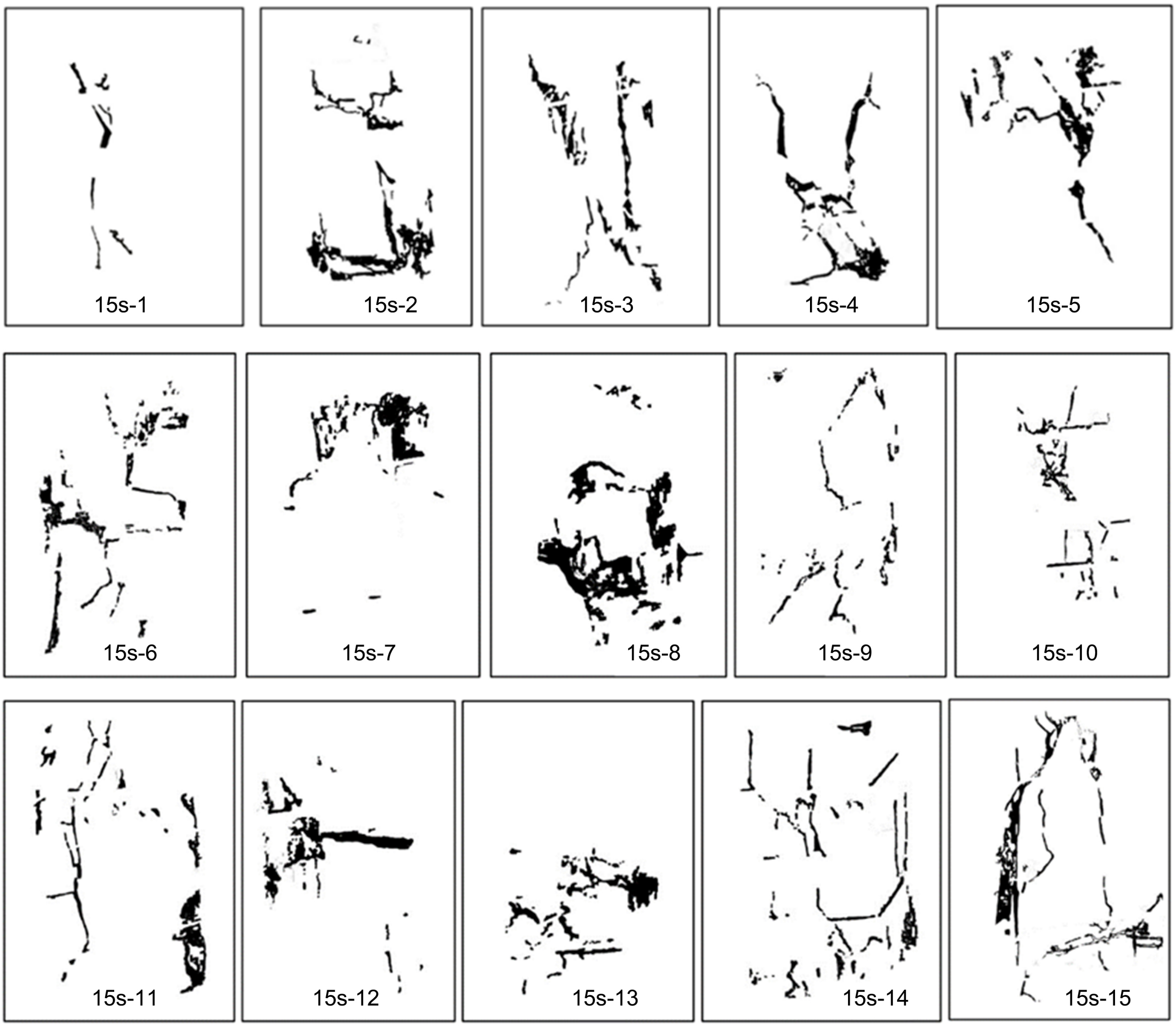
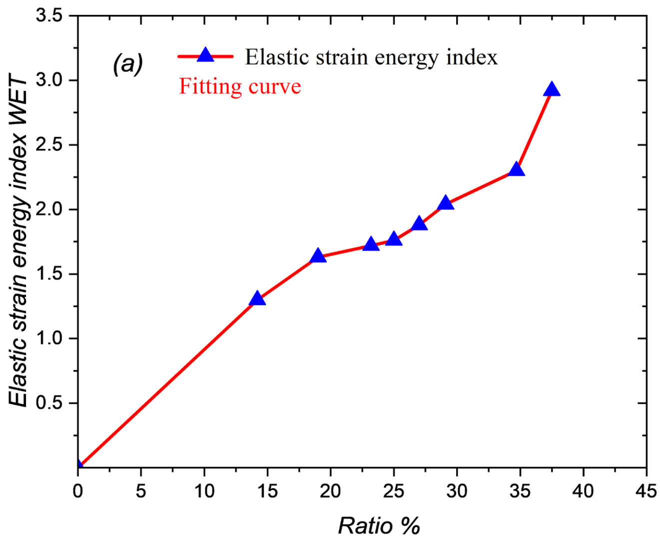


Figure 6. Schematic diagram of crack expansion after failure.



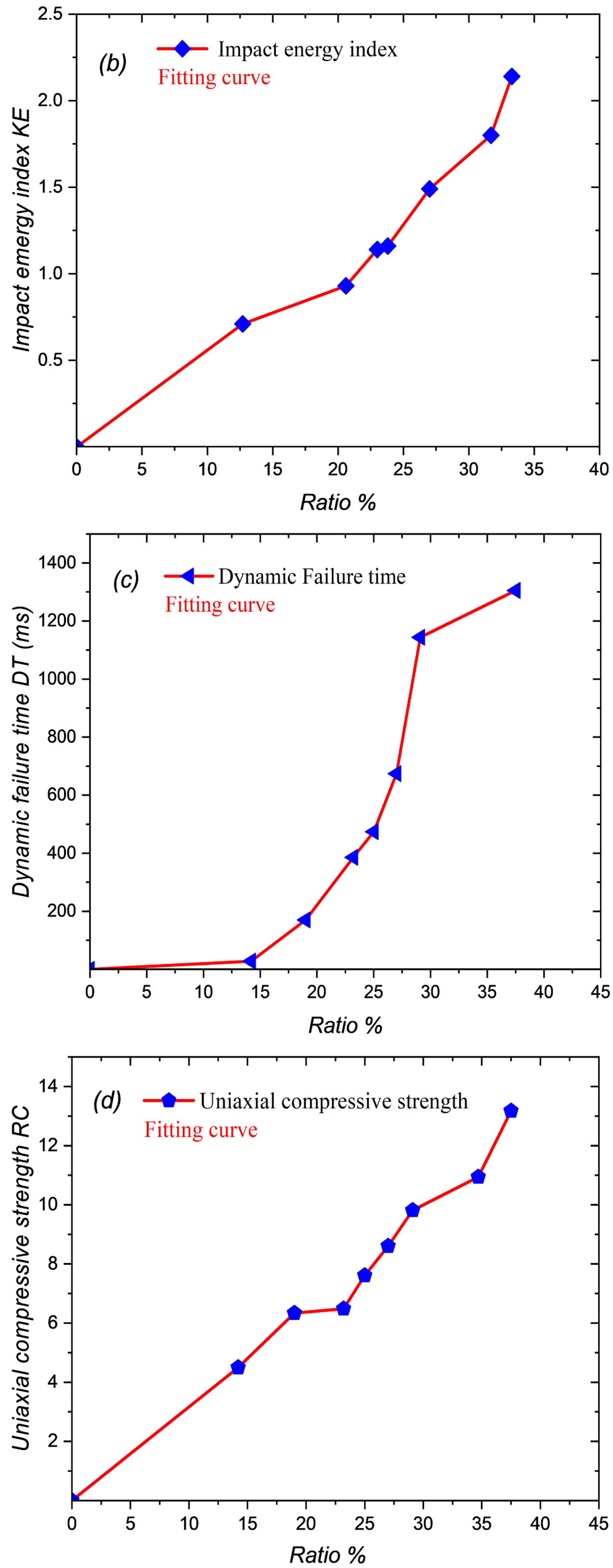


Figure 7. Relationship between the cracks and the coal burst propensity: (a) Elastic strain energy index, (b) Impact energy index, (c) Dynamic failure time, (d) Uniaxial compressive strength.

6. Conclusions

As a result, this article introduces the main indices of coal impact tendency and a new method of calculation of the surface area ratio of coal specimen cracks on the surface after coal specimen failure, as well as the link involving the crack ratio of the four impact propensity indications after coal sample failure. The mains conclusions are as follows:

1) The mechanical applicability and calculation methods of the four primary characteristics of coal sample impact tendency—dynamic failure time (DT), elastic strain energy index (W_{ET}), impact energy index (K_E), and uniaxial compressive strength (R_C) are examined.

2) The possibility of using the ratio of pre-peak and post-peak deformation modulus $K\lambda$ and the residual elastic strain energy index C_{EF} as the impact tendency indexes of coal samples is discussed with reference to rockburst risk of rock samples. The test results show that two new impact tendency indexes are linearly correlated with four basic impact tendency indexes, so it is feasible to use two new impact tendency indexes to characterize the impact tendency of coal samples.

3) After coal sample failure, the surface area ratio of the cracks is statistically investigated, and the correlation between the crack ratio and the four impact tendency indicators is also examined. The findings indicate that the four impact tendency indicators have a linear relationship with the coal sample surface crack ratio as well.

Acknowledgements

This research was supported by the Natural Science Foundation of China (NSFC, 32172310). We would like to thank Dr. Raud Eucaristia Mayoulou for his help in the visualization and reviewing of this paper.

Author Contributions

Diaka Cisse: Conceptualization, methodology, formal analysis, writing, original draft preparation, Wang Hao: Review and editing, funding acquisition.

Wen Ming Yang and Liu Zhang Hao helped with the laboratory experiments. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Yang, X.H., Ren, T., He, X.Q. and Tan, L.H. (2019) A Review of Energy Sources of Coal Burst in Australian Coal Mines. *Proceedings of the* 2019 *Coal Operators' Conference*, Wollongong, 18-20 February 2019, 287-296.

[2] Pan, Y.S. (1999) Study on Rockburst Initiation and Failure Propagation. Master's

Thesis, Tsinghua University, Beijing.

[3] Wang, W.X., Pan, C.L. and Feng, T. (2000) Fountain Rockburst and Inductive Rockburst. *Journal of Central South University of Technology*, **7**, 129-132.

[4] Braeuner, G. (1994) Rockbursts in Coal Mines and their Prevention. CRC Press, Boca Raton.

[5] Zhou, X.J. and Xian, X.F. (1998) Research Advance on Rockburst Theory and Its Engineering Application in Collieries. *Journal of Chongqing University*, **21**, 126-132.

[6] Guo, W., Gu, Q., Tan, Y. and Hu, S. (2019) Case Studies of Rock Bursts in Tectonic Areas with Facies Change. *Energies*, **12**, Article 1330.

[7] Zhou, J., Li, X.B. and Mitri, H.S. (2018) Evaluation Method of Rock Burst: State-of-the-Art Literature Review. *Tunnelling and Underground Space Technology*, **81**, 632-659.

[8] Dai, L.C., Wang, B. and Wang, K. (2014) The Impact Tendency Evaluation of Coal Mine and Rock Based on Fuzzy Clustering Method. *Advanced Materials Research*, **926-930**, 3653-3656.

[9] Pan, Y.S., Yang, Y., Luo, H., Li, Z.H. and Zhu, X.J. (2018) Experimental Study on the Mechanical Charge Induction Law of the Coal Bumping Proneness. *Journal of Safety and Environment*, **18**, 119-123.

[10] Meng, Z.P., Pan, J.N., Liu, L.L., Meng, G.X. and Zhao, Z.H. (2009) Influence of Moisture Contents on Mechanical Properties of Sedimentary Rock and Its Bursting Potential. *Chinese Journal of Rock Mechanics and Engineering*, **28**, 2637-2643.

[11] Su, C.D., Zhai, X.X., Wei, X.Z. and Li, B.F. (2014) Influence of Saturation Period on Bursting Liability Indices for Coal Seam# 2 in Qianqiu Coal Mine. *Chinese Journal of Rock Mechanics and Engineering*, **33**, 235-242.r

[12] Long, Y. (2021) Research on Prediction of Rock Burst Near-Fault Zone in Coal Mining Based on Microseismic Monitoring Technology. *Mineral Resources and Geology*, **35**, 309-314.

[13] Zhang, M.T., Song, W.Y. and Pan, Y.S. (2003) Study on Water Pouring into the Coal Seam to Prevent Rock-Burst. *China Safety Science Journal*, **13**, 69-72.

[14] Zhang, M.T. (2001) Forecast and Prevention of Rockburst in China. *Journal of Liaoning Technical University*: *Natural Science Edition*, **20**, 434-435.

[15] Li, Y.J., Pan, Y.S. and Zhang, M.T. (2006) Time Effect on Zonal Disintegration Process of Deep Rock Mass. *The Chinese Journal of Geological Hazard and Control*, **17**, 119-122.

[16] Qi, Q.X., Pan, Y.S., Li, H.T., *et al.* (2020) Theoretical Basis and Key Technology of Prevention and Control of Coal-Rock Dynamic Disasters in Deep Coal Mining. *Journal of China Coal Society*, **5**, 1567-1584.

[17] Yin, G., Li, X., Lu, J. and Li, M.H. (2017) Disaster-Causing Mechanism of Compound Dynamic Disaster in Deep Mining under Static and Dynamic Load Conditions. *Journal of China Coal Society*, **42**, 2316-2326.

[18] Zhang, X.C., Miao, X.X. and Yang, T.Q. (1999) The Simulation Test of Rockburst in Coal Mines. *Chinese Journal of Geotechnical Engineering*, **1**, 66-70.

[19] Zhang, X.C., Miao, X.X., Zhai, M.H. and Yang, T.Q. (1998) Analysis on Rockburst Mechanism in Sanhejian Coal Mine. *Chinese Journal of Rock Mechanics and Engineering*, **17**, 508-513.

[20] Zhang, X.C., Miao, X.X. and Yang, T.Q. (1999) The Layer-Crack-Plate Model and Testing Study of the Rockburst in Mines. *Chinese Journal of Rock Mechanics and Engineering*, **18**, 507-511.

[21] Zhu, L., Dang, F., Xue, Y., Jiao, K. and Ding, W. (2021) Multivariate Analysis of Effects of Microencapsulated Phase Change Materials on Mechanical Behaviors in Light-Weight Aggregate Concrete. *Journal of Building Engineering*, **42**, Article ID: 102783.

[22] Ortlepp, W.D. and Stacey, T.R. (1994) Rock Burst Mechanisms in Tunnels and Shafts. *Tunnelling and Underground Space Technology*, **9**, 59-65.

[23] Gong, F.Q. and Li, X.B. (2007) A Distance Discriminant Analysis Method for Prediction of Possibility and Classification of Rock Burst and Its Application. *Chinese Journal of Rock Mechanics and Engineering*, **26**, 1012-1018.

[24] Kaiser, P.K. and Cai, M.F. (2012) Design of Rock Support System under Rock-Burst Condition. *Journal of Rock Mechanics and Geotechnical Engineering*, **4**, 215-227.

[25] Zhou, H., Meng, F.Z., Zhang, C.Q., Hu, D.W., Yang, F.J. and Lu, J.J. (2015) Analysis of Rock Burst Mechanisms Induced by Structural Planes in Deep Tunnels. *Bulletin of Engineering Geology and the Environment*, **74**, 1435-1451.

[26] Gong, F.Q., Si, X.F., Li, X.B. and Wang, S.Y. (2018) Experimental Investigation of Strain Rock-Burst in Circular Caverns under Deep Three-Dimensional High-Stress Conditions. *Rock Mechanics and Rock Engineering*, **52**, 1459-1474.

[27] Ma, T.H., Tang, C.A., Tang, S.B., *et al.* (2018) Rock-Burst Mechanism and Prediction Based on Micro-Seismic Monitoring. *International Journal of Rock Mechanics and Mining Sciences*, **110**, 177-188.

[28] Kidybiński, A. (1981) Bursting Liability Indices of Coal. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, **18**, 295-304.

[29] Gong, F., Yan, J., Li, X. and Luo, S. (2019) A Peak-Strength Strain Energy Storage Index for Rock Burst Proneness of Rock Materials. *International Journal of Rock Mechanics and Mining Sciences*, **117**, 76-89.

[30] Dou, L.M., Lu, C.P., Mou, Z.L., Zhang, X.T. and Li, Z.H. (2006) Rock Burst Tendency of Coal-Rock Combinations Sample. *Journal of Mining and Safety Engineering*, **23**, 43-46.

[31] Yao, J.M., Yan, Y.Y., Li, S.Z., Yao, J.W. and Wang, X. (2011) Damage Index of Coal Seam Rock-Burst Proneness. *Journal of China Coal Society*, **36**, 353-357.

[32] Wang, C., Li, Y.F., Zhang, C.L., Liu, L. and Huang, X.C. (2019) Study on the Influence of Indicator Dimensionless on Classification Model of Coal's Bursting Liability. *China Safety Science Journal*, **29**, 20-25.