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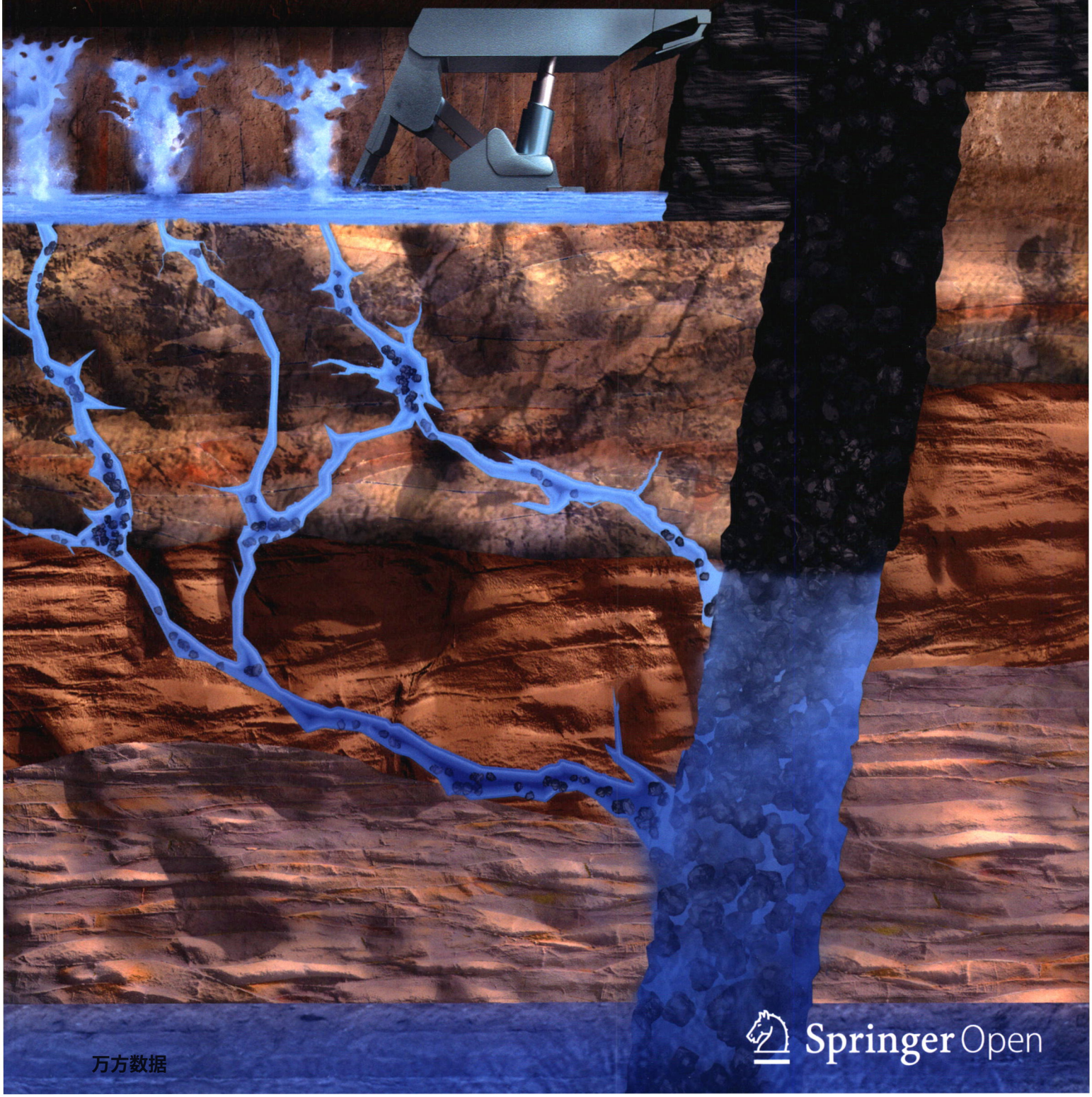

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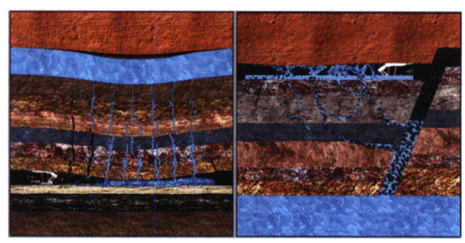
Review

DOI: https://doi.org/10.1007/s40789-022-00525-w

A state-of-the-art review on rock seepage mechanism of water inrush disaster in coal mines

Dan Ma, Hongyu Duan, Jixiong Zhang & Haibo Bai

Abstract: Water inrush is one of the most dangerous disasters in coal mining. Due to the large-scale mining and complicated hydrogeological conditions, thousands of deaths and huge economic losses have been caused by water inrush disasters in China. There are two main factors determining the occurrence of water inrush: water source and water-conducting pathway. Research on the formation mechanism of the water-conducting pathway is the main direction to prevent and control the water inrush, and the seepage mechanism of rock mass during the formation of the water-conducting pathway is the key for the research on the water inrush mechanism. This paper provides a state-of-the-art review of seepage mechanisms during water inrush from three aspects, i.e., mechanisms of stress-seepage coupling, flow regime transformation and rock erosion. Through numerical methods and experimental analysis, the evolution law of stress and seepage fields in the process of water inrush is fully studied; the fluid movement characteristics under different flow regimes are clearly summarized; the law of particle initiation and migration in the process of water inrush is explored, and the effect of rock erosion on hydraulic and mechanical properties of the rock media is also studied. Finally, some limitations of current research are analyzed, and the suggestions for future research on water inrush are proposed in this review.

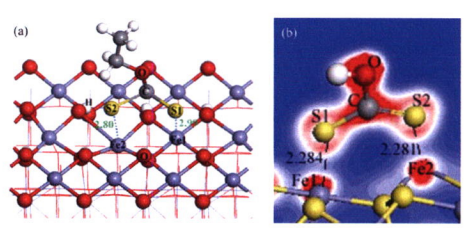


DOI: https://doi.org/10.1007/s40789-022-00526-9

Advances in depressants used for pyrite flotation separation from coal/minerals

Yulong Li, Gan Cheng, Mengni Zhang, Yijun Cao & Ee Von Lau

Abstract: Pyrite is separated from other minerals mainly by flotation. However, the hydrophilicity of pyrite is affected by many factors, causing it to easily enter the concentrate and consequently reduce the quality of concentrate. Highly efficient pyrite depressants can be selectively adsorbed on the surface of pyrite to improve its hydrophilicity, thereby increasing the flotation separation efficiency. Understanding the fundamental inhibition mechanism of depressants on pyrite is a prerequisite to improve the flotation desulfurization efficiency. The inhibition ability and mechanism of different types of pyrite depressants are reviewed in this manuscript. In recent years, molecular simulation has increasingly become a powerful tool to study the interaction between reagents and minerals, shedding new light on the adsorption mechanisms of reagents on mineral surfaces at the atomic and electronic levels. The properties of sulfide mineral and flotation reagents as well as the microscopic adsorption mechanistic studies of reagents on mineral surfaces based on quantum chemistry and molecular simulation are also reviewed.



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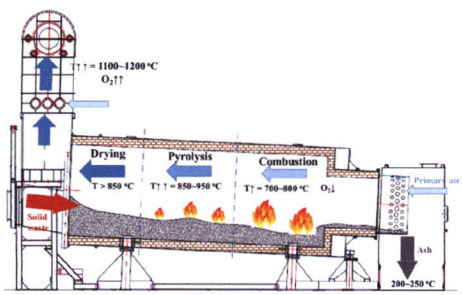
Research Articles

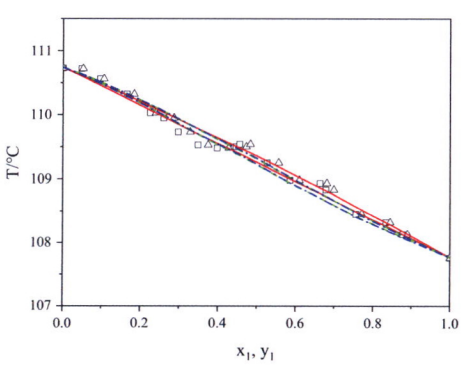


DOI: https://doi.org/10.1007/s40789-022-00523-y

Simulation research of a counter-flow rotary kiln hazardous waste incineration system

Shiqiao Yang, Qingfeng Kong, Dewang Zeng, Shiliang Wu, Feng Gong & Rui Xiao

Abstract: As industrialization accelerates and the amount of hazardous waste generated gradually increases, the means of disposal of hazardous waste is of increasing concern. In this paper, a 40 t/d counter-flow rotary kiln incineration system owned by a Jiangsu environmental protection company was researched. The software Aspen Plus was used to build the mixed pyrolysis model and the software Fluent was used to build the computational fluid dynamics model of the incineration system. The influence of the calorific value of the hazardous waste, the operating temperature and the air supply on the operational effectiveness of the incineration system were analyzed by varying the simulation conditions. The results show that the SO_x and NO_x content of the product is lower when the operating temperature is above 800 °C. The incineration system could only operate above 800 °C when the calorific value of the hazardous waste is not less than 1500 kcal/kg. The incineration system operated best at a primary air velocity of 1.5 m/s. The simulation results in this paper serve as a guide for the operation of counter-flow rotary kiln incineration systems.



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Thermodynamics fundamentals and energy efficiency for the separation and high-valued utilization of Fischer–Tropsch heavy oil

Zongchao Liu, Hong Li, Suli Liu, Jiuzhou Chen, Zisheng Zhang, Xingang Li, Angui Zhang, Wei Yuan & Xin Gao

Abstract: The development trend of Fischer–Tropsch (F–T) technology is to develop high value-added products. The separation of linear α-olefins with low cost is an effective method. Nevertheless, the lack of thermodynamic data and the huge energy consumption are the two main problems restricting the development of the separation process. The thermodynamic data of the key components (1-dodecene and n-dodecane) in the F–T product were measured. The Wilson binary interaction parameters of the key components were obtained. Next, one traditional distillation column sequence and two dividing wall column (DWC) sequences were designed to separate the F–T heavy oil to obtain narrow fractions with different carbon numbers. Then, the obtained fractions of C10 and C12 were simulated to obtain 1-decene and 1-dodecene, respectively. There was a traditional distillation and a differential pressure thermal coupling distillation process. When separating 95.0% purity 1-decene and 1-octene, the direct DWC process and differential pressure thermal coupled distillation are an excellent combination, which can reduce the energy by 33.1% (i.e., 11,286 kW) and total annual cost by 15.9% (i.e., 3.96×10^6 $) compared with traditional distillation.

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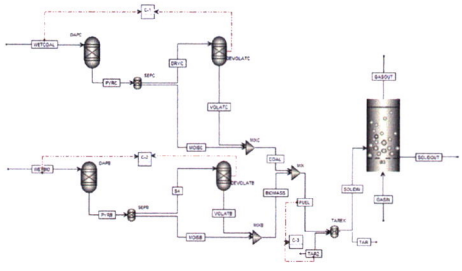
Flue gas analysis for biomass and coal co-firing in fluidized bed: process simulation and validation

Daulet Zhakupov, Lyazzat Kulmukanova, Yerbol Sarbassov & Dhawal Shah



Abstract: Coal-conversion technologies, although used ubiquitously, are often discredited due to high pollutant emissions, thereby emphasizing a dire need to optimize the combustion process. The co-firing of coal/biomass in a fluidized bed reactor has been an efficient way to optimize the pollutants emission. Herein, a new model has been designed in Aspen Plus® to simultaneously include detailed reaction kinetics, volatile compositions, tar combustion, and hydrodynamics of the reactor. Validation of the process model was done with variations in the fuel including high-sulfur Spanish lignite, high-ash Ekibastuz coal, wood pellets, and locally collected municipal solid waste (MSW) and the temperature ranging from 1073 to 1223 K. The composition of the exhaust gases, namely, $CO/CO_2/NO/SO_2$ were determined from the model to be within 2% of the experimental observations. Co-combustion of local MSW with Ekibastuz coal had flue gas composition ranging from 1000 to 5000 ppm of CO, 16.2%–17.2% of CO_2, 200–550 ppm of NO, and 130–210 ppm of SO_2. A sensitivity analysis on co-firing of local biomass and Ekibastuz coal demonstrated the optimal operating temperature for fluidized bed reactor at 1148 K with the recommended biomass-to-coal ratio is 1/4, leading to minimum emissions of CO, NO, and SO_2.

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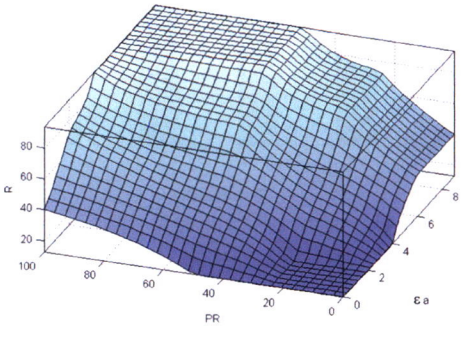
A novel fuzzy approach to gas pipeline risk assessment under influence of ground movement

Agnieszka Malinowska, Ximin Cui, Ebrahim Fathi Salmi & Ryszard Hejmanowski



Abstract: The gas transport infrastructure is frequently localized in areas subjected to anthropogenic movements and strains. The potential impact of the ground movements on the gas pipeline in the aspect of its damage can be properly assessed e.g. by predicting strains, taking into account the causes of terrain movement. On the other hand, the hazard is also related to technological factors like design of the pipeline. The presented method is based on artificial intelligence methods allowing for evaluation of probability of failure risk in gas supply pipeline sections. The Mamdani fuzzy inference was used in this study. Uncertainty of variables characterizing the resistance of the gas pipeline and predicted continuous deformations of ground surface were accounted for in the model by using triangular-shaped membership functions. Based on the surface deformations and gas pipeline resistance and the inference model one can make prediction when the gas pipeline is hazarded. There were estimated two the most hazarded parts for two pipelines. We proved that the proposed model can contribute to the protection, cost optimization of the designed pipelines and to the repairs of the existing gas pipelines.

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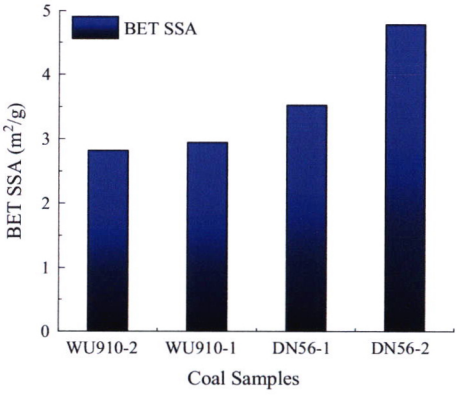
Energy evolution and water immersion-induced weakening in sandstone roof of coal mines

Wenjie Liu, Ke Yang, Shuai Zhang, Zhainan Zhang & Rijie Xu

Abstract: The instability of underground spaces in abandoned coal mines with water-immersed rocks is one of the main hazards hindering the geothermal energy use and ecological restoration of post-mining areas. This study conducted graded cyclic loading–unloading tests of five groups of sandstone samples with different water contents. The evolution of input, elastic, dissipated, damping, and plastic energies were explored, considering the damping effect. The normalized plastic energy serves to characterize the damage evolution of sandstone samples, whose failure characteristics were analyzed from both the macroscopic and microscopic perspectives. X-ray diffraction technique and scanning electron microscopy were used to reveal the softening mechanism of sandstone. The results show that under graded cyclic loading, input energy, elastic energy, and dissipated energy all increase gradually, and the fraction of elastic energy increases gradually at first and then tends to stabilize. The variation in the fraction of dissipated energy is opposite to that of elastic energy. In each cycle, the input energy is stored primarily in the form of elastic energy, whereas the dissipated energy is used primarily to overcome the damping of sandstone. When the normalized number of cycles approached unity, the plastic energy fraction sharply increases, while that of the dampening energy drops abruptly. With increasing water content, the effect of pore water on the lubrication, the water wedge, and dissolution of mineral particles becomes more obvious, reducing the elastic-storage limit of sandstone, meanwhile the sandstone damage factor increases significantly under the same cycle and the failure mode changes from brittle to ductile.



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Experimental analysis of pore structure and fractal characteristics of soft and hard coals with same coalification

Barkat Ullah, Yuanping Cheng, Liang Wang, Weihua Yang, Izhar Mithal Jiskani & Biao Hu

Abstract: Accurate and quantitative investigation of the physical structure and fractal geometry of coal has important theoretical and practical significance for coal bed methane (CBM) development and the prevention of dynamic disasters such as coal and gas outbursts. This study investigates the pore structure and fractal characteristics of soft and hard coals using nitrogen and carbon dioxide (N_2/CO_2) adsorption. Coal samples from Pingdingshan Mine in Henan province of China were collected and pulverized to the required size (0.20–0.25 mm). N_2/CO_2 adsorption tests were performed to evaluate the specific surface area (SSA), pore size distribution (PSD), and pore volume (PV) using Braunuer-Emmett-Teller (BET), Barrett-Joyner-Halenda (BJH), and Density Functional Theory (DFT). The pore structure was characterized based on the theory of fractal dimensions. The results unveiled that the strength of coal has a significant influence on pore structure and fractal dimensions. There are significant differences in SSA and PV between both coals. The BJH-PV and BET-SSA obtained by N_2-adsorption for soft coal are 0.029–0.032 cm^3/g and 3.523–4.783 m^2/g. While the values of PV and SSA obtained by CO_2-adsorption are 0.037–0.039 cm^3/g and 106.016–111.870 m^2/g. Soft coal shows greater SSA and PV than hard coal, which is consistent with the adsorption capacity (V_L). The fractal dimensions of soft and hard coal are respectively different. The Ding coal exhibits larger D_1 and smaller D_2, and the reverse for the Wu coal seam is observed. The greater the value of D_1 (complexity of pore surface) of soft coal is, the larger the pore surface roughness and gas adsorption capacity is. The results enable us to conclude that the characterization of pores and fractal dimensions of soft and hard coals is different, tending to different adsorption/desorption characteristics. In this regard, the results provide a reference for formulating corresponding coal and gas outburst prevention and control measures.

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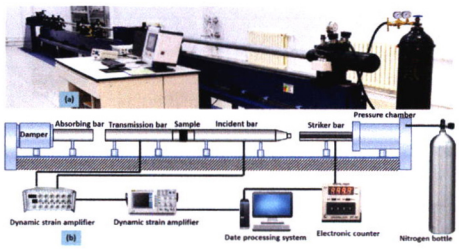
Water-immersion softening mechanism of coal rock mass based on split Hopkinson pressure bar experiment

Zhiyuan Liu, Gang Wang, Jinzhou Li, Huaixing Li, Haifeng Zhao, Hongwei Shi & Jianli Lan



Abstract: The coal mining process is affected by various water sources such as groundwater and coal seam water injection. Understanding the dynamic mechanical parameters of water-immersed coal is helpful for coalmine safe production. The impact compression tests were performed on coal with different moisture contents by using the ϕ50 mm Split Hopkinson Pressure Bar (SHPB) experimental system, and the dynamic characteristics and energy loss laws of water-immersed coal with different compositions and water contents were analyzed. Through analysis and discussion, it is found that: (1) When the moisture content of the coal sample is 0%, 30%, 60%, the stress, strain rate and energy first increase and then decrease with time. (2) When the moisture content of the coal sample increases from 30% to 60%, the stress "plateau" of the coal sample becomes more obvious, resulting in an increase in the compressive stress stage and a decrease in the expansion stress stage. (3) The increase of moisture content of the coal sample will affect its impact deformation and failure mode. When the moisture content is 60%, the incident rod end and the transmission rod end of the coal sample will have obvious compression failure, and the middle part of the coal sample will also experience expansion and deformation. (4) The coal composition ratio suitable for the coal immersion softening impact experiment is optimized.

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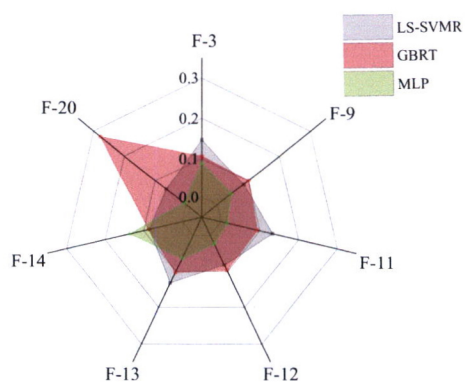
Cooperative prediction method of gas emission from mining face based on feature selection and machine learning

Jie Zhou, Haifei Lin, Hongwei Jin, Shugang Li, Zhenguo Yan & Shiyin Huang



Abstract: Collaborative prediction model of gas emission quantity was built by feature selection and supervised machine learning algorithm to improve the scientific and accurate prediction of gas emission quantity in the mining face. The collaborative prediction model was screened by precision evaluation index. Samples were pretreated by data standardization, and 20 characteristic parameter combinations for gas emission quantity prediction were determined through 4 kinds of feature selection methods. A total of 160 collaborative prediction models of gas emission quantity were constructed by using 8 kinds of classical supervised machine learning algorithm and 20 characteristic parameter combinations. Determination coefficient, normalized mean square error, mean absolute percentage error range, Hill coefficient, mean absolute error, and the mean relative error indicators were used to verify and evaluate the performance of the collaborative forecasting model. As such, the high prediction accuracy of three kinds of machine learning algorithms and seven kinds of characteristic parameter combinations were screened out, and seven optimized collaborative forecasting models were finally determined. Results show that the judgement coefficients, normalized mean square error, mean absolute percentage error, and Hill inequality coefficient of the 7 optimized collaborative prediction models are 0.969–0.999, 0.001–0.050, 0.004–0.057, and 0.002–0.037, respectively. The determination coefficient of the final prediction sequence, the normalized mean square error, the mean absolute percentage error, the Hill inequality coefficient, the absolute error, and the mean relative error are 0.998%, 0.003%, 0.022%, 0.010%, 0.080%, and 2.200%, respectively. The multi-parameter, multi-algorithm, multi-combination, and multi-judgement index prediction model has high accuracy and certain universality that can provide a new idea for the accurate prediction of gas emission quantity.

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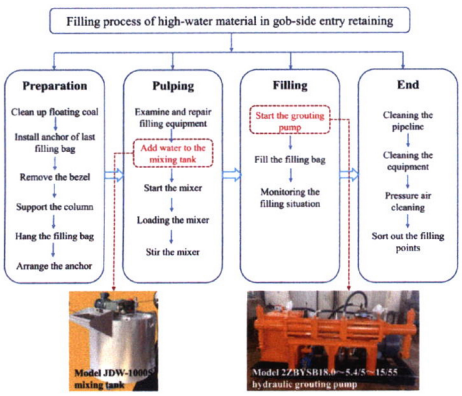

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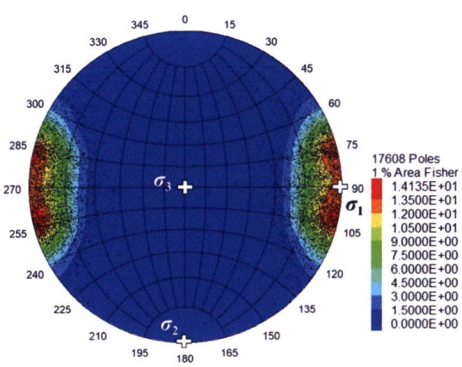
Stability analysis and control technology of gob-side entry retaining with double roadways by filling with high-water material in gently inclined coal seam

Shengrong Xie, En Wang, Dongdong Chen, Hui Li, Zaisheng Jiang & Hongzeng Yang

Abstract: To ameliorate the defects of insufficient support resistance of traditional roadside filling bodies for gob-side entry retaining (GER), overcome the inability to adapt to the deformation of surrounding rock, and isolate the goaf effectively, a new type of high-water material as a roadside filling body for GER technology with double roadways was proposed. The instability analysis and control technology of GER with double roadways by filling high-water material into a gently inclined coal seam were studied. The basic mechanical properties of the new high-water material were investigated through laboratory experiments, and their main advantages were identified. The reasonable width of the roadside filling wall of a high-water material was obtained by combining ground pressure observation and theoretical calculations. The distribution characteristics of the stress and plastic zone of surrounding rock of GER after being stabilized by the disturbance of the working face were studied using numerical simulations, and the failure range of GER by filling with high-water material was revealed. Based on this, a coupling control technology of anchor cables and bolts+single props+metal mesh+anchor bolts is proposed. Through the coupling methods of arranging borehole peeping and observing the convergences of surrounding rock, the results demonstrate that GER with double roadways by filling with a 1.8-m-wide high-water material has a good control effect. The above research will play an active role in promoting the application of high-water materials in GER roadside filling.



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Using true-triaxial stress path to simulate excavation-induced rock damage: a case study

Qingsheng Bai, Cun Zhang & R. Paul Young

Abstract: This study presents an example illustrating the role of in situ 3D stress path method in simulating the roof damage development observed in the Mine-by tunnel at Underground Research Laboratory (URL) located in Manitoba, Canada. The 3D stress path, at the point 1 cm in the crown of the Mine-by tunnel, was applied to a cubic Lac du Bonnet (LdB) granite sample to further understand the roof damage process and the associated seismicity. After careful calibrations, a numerical model was used to reproduce the experiment, which produced similar seismicity processes and source mechanisms. Acoustic emission (AE) events obtained from laboratory and numerical modeling were converted to locations in relation to the tunnel face and were compared to the field microseismicity (MS) occurring in the upper notch region of the Mine-by tunnel. The crack development and damage mechanism are carefully illustrated. The difference between tests and field monitoring was discussed. The intermediate principal stress (σ_2) unloading process was carried out in numerical simulation to investigate its role in rock damage development. The results clearly showed σ_2 could play a significant role both in damage development and failure mode. It should be considered when predicting the damage region in underground excavations. This study highlights the potential role of laboratory and numerical stress path tests to investigate fracture processes and mechanisms occurring during engineering activities such as tunnel excavation.

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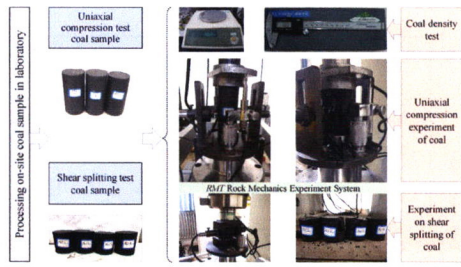
Reasonable location of stopping line in close-distance underlying coal seam and partition support of large cross-section roadway

Dongdong Chen, Yiyi Wu, Shengrong Xie, Fangfang Guo, Fulian He & Ruipeng Liu



Abstract: Close-distance coal seams are widely distributed over China, and the coal pillars left by the overlying coal seams affect the retracement channel of the underlying coal seam in the stopping stage. Based on the engineering background of close-distance seam mining in a coal mine, the reasonable position of the underlying coal seam's stopping line and the support method of the large section roadway during stopping are investigated using field measurements, similar simulation experiments, and numerical simulations. There are three types of location relationships between the stopping line of the underlying coal seam and the stopping line of the overlying coal seam: "externally staggered with the upper stopping line" (ESUL, stops mining under the overlying goaf), "overlapped with upper stopping line" (OUL), and "internally staggered with the upper stopping line" (ISUL, ISUL-SD for shorter internal staggered distances, ISUL-LD for longer ones). There are different stress arch structures in the overlying strata of the above three positions, and the stress arch evolution process exists in the process of ESUL → OUL → ISUL-SD → ISUL-LD: a front and rear double stress arch structure → the front arch gradually decreases → the front arch dies out, and the double arch synthesizes the single arch → the single-arch range expands → the nested double arch. The relationship between the stress arch structure and the position of the stopping line is evaluated as follows: (1) ESUL: the stress concentration in the roof plate of the retracement channel of the underlying coal seam is the highest, because the overburden block of the extensive collapse zone acts directly on the roof plate of the retracement channel, resulting in relative difficulties in roof support. (2) OUL: although the retracement channel roof pressure is minimal, the overlying rock structure has the potential for rotation or slippage instability. (3) ISUL-SD: the pressure on the roof of the retracement channel is small and the overburden structure is stable, which is conducive to the safe retraction of the support and not limited by the width of the end-mining coal pillar. (4) ISUL-LD: it is basically the same as the condition of stopping under the non-goaf; however, it has a limitation on the width of the end-mining coal pillar. The location of the stopping line is selected as ISUL-SD, and the retraction process of the self-excavating retraction channel was adopted. A partition asymmetric support scheme which is proven by field practice is proposed, through a comprehensive analysis of the pre-stress field simulation of the support scheme, based on the different control requirements of the roof above the support and the roof of the retracement channel in the stopping area. This method realizes safe and smooth withdrawal of the support.

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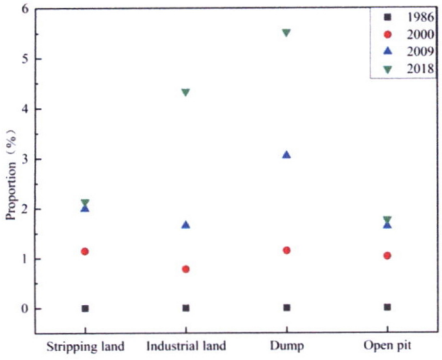

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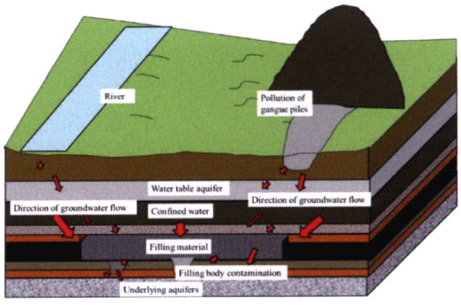
Division of carbon sink functional areas and path to carbon neutrality in coal mines

Boyu Yang, Zhongke Bai, Shuai Fu & Yingui Cao

Abstract: Remote sensing image data of typical mining areas in the Loess Plateau from 1986 to 2018 were used to analyze the evolution of land use, explore the division of carbon sink functional areas, and propose carbon neutrality paths to provide a reference for the coal industry carbon peak, carbon-neutral action plan. Results show that (1) land use has changed significantly in the Pingshuo mining area over the past 30 years. Damaged land in industrial, opencast, stripping, and dumping areas comprises 4482.5 ha of cultivated land, 1648.13 ha of grassland, and 963.49 ha of forestland. (2) The carbon sink functional areas of the Pingshuo mining land is divided into invariant, enhancement, low carbon optimization, and carbon emission control areas. The proportion of carbon sinks in the invariant area is decreasing, whereas the proportion in enhancement, low carbon optimization, and carbon emission control areas is gradually increasing. (3) The carbon neutrality of the mining area must be reduced from the entire process of *stripping–mining–transport–disposal–reclamation*, and carbon emissions and carbon sink accounting must start from the life cycle of coal resources. Therefore, carbon neutrality in mining areas must follow the 5R principles of *reduction, reuse, recycling, redevelopment, and restoration*, and attention must be paid to the potential of carbon sinks in ecological protection and restoration projects in the future.



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Environmental risk assessment of industrial byproduct gypsum utilized for filling abandoned mines

Xuehong Du, Xiangdong Li, Qiyan Feng, Lei Meng & Yue Sun

Abstract: In response to the basic policy of green and low-carbon circular development to solve resource, environmental and ecological problems, gypsum is considered to be a filling material for mine backfilling. To explore the potential risks of gypsum to the groundwater environment due to the backfilling of abandoned mines, a sequential batch leaching experiment was carried out in this paper, which used three types of industrial waste gypsum, namely, phosphorus gypsum (PG), titanium gypsum (TG) and flue gas desulfurization gypsum (FGDG). COMSOL Multiphysics 5.4 software was used to simulate and solve the migration process of the leached metal elements in the mine floor when these three gypsum types were used as filling materials to observe the concentration distributions and diffusion distances of the metal elements from these three gypsum types in the mine floor. The results show that (1) during repeated contact of the three types of industrial waste gypsum with the leaching medium, the pH levels changed, and the changes in pH affected the leaching patterns for the heavy metal elements in the gypsum. (2) Based on the concentrations of the metal elements that were leached from the three types of gypsum, it can be determined that these three types of gypsum are not classified as hazardous solid wastes, but they cannot be ruled out with regard to their risk to the groundwater environment when they are used as mine filling materials. (3) When the three types of gypsum are used as filling materials, the concentration distributions of the metal elements and their migration distances all exhibit significant changes over time. The concentration distributions, diffusion rates and migration distances of the metal elements from the different gypsum types are affected by their initial concentrations in the leachate. The maximum migration distances of Zn in the floor from the PG, FGDG and TG are 8.2, 8.1 and 7.5 m, respectively.

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