Journal of Geomine (2023), 1(2), 47-55
DOI: 10.22077/jgm.2023.6443.1008

Studying the effect of coal strength parameters on coal and gas outburst: A case study of Tabas coal mine

Hossein Khakshour[1], Hossain Noferesti[1]

Recived: 2023 May 31, Revised: 2023 Jul. 17, Online Published: 2023 Jul. 23

ABSTRACT

Coal has been used for centuries as a energy source, and it remains a vital fuel for electricity generation in many countries. However, the risks of coal mining are high, and outbursts and gas emissions are two significant hazards associated with underground coal mining. Coal and gas outbursts are sudden and violent ejections of coal, gas, and rock from the working face of an underground coal mine. They occur when high gas levels, such as methane, accumulate in the coal seam and are released rapidly due to the stress and pressure caused by mining activities. Numerical simulation is one of the most powerful methods to study this complex phenomenon. The purpose of this article is to investigate the effect of coal strength parameters on the occurrence of the desired phenomenon in underground coal mines using the finite element numerical method. For the study, the sub-tunnel of the E4 workshop of the Parvade 1 Mine of Tabas, which is located at a depth of 472 meters from the ground, was investigated in the Phase2 simulation software and the possibility of an outburst in this layer assuming the existence of a pocket with a pressure of 0.6 MPa and crushed rock. The unstable failure index has been used to determine outburst-prone areas. In general, the application of UFI is to detect areas prone to brittle failure in phenomena such as Spalling, Rockburt, and Outburst. When this index is greater than 1, there is a possibility of this phenomenon because there is excess energy in the rock. According to the results of this research, strength parameters such as cohesion, angle of internal friction, and modulus of elasticity have a significant effect on the severity of outburst, at the same time the probability of this phenomenon is estimated independently of the tensile strength of coal. Considering that the UFI index used confirmed the results of previous researchers about this phenomenon, it can help predict this phenomenon. For the first time, this criterion is written based on energy components instead of stress and was able to show the effect of different parameters on outbursts.

KEYWORDS

Pocket, coal and gas outburst, numerical simulation, Tabas Coal mine

I. INTRODUCTION

The occurrence of outburst is disastrous for coal mines because it leads to equipment failure, worker collapse, suffocation of employees, methane gas explosion, or pollution of the mine environment by carbon dioxide. Over the past 150 years, many outburst events have caused significant loss of mine workers worldwide. Despite extensive research efforts, the basic mechanisms of this phenomenon are still far from the scientific community. Difficulties in outburst understanding can be attributed to many factors, including diverse geological structures, anisotropic and heterogeneous coal properties, gas content, in situ stress on the coal, and mining methods. A coal and gas outburst is when coal or rocks suddenly enter the mining area from an advancing working face, releasing a large amount of gas. This phenomenon in coal mines can lead to damage to equipment and infrastructure, collapse of the face, injury or death to miners, production delays, financial losses, explosion of methane gas, or pollution of the mine environment by carbon dioxide (Farhadian, 2021; Maleki and Farhadian, 2022). Several factors can complicate outburst analysis in underground coal mining. The following are some of the factors that can make outburst analysis challenging:

1. Complex geology: Coal seams are often located in complex geological formations, which can make it challenging to predict the likelihood and severity of outbursts accurately.
2. Variability in coal properties: Coal properties, such as coal seam thickness, gas content, and stress distribution, can vary significantly within a single mine or a single coal seam. This variability can make it difficult to predict the occurrence and severity of outbursts.
3. Dynamic mining conditions: Mining activities, such as coal extraction and ventilation, can change the stress and pressure conditions within the mine workings and affect the likelihood and severity of outbursts.
4. Limited data: Data on coal properties and geological conditions may be limited, particularly in old mines or in regions where mining is less developed. This limited data can make it challenging to predict the likelihood and severity of outbursts accurately.

[1] Department of Mining Engineering, Faculty of Engineering, University of Birjand, Birjand, Iran
✉ H. Noferesti: hnoferesty@birjand.ac.ir

5. Incomplete understanding of outburst mechanisms: While significant research has been conducted on coal and gas outbursts, much remains to learn about the mechanisms that cause outbursts and how they can be prevented (Wang and Xue 2018). According to the research of the researcher, coal and gas outbursts are a complex phenomenon that can result from a combination of factors, including gas pressure, ground stress, strength properties, and geological structure of coal. The interaction between these factors can be challenging to predict and can vary significantly between different coal seams and mining operations. Gas pressure is a critical factor in coal and gas outbursts, as high gas pressure in the coal seam can cause a sudden and violent release of gas and coal. Ground stress, the stress and pressure exerted on the coal seam by the surrounding rock formations, can also play a significant role in outburst occurrence. If the ground stress exceeds the strength of the coal and surrounding rock, it can cause a sudden release of gas and coal. The strength properties of the coal and surrounding rock formations can also influence the likelihood and severity of outbursts. Coal with high-strength properties is less likely to experience outbursts than coal with low-strength properties. Similarly, rock formations with high-strength properties can provide better support for the coal seam and reduce the risk of outbursts. Finally, the geological structure of the coal seam can also play a significant role in outburst occurrence. Coal seams located in complex geological formations, such as fault zones or regions with high rates of tectonic activity, are more likely to experience outbursts than coal seams located in more stable geological formations (Jiang and Yu, 1995).

The stages of coal and gas outbursts can be broadly classified into three phases: the pre-outburst phase, the outburst phase, and the post-outburst phase.

Pre-outburst phase: This phase is characterized by the build-up of gas pressure in the coal seam. As mining activities create voids in the coal seam, gas can accumulate and increase the pressure within the coal seam. This phase can last for days, weeks, or even months before an outburst occurs.

Outburst phase: The outburst phase is characterized by a sudden and violent release of gas and coal from the working face of the mine. The release of gas and coal can cause significant damage to infrastructure and equipment and can result in injury or death to miners working near the outburst. The outburst phase typically lasts for a few seconds to a few minutes.

Post-outburst phase: The post-outburst phase is characterized by a reduction in gas pressure and a gradual return to normal mining operations. This phase can last for several hours or days, depending on the severity of the outburst and the extent of the damage caused.

It is important to note that not all outbursts follow this exact sequence, and the severity and duration of each phase can vary significantly depending on the specific circumstances of the outburst. Additionally, some outbursts may occur without warning, making it difficult to predict and prevent these events. As such, effective outburst prevention and mitigation strategies require ongoing monitoring and analysis of gas and stress levels in the mine workings, as well as the implementation of safety procedures and equipment to protect miners and infrastructure in the event of an outburst (Wu et al., 2020).

The finite element method and Phase2 software have been used for numerical modeling of coal and gas outbursts. Phase2 is a 2-dimensional plastic finite element program for calculating stresses and displacements around underground openings it can be used to solve a wide range of mining and civil engineering problems, involving: plane strain or axisymmetric, elastic, or plastic materials, staged excavations (up to 50 stages), multiple materials, support (bolts/shotcrete), constant or gravity field stress, jointed rock, groundwater (include pore pressure in analysis). The phase 2 program consists of 3 modules: model, compute, and interpret (Curran and Corkum, 1998).

Mechanisms of outburst phenomenon: The mechanisms that have been mentioned so far about the occurrence of this phenomenon by mining scientists are classified into three groups including single-factor mechanisms, multi-factor mechanisms, and other mechanisms.

Single-factor theories based on the dominant role of gas pressure: These theories believe that high-pressure methane stored in coal is the main cause of the outburst. Another of these theories is that the most common and direct cause of this phenomenon is the free gas found in coal seams and pores. Taylor in 1852 and Rowan in 1911 presented theories based on this mechanism (Lei et al., 2023).

Single-factor theories based on the dominant role of earth stress: In these theories, the main factor in the occurrence of outburst is ground stress. Caulfield in 1931 and Pechuk in 1933 supported this idea (Lei et al., 2023).

Multifactorial mechanisms: According to this theory, outburst results from several factors, including coal gas content and pressure, mechanical and physical properties of pores, geological structure, and ground stress. Lama and Bodziony in 1996 and Beamish and Crosdale in 1998 supported this idea (Yin et al., 2016).

Other mechanisms: Jiang 1998 proposed the spherical shell destabilization hypothesis, in which the rock stress first crushes the coal and creates cracks inside the coal seam, then the coal seams form into a spherical shell. According to this hypothesis, the coal transfers the gas to the fractured areas, and the accumulation of high-pressure gas causes the development of cracks, finally, the coal layers are broken in the form of spherical shells and poured into the working face. As this process continues, stress redistribution breaks the coal near the working face and becomes a continuous outburst (Yin et al., 2016). Guan et al. 2009 considered the phenomenon of coal outbursts similar to the eruption of volcanic materials. According to the statements Govan, the increase of gas pressure inside the coal compared to the pressure of the surrounding environment leads to the crushing of coal and the release of high-pressure gas, and finally, in the form of a shock wave, the gas outburst (Guan et al., 2009).

Effective factors in the occurrence of outburst: The most important factors that affect the occurrence of outburst are summarized as follows: the amount and pressure of coal layer gas b- geological factors (mining depth, slope angle, layer thickness, folding, fracture, fault, shear zones, thickness changes magmatic layer and penetration) c- coal properties (permeability and diffusion, absorption/repulsion properties, resistance and grade of coal). d- stress conditions (Maleki et al., 2022).

According to these factors, the coal layer leads to outbursts under the following conditions: An increase in gas content or pressure, the presence of complex geological factors, such as folds, fractures, faults, dikes, shear zones, changes in layer thickness and magmatic intrusion, increasing mine depth, increasing the angle of layer inclination, increasing layer thickness, reducing layer strength, permeability Less coal seam, higher emission factor If the coal seam gas is mainly carbon dioxide, the seam will be much more susceptible to outburst, as opposed to cases where the coal seam gas is mostly methane, increasing the gas rejection rate, higher coal rank, and increased ground stress (Guan et al., 2009; Maleki et al., 2022; Khakshour et al., 2023).

Outburst control: Outburst control is mainly to control the time of its occurrence so that no miner's life is endangered during this incident. For successful and efficient outburst control, determining the amount of gas within 100 meters of a forward tunnel is necessary, which requires the development of mining methods that provide accurate values within a short time of sampling. Therefore, there is a need to develop methods for predicting the shear areas of the coal layer to predict suspicious locations. Due to the contraction of the coal matrix when using suction, the flow rate, which depends on the direction of the joint and the expansion of the fracture at the bottom of the coal layer, may increase significantly in case of strong suction. While planning for ventilation, emissions cannot be considered proportional to production. This relationship is not linear. Also, degassed is a different mixture of gas content instead of coal. Managing mining in outburst conditions, maintaining ventilation, monitoring environmental conditions, and acting by a risk management plan are other methods of outburst control (Tu et al., 2021).

Outburst prediction: As mentioned earlier, four important and accepted factors of outcrop include gas content, geological anomalies, stress regime, and strata properties. All four factors combine to create an outburst. Gas content can be measured or estimated relatively reliably. A function of gas pressure and porosity determines the energy available for the outburst and it throws the involved material for a short or long distance from the place of occurrence. Gas content affects coal and rock properties. Without the necessary amount of gas, outbursts of gas, coal, and rock will not happen. The role of stress should be evaluated about the strength of coal. The strength of the material determines the required stress level at which the outburst begins. A stress level sufficient to break the rock to a nearly crushed state will cause a violent outburst. It is almost possible to measure the stress in the operational conditions of the mines regularly. Core disking describes a state of extreme stress, but it is also influenced by gas pressure and drilling speed. Radio imaging is based on the dielectric strength of coal, but its accuracy is highly dependent on moisture levels. Its use in structure prediction depends on moisture level anomalies. The approximate prediction of this phenomenon is made according to the mentioned points, which depends on the interaction of the effective factors (Liu et al., 2020).

Management systems for outburst control: The purpose of management systems is to ensure that valid procedures are strictly followed and that mining proceeds without jeopardizing operations. Therefore, a management system relies on the control and balance of activities to achieve the desired result. The mining of outburst-prone layers requires the development of specific procedures to ensure that risks threatening miners and equipment are eliminated or reduced. Most mines have established basic parameters that, if followed, can provide safe mining of coal seams. These conditions may be based on achieving a critical threshold level value (TLV = Threshold Level Value) of gas content, gas flow, etc., and the methods of achieving them depend on local conditions (Aziz et al., 2011; Liu et al., 2020).

In the present study, the unstable failure index, based on energy, was used for outburst analysis in coal mines. Outburst is a kind of rock burst, considering with the difference that in addition to the earth stress, it is also the effect of gas pressure. In this case, the Unstable Failure Index (UFI) can be used to detect outburst-prone areas.

II. UNSTABLE FAILURE INDEX AND ITS USE IN OUTBURST STUDY

In UFI, to determine the areas prone to brittle failure, the values of elastic strain energy and stored energy apacity until the moment of failure are used. Unstable failure is a type of brittle failure, during which the strain energy drops drastically. In this type of failure, the plastic strain before rupture occurs is small. Therefore, the behavior of the rock until the moment of failure can be assumed to be elastic. The unstable failure criterion can be calculated by dividing the applied elastic strain energy by the bearing capacity of the elastic strain energy of the rock. In this case, the applied elastic strain energy density in the three-dimensional state is obtained from Eq. (1) (Li et al., 2018; Ghadimi et al., 2018).

$$\frac{1}{2}\sum\sigma_{ii}\varepsilon_{ii}+\sum\sigma_{ij}\varepsilon_{ij}=\frac{1}{2}\left(\sigma_{xx}\varepsilon_{xx}+\sigma_{yy}\varepsilon_{yy}+\sigma_{zz}\varepsilon_{zz}\right)+\left(\sigma_{xy}\varepsilon_{xy}+\sigma_{yz}\varepsilon_{yz}+\sigma_{zx}\varepsilon_{zx}\right)=\frac{1}{2}\left(\sigma_x\varepsilon_x+\sigma_y\varepsilon_y+\sigma_z\varepsilon_z\right)+\left(\tau_{xy}\gamma_{xy}+\tau_{yz}\gamma_{yz}+\tau_{zx}\gamma_{zx}\right) \quad (1)$$

In this regard, ε: strain, σ: values of normal stress (MPa), τ: shear stress (MPa), and γ: shear strain. In addition, the applied elastic strain energy density in 2D mode can be calculated from Eq. (2).

$$\frac{1}{2}\sum\sigma_{ii}\varepsilon_{ii}+\sum\sigma_{ij}\varepsilon_{ij}=\frac{1}{2}\left(\sigma_{xx}\varepsilon_{xx}+\sigma_{yy}\varepsilon_{yy}\right)+\left(\sigma_{xy}\varepsilon_{xy}\right)=\frac{1}{2}\left(\sigma_x\varepsilon_x+\sigma_y\varepsilon_y\right)+\left(\tau_{xy}\gamma_{xy}\right) \quad (2)$$

In this case, the bearing capacity of elastic strain energy in 3D mode is calculated according to Eq. (3).

$$\left(\frac{1}{2}\sum\sigma_{ii}\varepsilon_{ii}+\sum\sigma_{ij}\varepsilon_{ij}\right)_{at\ Failure\ point}=\left(\frac{1}{2}\left(\sigma_{xx}\varepsilon_{xx}+\sigma_{yy}\varepsilon_{yy}+\sigma_{zz}\varepsilon_{zz}\right)+\left(\sigma_{xy}\varepsilon_{xy}+\sigma_{yz}\varepsilon_{yz}+\sigma_{zx}\varepsilon_{zx}\right)\right)_{at\ Failure\ point}=\left(\frac{1}{2}\left(\sigma_1\varepsilon_1+\sigma_2\varepsilon_2+\sigma_3\varepsilon_3\right)\right)_{at\ Failure\ point} \quad (3)$$

In this regard, the values of ε_1, ε_2, and ε_3 can be calculated from Eq.s (4), (5) and (6), respectively.

$$\varepsilon_1=\frac{1}{E}\left(\sigma_1-\upsilon(\sigma_2+\sigma_3)\right) \quad (4)$$

$$\varepsilon_2=\frac{1}{E}\left(\sigma_2-\upsilon(\sigma_1+\sigma_3)\right) \quad (5)$$

$$\varepsilon_3=\frac{1}{E}\left(\sigma_3-\upsilon(\sigma_1+\sigma_2)\right) \quad (6)$$

In these relations, υ is Poisson's ratio.

On the other hand, according to the Mohr-Coulomb rupture criterion, Eq. (7) holds.

$$\sigma_1=\sigma_c+\sigma_3 tan\psi=\frac{2cCos\varphi}{1-Sin\varphi}+\sigma_3\frac{1+Sin\varphi}{1-Sin\varphi} \quad (7)$$

In this regard, c: cohesion (MPa) and φ: internal friction angle of the rock mass (degrees). Therefore, the density of bearing capacity of elastic strain energy in a 3D state is calculated from Eq. (8) (Li et al., 2018; Ghadimi et al., 2018).

$$\left(\frac{1}{2E}\left({\sigma_1}^2+{\sigma_2}^2+{\sigma_3}^2-2\upsilon(\sigma_1\sigma_2+\sigma_2\sigma_3+\sigma_1\sigma_3)\right)\right)_{at\ Failure\ point}=\frac{1}{2E}\left((\sigma_c+\sigma_3 tan\psi)^2+{\sigma_2}^2+{\sigma_3}^2-2\upsilon\left((\sigma_c+\sigma_3 tan\psi)\sigma_2+\sigma_2\sigma_3+(\sigma_c+\sigma_3 tan\psi)\sigma_3\right)\right) \quad (8)$$

In this regard, υ: Poisson's ratio, E: Young's modulus (Mpa), and φ: internal friction angle of the rock mass (degrees). In this case, the capacity density of elastic strain energy can be calculated in the 2D state from Eq. (9) (Li et al., 2018; Ghadimi et al., 2018).

$$\left(\frac{1}{2E}\left({\sigma_1}^2+{\sigma_3}^2-2\upsilon\sigma_1\sigma_3\right)\right)_{at\ Failure\ point}=\frac{1}{2E}\left((\sigma_c+\sigma_3 tan\psi)^2+{\sigma_3}^2-2\upsilon(\sigma_c+\sigma_3 tan\psi)\sigma_3\right)=\frac{1}{2E}\left(\left(\frac{2cCos\varphi}{1-Sin\varphi}+\sigma_3\frac{1+Sin\varphi}{1-Sin\varphi}\right)^2+\sigma_3^2-2\upsilon\left(\frac{2cCos\varphi}{1-Sin\varphi}+\sigma_3\frac{1+Sin\varphi}{1-Sin\varphi}\right)\sigma_3\right) \quad (9)$$

Since the Phase2 software is a 2D finite element software, the *UFI* is required in 2D mode, obtained from Eq. (10).

$$UFI\ (2D)=\frac{\left[\frac{1}{2}(\sigma_x\varepsilon_x+\sigma_y\varepsilon_y)+(\tau_{xy}\gamma_{xy})\right]}{\left[\frac{1}{2E}\left(\left(\frac{2cCos\varphi}{1-Sin\varphi}+\sigma_3\frac{1+Sin\varphi}{1-Sin\varphi}\right)^2+\sigma_3^2-2\upsilon\left(\frac{2cCos\varphi}{1-Sin\varphi}+\sigma_3\frac{1+Sin\varphi}{1-Sin\varphi}\right)\sigma_3\right)\right]} \quad (10)$$

If the value of this index is greater than 1, it is a sign of excess unbalanced energy in the rock and indicates the possibility of an outburst. The higher the amount of this extra energy, the higher the probability of an outburst and its intensity.

III. The formation of a pocket area containing crushed coal and high-pressure gas

The mining activity changes the state of the stress in the coal layer. As can be seen from Fig. 1, a zone with high stress is formed in front of the tunnel face as the tunnel advances, which increases with each step. In this area, due to high stress, the pores of the coal layer that contain gas become smaller. Therefore, the gas in these pores becomes denser and gets more pressure. These gases tend to leave this stressed area due to their high molecular kinetic energy. The mining operation pushes some of these gases towards the front of the face (if there are no geological effects such as faults, dikes, sudden changes in thickness, or the presence of impermeable materials in the coal layer) and some of them are pushed towards the inside of the face. In the case of geological anomalies such as faults, dikes, sudden changes in thickness, or the presence of impermeable materials in the coal layer, there are two situations. In the first case, the fault is such that it causes gas from the coal layer to escape to other layers. If this gas enters the fault and goes to other layers, there is no danger. Sometimes this gas may escape to the upper or lower layer of coal and cause an outburst from the roof or floor. In the second case, the geological features are such that they prevent the gas from moving forward and the gases get stuck in the high-stress area. With each advancing stage of the tunnel, the stress in this area increases, and as a result, the pressure of the gas trapped in this area increases and the rock is crushed. This area, which is formed as a result of mining and due to impenetrable geological features, is called a "Pocket". In this area, there is high-pressure gas and very crushed rock. If the coal layer has high gas permeability, as the tunnel progresses, this gas pocket becomes the basis for a strong outburst. The pocket gas pressure increases with each advanced step and is not constant, but in this research, the gas pressure of the region is considered to be 0.6 MPa (because according to the research of Fu et al. 2009, the minimum gas pressure required for the occurrence of outburst is 0.6 MPa.) (Li et al., 2018).

IV. Construction of THE numerical model

To create the numerical model, the stope E4 of Parvadeh1 Tabas Mine will be simulated. This stope, located in the C1 coal layer at a depth of 472 meters, was mined. It should be noted that the ratio of horizontal to vertical stress in this area is 1.2 applied according to the information of the technical office of the mine. The strength parameters of the layers used to build the numerical model are given in Table 1. The thickness of the C1 coal layer is assumed to be 2 meters in the simulation, and a gas pocket (3.6*3.6m) and a gas pressure of 0.6 MPa is assumed in the simulation. The tunnel height is 3.6 m. The analysis is based on stress analysis, and the pressure exerted by the high-pressure zone gas on the cavity wall is applied as an equivalent stress.

The tunnel maintenance system includes rock bolt, Flexi, and stinger (for temporary maintenance, before rock bolt installation). In the simulation, the roof of the advancing tunnel is reinforced with rock bolts. Fig. 3 shows the tunnel maintenance system and Table 2 shows the characteristics of the rock bolt, which is an all-injection type.

According to the information, the intended advancing tunnel is modeled in Phase 2 software. Fig. 4 shows the drilling steps.

V. Sensitivity analysis of effective factors in outburst

After entering the *UFI* 2D formula in the software and solving the model, the maximum value of this index If there is a pocket with a gas pressure of 0.6 MPa, is estimated as 33.93. If there is no pocket, it is estimated as 27.14, which can be seen in Fig. 5. According to Eq. (10), because this value is greater than one, there is a possibility of an outburst phenomenon. Moreover, the higher this index is, the more likely this phenomenon will occur. So, assuming the existence of a gas pocket with a pressure of 0.6 MPa in this stope, the working face of the advancing tunnel is subject to outburst.

To analyze the sensitivity of the strength parameters of coal, with the assumption of keeping other parameters constant, the sensitivity of the unstable failure index has been analyzed concerning each of the indices of modulus of elasticity, tensile strength, angle of internal friction, and cohesion of coal. The analyses were performed in two limit states of zero and 0.6 MPa pressure. According to Fig. 6, with the increase of the modulus of elasticity (E) of coal, the *UFI* has decreased. That is, the risk of outburst occurrence is higher in weaker layers. The role of this index in the possibility of outbursts is similar to the cohesion and internal friction angle of the coal layer. By increasing the stickiness of the coal layer, the value of the *UFI* has decreased. In other words, the stronger the coal layer is, the lower the probability of coal outbursts. Because the strain energy applied to the rock must overcome the energy-bearing capacity. According to Fig. 6, with the increase of the internal friction angle (φ), the value of *UFI* has decreased. This parameter, like cohesion (C), is one of the strength parameters of the coal layer, which indicates the low probability of outbursts in resistant layers. According to the curve of changes in the tensile strength of the layer, since *UFI* is based on the assumption of rock shear failure, the value of this index is estimated independently of the tensile strength of coal, or this parameter may not affect the occurrence of outburst. Nevertheless, investigating the effect of the tensile strength of the layer on the probability of outburst requires independent research.

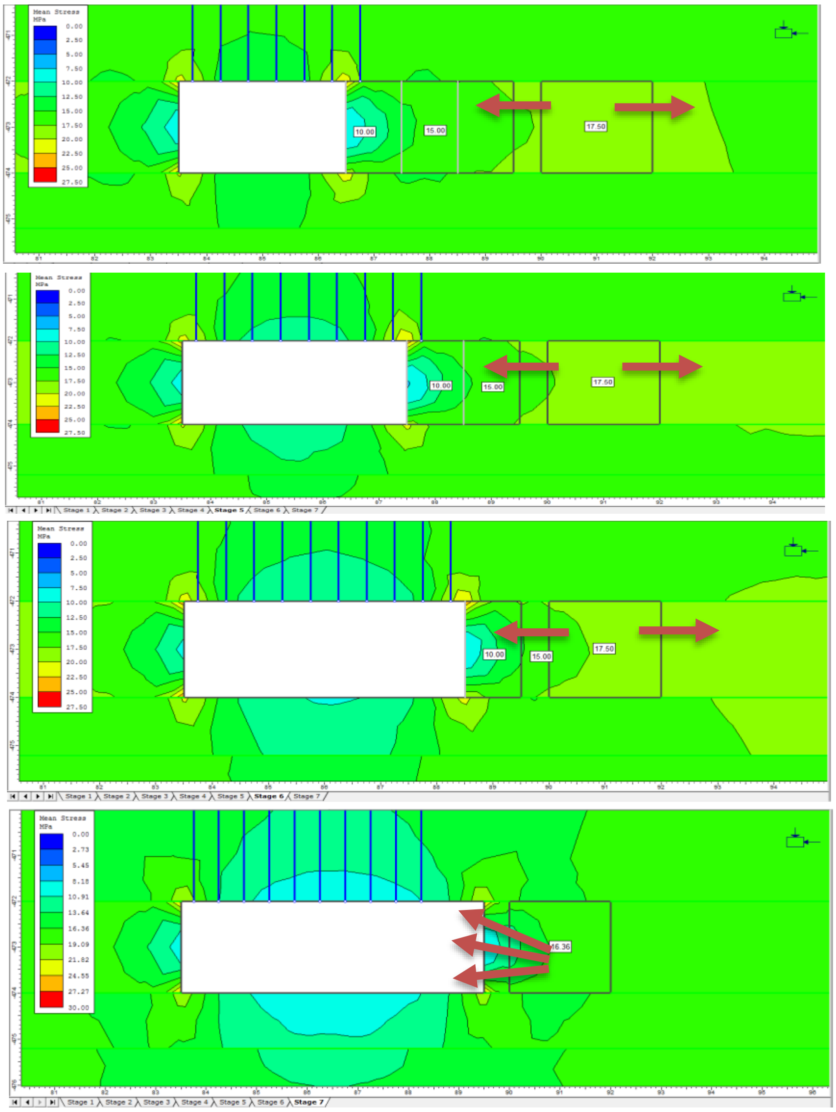

Fig. 1. Formation of the pocket zone (zone with dense gas and crushed rock) with the start of advancing in the tunnel (Li et al., 2018)

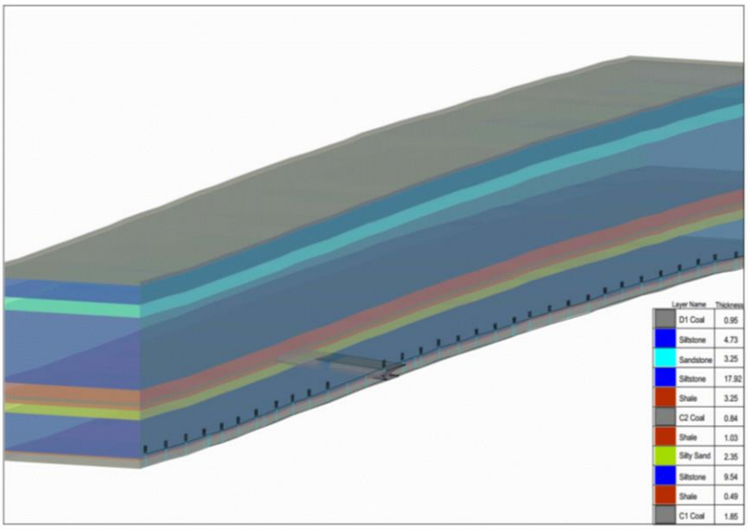

Fig. 2. The position of the C1 coal layer and the thickness of its upper and lower layers layer (Mehdori et al., 2017; Khakshour 2021)

Table 1. Strength characteristics of layers (Salimi et al., 2018; Salimi et al., 2018)

Type of stone	density (MN/m3)	Tensile strength (MPa)	φ (deg.)	C (MPa)	E (MPa)	υ
Silt	0.027	2.5	24.12	1.3	2838	0.26
Sandy silt	00.25	2.6	31.75	0.443	2987	0.25
Coal	0.016	0.002	15-25	0.5	316	0.25
Mudstone	0.026	0.013	18.62	0.94	2838	0.31
Sandstone	0.027	6.3	21.75	8.69	5281	0.25

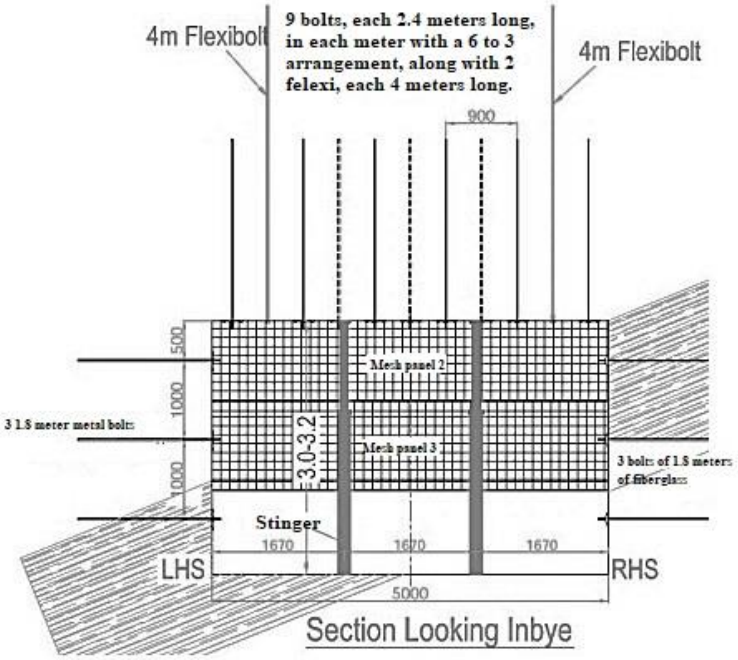

Fig. 3. section looking inbye of the support system (Li et al., 2018; Khakshour, 2021).

Table 2. Parameters of rock bolts used in Tabas mine (Salimi et al., 2018; Salimi et al., 2018)

Parameter	Tensile yield load	Elastic modulus	tread spacing	tread width	tread height	Diameter
Unit	Ton	GPa	mm	mm	mm	mm
Value	25	200	12	1.5	1.3	22

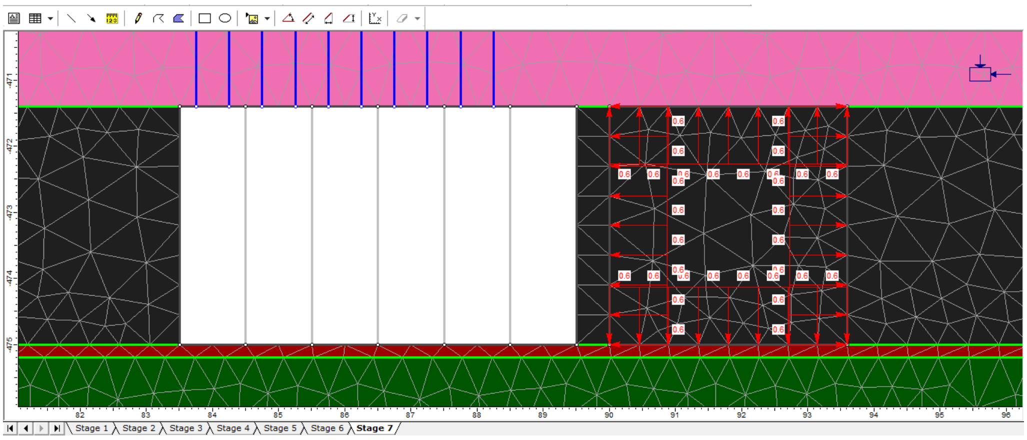

Fig. 4. Tunnel and digging steps

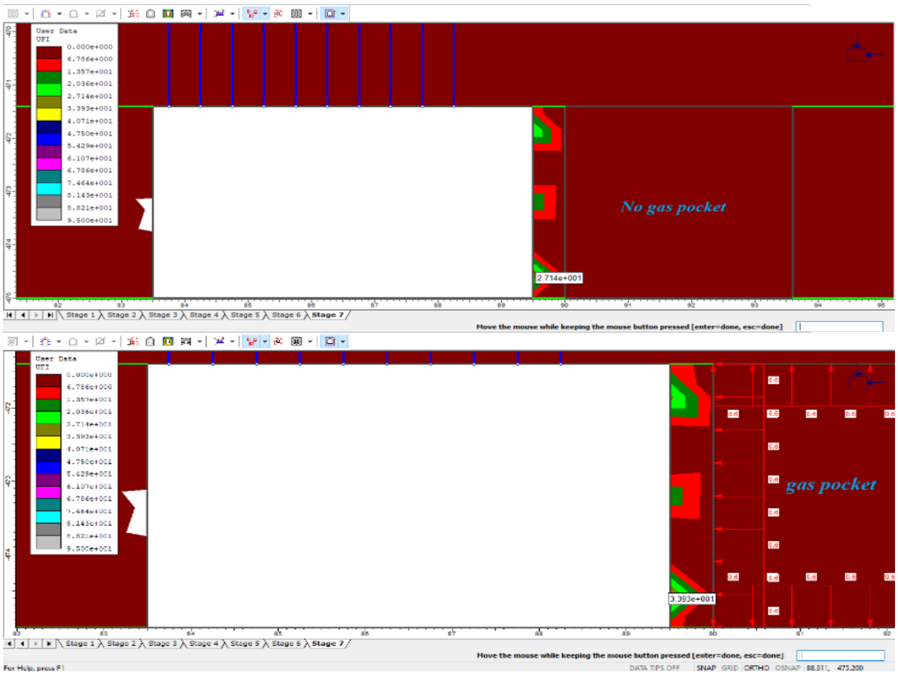

Fig. 5. UFI with or without gas pockets

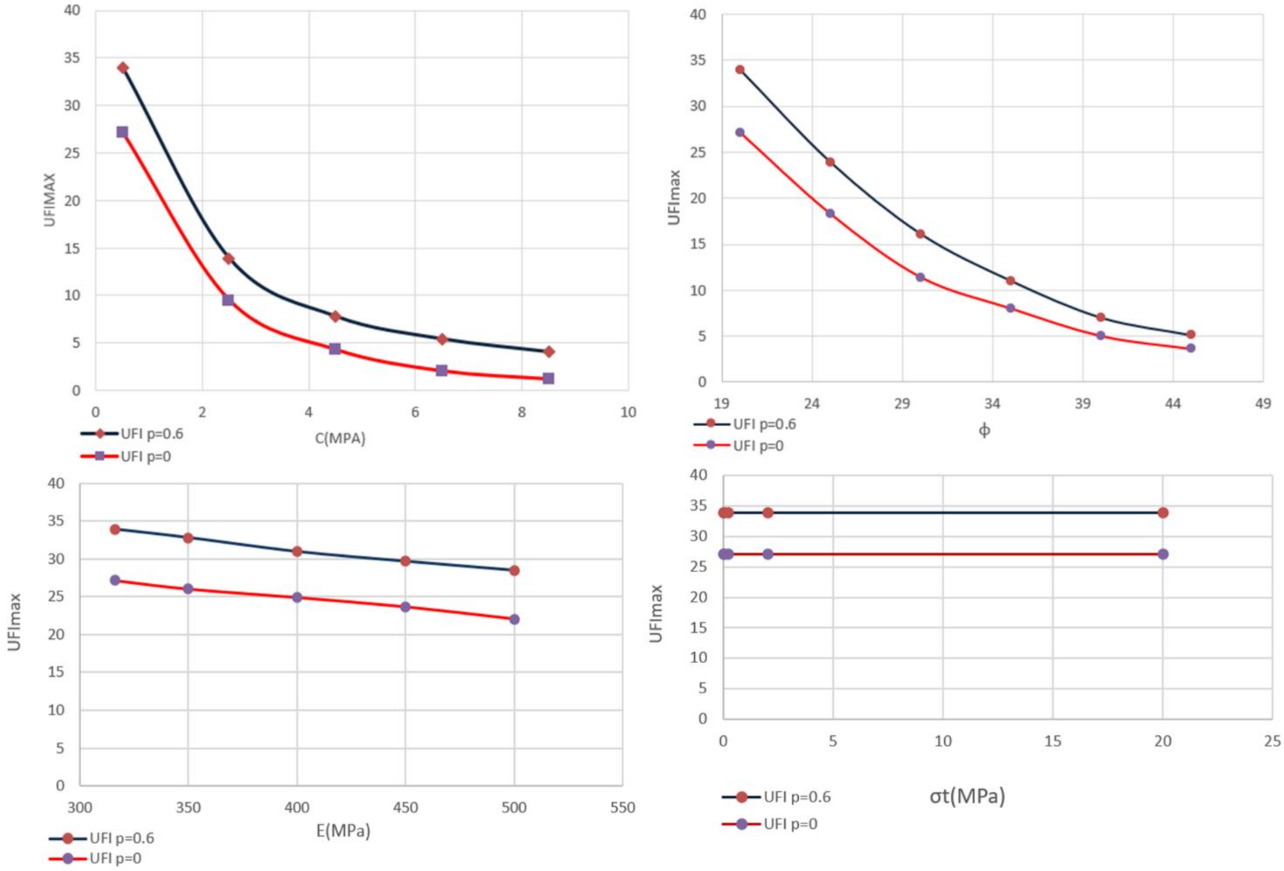

Fig. 5. Investigating the effect of tensile strength (σ_t), modulus of elasticity of coal (E), cohesion (C), and friction angle of coal (φ) on unstable failure index

VI. Conclusion

The unstable failure index that was used in this study confirmed the researchers' statements about this phenomenon, and it can significantly help to detect prone areas. By conducting this research, it was found that the sensitivity of the outburst to the angle of internal friction and modulus of elasticity is higher than the cohesion of the coal layer. The gas pressure of the coal layer has an extremely important effect on this phenomenon because when there was a gas pocket with a pressure of 0.6 MPa, the *UFI* index was 6.79 units higher than the zero pressure state. The more strength the coal layer is, the less susceptible it is to danger. To identify and characterize outburst-prone areas, methods such as gas pressure measurement composition detection and micro-seismic monitoring have been proven to be effective. In addition to these methods, the use of unstable failure index, which was used in the present study and confirmed the research of previous researchers, is suggested. It is recommended to perform coring from points ahead of the face before extracting. This coring is done from higher, lower, or ground horizons by vertical boreholes, it is worth mentioning that these boreholes can also be used for gas drainage. If crushed and soft coal is observed in these cores, extraction should be done under the conditions of possible outbursts.

References

Aziz, N., Black, D., Ren, T. (2011). Keynote paper mine gas drainage and outburst control in Australian underground coal mines. Procedia Engineering, 26, 84-92.

Curran, J. H., Corkum, B.T. (1998). Phase2. 2D finite element program for calculating stresses and estimating support around underground excavations. Reference Manual and Tutorial Manual. Rockscience, Toronto, Canada.

Farhadian, H. (2021). A new empirical chart for rockburst analysis in tunnelling: Tunnel rockburst classification (TRC). International Journal of Mining Science and Technology, 31(4), 603-610.

Ghadimi, M., Nikgoftar, M.R., Ataei, M., Rezvanianzadeh, M.R. (2018). Pull out test in Tabas Coal Mine by using analytical, numerical, and experimental methods, 4th National Iranian Coal Conference, Shahrood, Iran.

Guan, P., Wang, H., Zhang, Y. (2009). Mechanism of instantaneous coal outbursts. Geology, 37(10), 915-918.

Jiang, C.L, Yu, Q.X. (1995). The hypothesis of spherical shell destabilization of coal and gas outburst, Safety in Coal Mines, 2, 17-25.

Khakshour, H. (2021). Numerical Simulation of Coal and Gas Outburst Phenomena in Underground Collieries, Master Thesis, Department of Mining Engineering, University of Birjand, 59-60.

Khakshour, H., Noferesti, H., Rahimdel, M.J. (2023). Outburst analysis due to the sudden outburst phenomenon of gas and coal in underground mining using unstable failure index (Case study: Tabas Coal Parvadeh Mine). Tunnelling and Underground Space Engineering, 11(2), 155-172.

Lei, Y., Cheng, Y., Wang, L., Ren, T., Tu, Q. (2023). Mechanisms of Coal and Gas Outburst Experiments: Implications for the Energy Principle of Natural Outbursts. Rock Mechanics and Rock Engineering, 56(1), 363-377.

Li, C.W., Fu, S., Jie, B.J., Zhang, M.J., Dong, L.H., Wang, F.Y., & Xue, H. (2018). Establishment of the prediction model of coal and gas outburst energy and its application in the Pingdingshan mining area. Journal of China University of Mining Technology, 47(2), 231–9.

Liu, H., Dong, Y., Wang, F. (2020). Gas outburst prediction model using improved entropy weight grey correlation analysis and IPSO-LSSVM. Mathematical Problems in Engineering, 2020, 1-10.

Maleki, Z., & Farhadian, H. (2022). Prediction of rockburst in water conveyance tunnel: a case study of Gelas tunnel. International Journal of Mining and Geo-Engineering.

Maleki, Z., Farhadian, H., Rahimi, E. (2022). A comparative study on the prediction of squeezing behavior: a case study of Gelas tunnel-NW Iran. Arabian Journal of Geosciences, 15(2), 1-17.

Mehdori, Sattar, Shahriar, Korosh, Sharifzadeh. (2017). Evaluating the failure mechanism of the roof of long working front workshops by the analysis of induced seismic waves. Journal of Mining Engineering, 12(37), 39-52.

Salimi, M., Baghbanan A., Hashemolhosseini, H. (2018). Determining the parameters of Geo-mechanical faults using the back-analysis process faulting - case study Parvadeh Tabas Coal Mine, 4th National Iranian Coal Conference, Shahrood, Iran, 3-15.

Si, G. (2015). An investigation into gas emission and outburst control in thick seam coal mining (Doctoral dissertation, Imperial College London).

Tu, Q., Cheng, Y., Xue, S., Ren, T., Cheng, X. (2021). Analysis of the coal and gas outburst mechanism from the perspective of tectonic movement. Geofluids, 1-18.

Wang, Y., & Xue, S. (2018). A Review on numerical models for coal and gas outbursts. Fault-Zone Guided Wave, Ground Motion, Landslide and Earthquake Forecast, 191.

Wu. Y, Gao. R, Yang. J, (2020). Prediction of coal and gas outburst: A method based on the BP neural network optimized by GASA. Process Safety and Environmental Protection.133, 64-72.

Yin, G., Jiang, C., Wang, J. G., Xu, J., Zhang, D., Huang, G. (2016). A new experimental apparatus for coal and gas outburst simulation. Rock Mechanics and Rock Engineering, 49, 2005-2013.