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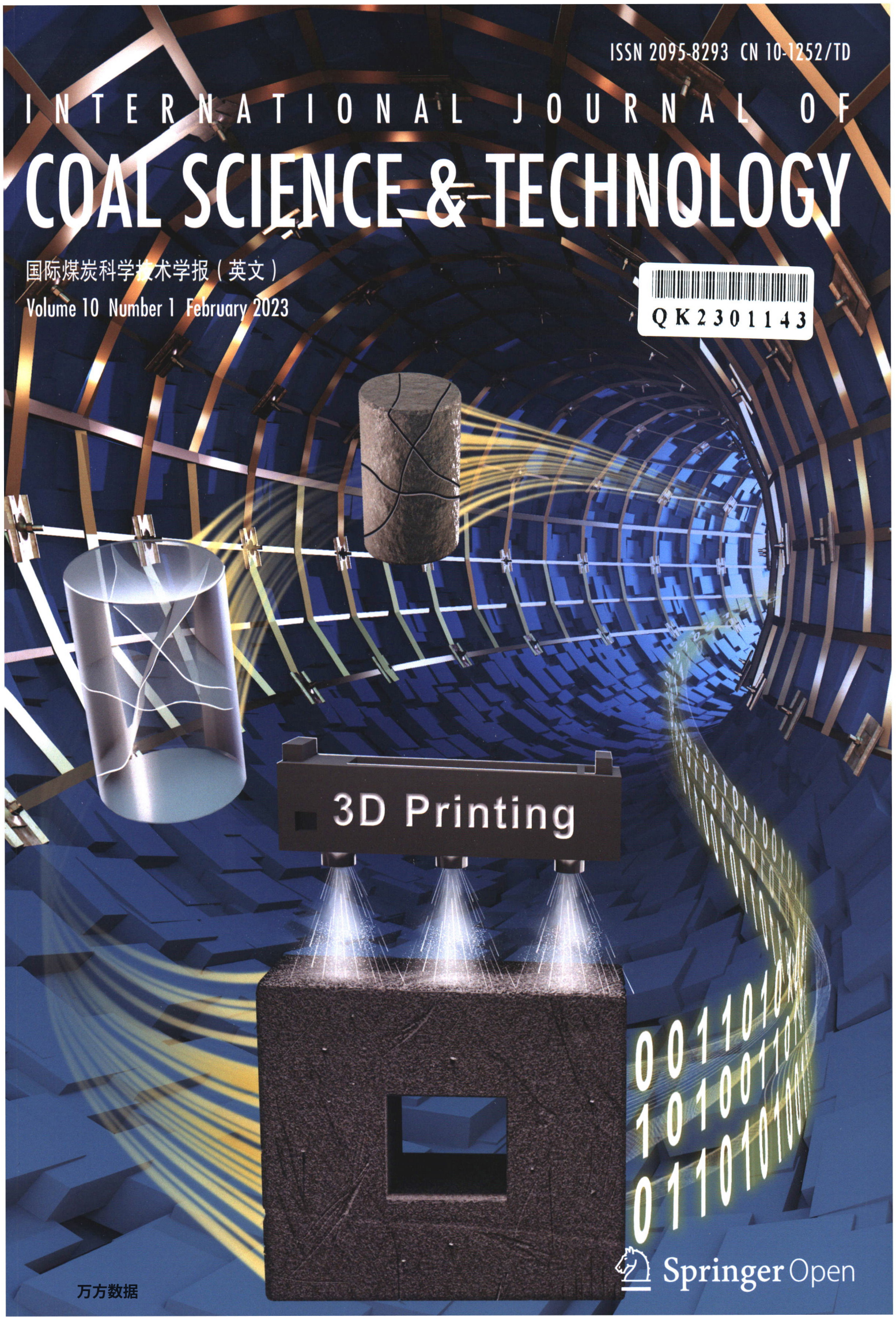

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Review

DOI: https://doi.org/10.1007/s40789-023-00567-8

Application and prospects of 3D printing in physical experiments of rock mass mechanics and engineering: materials, methodologies and models

Qingjia Niu, Lishuai Jiang, Chunang Li, Yang Zhao, Qingbiao Wang & Anying Yuan

Abstract: The existence of joints or other kinds of discontinuities has a dramatic effect on the stability of rock excavations and engineering. As a result, a great challenge in rock mass mechanics testing is to prepare rock or rock-like samples with defects. In recent years, 3D printing technology has become a promising tool in the field of rock mass mechanics and engineering. This study first reviews and discusses the research status of traditional test methods in rock mass mechanics tests of making rock samples with defects. Then, based on the comprehensive analysis of previous research, the application of 3D printing technology in rock mass mechanics is expounded from the following three aspects. The first is the printing material. Although there are many materials for 3D printing, it has been found that 3D printing materials that can be used for rock mass mechanics research are very limited. After research, we summarize and evaluate printing material that can be used for rock mass mechanics studies. The second is the printing methodology, which mainly introduces the current application forms of 3D printing technology in rock mass mechanics. This includes printed precise casting molds and one-time printed samples. The last one is the printing model, which includes small-scale samples for mechanical tests and large-scale physical models. Then, the benefits and drawbacks of using 3D printing samples in mechanical tests and the validity of their simulation of real rock are discussed. Compared with traditional rock samples collected in nature or synthetic rock-like samples, the samples made by 3D printing technology have unique advantages, such as higher test repeatability, visualization of rock internal structure and stress distribution. There is thus great potential for the use of 3D printing in the field of rock mass mechanics. However, 3D printing materials also have shortcomings, such as insufficient material strength and accuracy at this stage. Finally, the application prospect of 3D printing technology in rock mass mechanics research is proposed.

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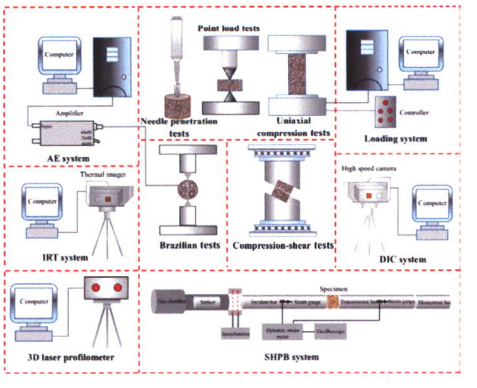
Strength weakening and its micromechanism in water–rock interaction, a short review in laboratory tests

Cun Zhang, Qingsheng Bai, Penghua Han, Lei Wang, Xiaojie Wang & Fangtian Wang

Abstract: Water–rock interaction (WRI) is a topic of interest in geology and geotechnical engineering. Many geological hazards and engineering safety problems are severe under the WRI. This study focuses on the water weakening of rock strength and its influencing factors (water content, immersion time, and wetting–drying cycles). The strength of the rock mass decreases to varying degrees with water content, immersion time, and wetting–drying cycles depending on the rock mass type



and mineral composition. The corresponding acoustic emission count and intensity and infrared radiation intensity also weaken accordingly. WRI enhances the plasticity of rock mass and reduces its brittleness. Various microscopic methods for studying the pore characterization and weakening mechanism of the WRI were compared and analyzed. Various methods should be adopted to study the pore evolution of WRI comprehensively. Microscopic methods are used to study the weakening mechanism of WRI. In future work, the mechanical parameters of rocks weakened under long-term water immersion (over years) should be considered, and more attention should be paid to how the laboratory scale is applied to the engineering scale.

Research Articles

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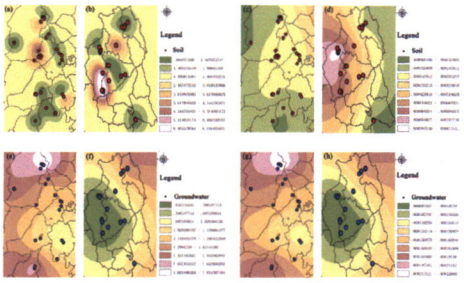
Contamination and human health risk assessment of heavy metal(loid)s in topsoil and groundwater around mining and dressing factories in Chifeng, North China

Di Zhao, Qiang Wu, Yifan Zeng, Juan Zhang, Aoshuang Mei, Xiaohui Zhang, Shuai Gao, Hanyuan Wang, Honglei Liu, Yong Zhang, Shuai Qi & Xu Jia



Abstract: Chifeng is a concentrated mining area for non-ferrous metal minerals, as well as a key prevention and control area for heavy-duty enterprises. This situation necessitates an effective ecological and human health risk assessment of heavy metal(loid)s driven by the wide distribution of metal ore processing, mining, and smelting factories in Hexigten Banner and Bairin Left Banner. We conducted surveys to assess the levels of heavy metal(loid)s (Cr, As, Pb, Cd, and Hg) in the topsoil and groundwater of the areas. The results indicated that the concentrations of As, Cd, and Pb in partial soil samples exceeded the environmental quality standards of Grade II. Based on contamination assessments, such as geoaccumulation indices and pollution indices, we inferred that Cd, Pb, and As were primary pollutants in topsoil. Potential ecological risks when considered as part of the average risk indices (RI) are up to 1626.40 and 2818.76, respectively, in the two areas. Comparative analysis revealed that Cd posed a very high potential ecological risk, followed by As. Moreover, the evaluation showed that the three exposure pathways of carcinogenic and non-carcinogenic risk followed a descending order: inhalation>ingestion>dermal contact, except for Pb. Arsenic in topsoil posed a potential non-carcinogenic risk to human health, while there were no adverse effects of As in groundwater. In addition, the average total carcinogenic risk for As in the two areas, as well as the risk of Pb in the topsoil of Bairin Left Banner and all the five heavy metal(loid)s in groundwater, exceeded human tolerance. Pb–Zn mines caused higher human health risks. In addition, the tandem contamination of heavy metal(loid)s in soil and groundwater was not obvious. This research study provides a basis for pollution remediation to control heavy industry-induced ecological and health risks of heavy metal(loid)s.

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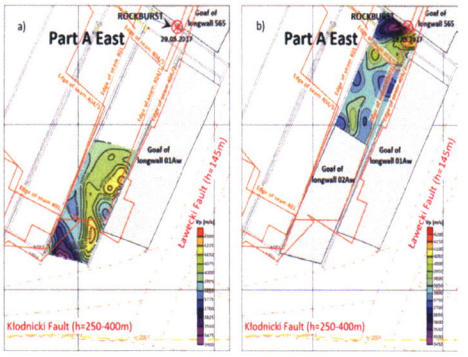
Comprehensive use of the Gutenberg–Richter law and geotomography for improving seismic hazard evaluation in hard coal mines

Józef Dubiński, Krystyna Stec & Jacek Krupanek

Abstract: Mining-induced seismicity occurs in numerous underground mines worldwide where extraction is conducted at great depths or in areas characterised by

complex tectonic structure. It is accompanied by rock bursts, which result in the loss of working functionality and the possibility of accidents among personnel. The issue of a constant and reliable seismic hazard evaluation is of key significance for both the safety of miners and the stability of production. Research on its improvement is directed at developing new interpretive solutions and methods. The nature of the presented solution is the complex interpretation of seismological data that characterise rock mass seismicity and of underground measurement results in the form of a map presenting the longitudinal wave propagation velocity distribution in the rock surrounding the mined coal seam. The solution was tested in hard coal mines located in the Upper Silesian Coal Basin. The mines are equipped with a modern seismological system enabling the constant monitoring of seismicity together with hazard level evaluation as well as with seismic apparatus for conducting periodic measurements of the seismic wave propagation velocity before the mining face. Comprehensive seismic hazard evaluation criteria were determined based on the obtained results, involving the anomaly of the Gutenberg–Richter law "b" value and the maximum longitudinal seismic wave propagation velocity in the roof rock. The obtained experience and the result validation of this new comprehensive hazard evaluation method confirm its practical usefulness and indicate the directions of improvement for the solution in question.



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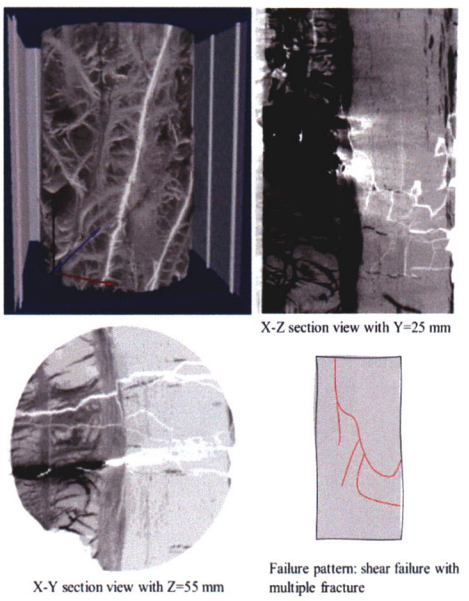
Fracture features of brittle coal under uniaxial and cyclic compression loads

Shikang Song, Ting Ren, Linming Dou, Jian Sun, Xiaohan Yang & Lihai Tan

Abstract: Under the effects of complex geological and stress environments, burst hazards continue to be a major challenge for underground space utilization and deep resources exploration as its occurrence can lead to personnel causalities, equipment damage and structural collapse. Considering the stress path experienced by in-situ coal body, cyclic loading appears in quite various forms for instance shearer cutting, overlying strata breakage, hydro-fracturing and blasting, during tunnel, mining and underground space utilizing process. The stability of the underground coal body subject to periodic loading/unloading stress is extremely important for maintain the function of designed engineering structure for waste storage, safe mining, roadway development, gas recovery, carbon sequestration and so on. The mechanical properties of hard rock subject to cyclic fatigue loads has been intensively investigated by many researchers as the rock burst induced by supercritical loads has long been a safety risk and engineering problems for civil and tunneling engineering under deep overburden. More recently, the mechanical properties of coal samples under cyclic fatigue loads is investigated from the aspect of hysteresis, energy dissipation and irreversible damage as the burst hazards of brittle coal is rising in many countries. However, the crack propagation and fracture pattern of brittle coal need more research to understand the micro mechanism of burst incubation subject to cyclic fatigue loads as brittle coal can store more elastic strain energy and rapidly release the energy when its ultimate strength once reached. This research studied the internal crack status corresponding to different cyclic fatigue loading stage of brittle coal samples. The AE monitoring was applied during the uniaxial and cyclic loading process of brittle coal samples to record the crack intensity of samples at different loading stages. The damage evolution curve corresponding to loading status was then determined. The fracture pattern of coal samples determined by micro-CT scan was observed and discussed. It has been found by this paper that brittle coal of uniaxial compression tests demonstrated sudden failure caused by major splitting fracture while that of cyclic fatigue tests experienced progressive failure with mixture fracture network.


X-Z section view with Y=25 mm

X-Y section view with Z=55 mm

Failure pattern: shear failure with multiple fracture

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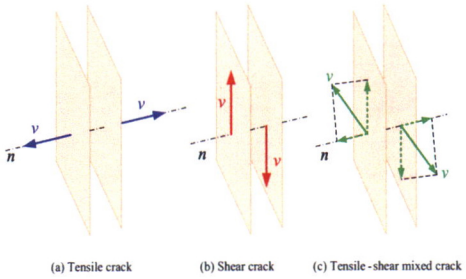
Master crack types and typical acoustic emission characteristics during rock failure

Tongbin Zhao, Pengfei Zhang, Yaxun Xiao, Weiyao Guo, Yulong Zhang & Xiufeng Zhang



Abstract: Acoustic emission (AE) signals contain substantial information about the internal fracture characteristics of rocks and are useful for revealing the laws governing the release of energy stored therein. Reported here is the evolution of rock failure with different master crack types as investigated using Brazilian splitting tests (BSTs), direct shear tests (DSTs), and uniaxial compression tests (UCTs). The AE parameters and typical modes of each fracture type were obtained, and the energy release characteristics of each fracture mechanism were discussed. From the observed changes in the AE parameters, the rock fracture process exhibits characteristics of staged intensification. The scale and energy level of crack activity in the BSTs were significantly lower than those in the DSTs and UCTs. The proportion of tensile cracks in the BSTs was 65%–75%, while the proportions of shear cracks in the DSTs and UCTs were 75%–85% and 70%–75%, respectively. During the rock loading process under different conditions, failure was accompanied by an increased number of shear cracks. The amplitude, duration, and rise time of the AE signal from rock failure were larger when the failure was dominated by shear cracks rather than tensile ones, and most of the medium- and high-energy signals had medium to low frequencies. After calculating the proposed energy amplitude ratio, the energy release of shear cracks was found to exceed that of tensile cracks at the same fracture scale.

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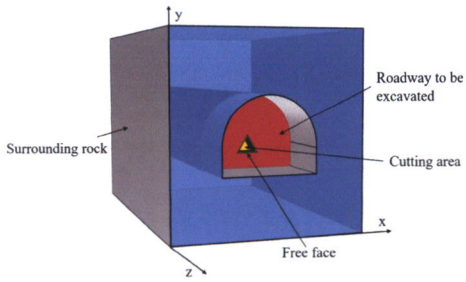
Theoretical and numerical simulation investigation of deep hole dispersed charge cut blasting

Chengxiao Li, Renshu Yang, Yanbing Wang, Yiqiang Kang, Yuantong Zhang & Pin Xie



Abstract: Drilling and blasting methods have been used as a common driving technique for shallow-hole driving and blasting in rock roadways. With the advent of digital electronic detonators and the need for increased production efficiency, the traditional blasting design is no longer suitable for deep hole blasting. In this paper, a disperse charge cut blasting method was proposed to address the issues of low excavation depth and high block rate in deep hole undercut blasting. First, a blasting model was used to illustrate the mechanism of the deep hole dispersive charge cut blasting process. Then, continuous charge and dispersed charge blasting models were developed using the smooth particle hydrodynamics-finite element method (SPH-FEM). The cutting parameters were determined theoretically, and the cutting efficiency was introduced to evaluate the cutting effect. The blasting effects of the two charging models were analyzed utilizing the evolution law of rock damage, the number of rock particles thrown, and the cutting efficiency. The results show that using a dispersed charge improves the cutting efficiency by about 20% and the rock breakage for the deep hole cut blasting compared to the traditional continuous charge. In addition, important parameters such as cutting hole spacing, cutting hole depth and upper charge proportion also have a significant impact on the cutting effect. Finally, the deep hole dispersed charge cut blasting technology is combined with the digital electronic detonator through the field engineering practice. It provides a reference for the subsequent deep hole cutting blasting and the use of electronic detonators in rock roadways.

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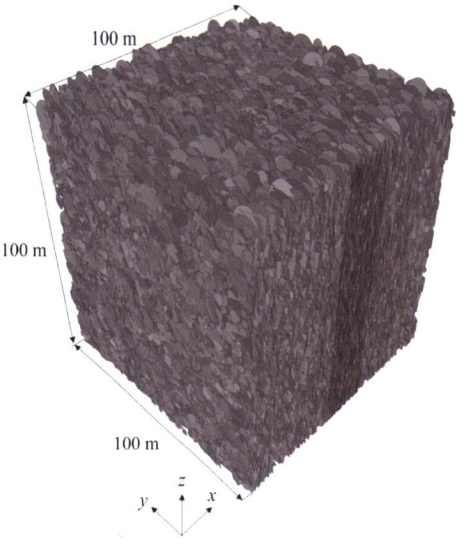
Numerical modelling of spatially and temporally distributed on-fault induced seismicity: implication for seismic hazards

Atsushi Sainoki, Adam Karl Schwartzkopff, Lishuai Jiang & Hani Mitri

Abstract: Induced seismicity is strongly related to various engineering projects that cause anthropogenic in-situ stress change at a great depth. Hence, there is a need to estimate and mitigate the associated risks. In the past, various simulation methods have been developed and applied to induced seismicity analysis, but there is still a fundamental difference between simulation results and field observations in terms of the spatial distribution of seismic events and its frequency. The present study aims to develop a method to simulate spatially distributed on-fault seismicity whilst reproducing a complex stress state in the fault zone. Hence, an equivalent continuum model is constructed, based on a discrete fracture network within a fault damage zone, by employing the crack tensor theory. A fault core is simulated at the center of the model as a discontinuous plane. Using the model, a heterogeneous stress state with stress anomalies in the fault zone is first simulated by applying tractions on the model outer boundaries. Subsequently, the effective normal stress on the fault plane is decreased in a stepwise manner to induce slip. The simulation result is validated in terms of the b-value and other seismic source parameters, hence demonstrating that the model can reproduce spatially and temporally distributed on-fault seismicity. Further analysis on the parameters shows the variation of frequency-magnitude distribution before the occurrence of large seismic events. This variation is found to be consistent with field observations, thus suggesting the potential use of this simulation method in evaluating the risk for seismic hazards in various engineering projects.

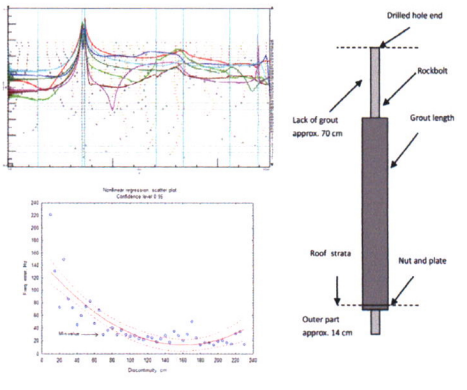


DOI: https://doi.org/10.1007/s40789-023-00566-9

Technical problems and non destructive testing of rock bolt support systems in mines

Andrzej Staniek

Abstract: The problem of proper assessment of the technical functionality of rock bolt support systems is still valid. Many research centers have undertaken efforts to diagnose and monitor the technical state of such a support system used in mines and tunneling. With that aim the method of quality assessment of grouted rock bolts was invented and a relevant apparatus was constructed. The method concerns non-destructive identification of discontinuity of a resin layer (grout) surrounding rock bolts. The method is based on an impact excitation of a rock bolt and uses modal analysis procedures. Assuming that the installed rock bolt acts as an oscillator, different lengths and positions of grouting discontinuity alter its modal parameters. The extraction of these modal parameters, of which a resonant frequency is seen as the most valued, enable the relevant identification of grout discontinuity. After constructing a prototype version and validating the results for known cases of resin discontinuity in an experimental coal mine, the apparatus fulfilling ATEX requirements was developed. Subsequently that version was also verified both in laboratory conditions and in an experimental coal mine. As necessary for proper identification of discontinuity length, the reference data base was developed and elaborated consisting of a very large number of finite element models (FE models), namely discontinuity cases. The models encountered different rock bolt lengths and diameters, different rock strata parameters and different positions and lengths of resin layers. Then the method was used in a working coal mine to monitor a technical state of rock bolt support system mounted to reinforce long underground openings. The data base was utilized as reference for investigated rock bolts.



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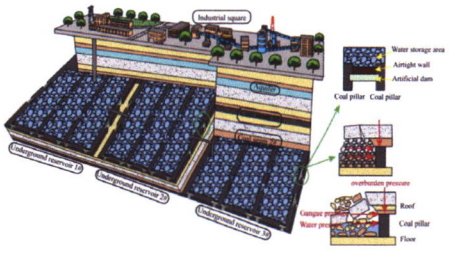

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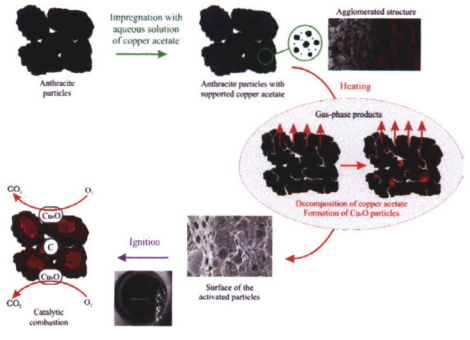
Creep behavior and permeability evolution of coal pillar dam for underground water reservoir

Yulong Chen, Xianjie Hao, Dongjie Xue, Zhe Li & Xiaoran Ma

Abstract: Using goof as water storage space plays a vital role in the ecological environment and economic development of arid mining areas, while the rock strength and the stability of coal pillars in underground water reservoirs are closely related to creep process. In this work, triaxial creep-seepage tests were conducted for coal samples to develop new insights into the creep behavior and permeability evolution. The results showed that the creep deformation and permeability evolution of coal samples exhibit three stages, namely, the compaction hardening stage before the stress threshold, volumetric compaction stage, and volumetric dilatancy stage. The coal permeability decreases first and then increases with the creep strain and it is well correlated with the variation of volumetric strain.



DOI: https://doi.org/10.1007/s40789-023-00573-w

Activation of anthracite combustion by copper acetate: mechanism, effect of particle size and introduction method

K. B. Larionov, I. V. Mishakov, N. I. Berezikov, A. S. Gorshkov, A. Zh. Kaltaev, K. V. Slyusarskiy, A. S. Ruban & A. A. Vedyagin

Abstract: This paper addressed the effect of copper acetate on the combustion characteristics of anthracite depending on the fractional composition of fuel and additive introduction method. Anthracite was impregnated with 5 wt% of $Cu(CH_3COO)_2$ by mechanical mixing and incipient wetness impregnation. Four anthracite samples of different fraction with $d<0.1$ mm, $d=0.1$–0.5 mm, $d=0.5$–1.0 mm, and $d=1.0$–2.0 mm were compared. According to EDX mapping, incipient wetness impregnation provides a higher dispersion of the additive and its uniform distribution in the sample. The ignition and combustion characteristics of the modified anthracite samples were studied by thermal analysis and high-speed video recording of the processes in a combustion chamber (at heating medium temperature of 800 °C). It was found that copper acetate increases anthracite reactivity, which was evidenced by decreased onset temperature of combustion (ΔT_i) by 35–190 °C and reduced ignition delay time ($\Delta\tau_i$) by 2.1–5.4 s. Copper acetate reduces fuel underburning (on average by 70%) in the ash residue of anthracite and decreases the amount of CO and NO_x in gas-phase products (on average by 18.5% and 20.8%, respectively). The mechanism for activation of anthracite combustion by copper acetate is proposed.

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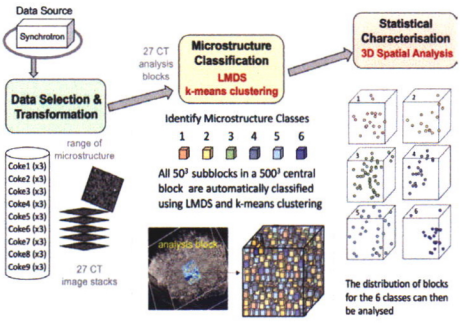
Classifying coke using CT scans and landmark multidimensional scaling

Keith Nesbitt, Fayeem Aziz, Merrick Mahoney, Stephan Chalup & Bishnu P. Lamichhane

Abstract: One factor that limits development of fundamental research on the influence of coke microstructure on its strength is the difficulty in quantifying the way that microstructure is both classified and distributed in three dimensions. To support such fundamental studies, this study evaluated a novel volumetric approach for classifying small (approx. 450 μm^3) blocks of coke microstructure from 3D computed tomography scans. An automated process for classifying microstructure blocks was described. It is based on Landmark Multi-Dimensional Scaling and uses the Bhattacharyya metric and k-means clustering. The approach was evaluated using 27 coke samples across a range of coke with different properties and reliably identified 6 ordered class of coke microstructure based on the distribution of voxel intensities associated with structural density. The lower class (1–2) subblocks tend to be dominated by pores and thin walls. Typically, there is an increase in wall thickness and reduced pore sizes in the higher classes. Inert features are also likely to be seen in higher classes (5–6). In general, this approach provides an efficient automated means for identifying the 3D spatial distribution of microstructure in CT scans of coke.

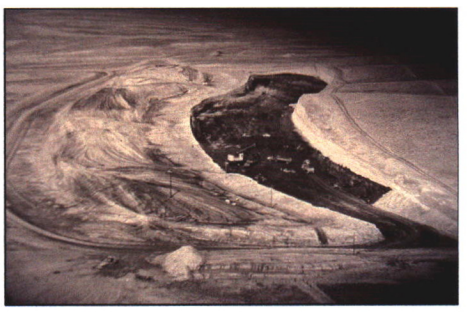


DOI: https://doi.org/10.1007/s40789-023-00572-x

Sustainable and responsible mining through sound mine closure

Yoginder P. Chugh, Brenda K. Schladweiler & Chet Skilbred

Abstract: This paper provides an overview of planning requirements, including regulatory, and implementation approaches for achieving ecologically sound reclamation and restoration of mines upon closure in the USA. Mine closure includes mined-out areas, decommissioning of plants and structures, and appropriate monitoring of post-mining land, water, and air resources. Although the discussion provides general guidelines, each mine closure site presents unique challenges. The overall chemical composition of coal and associated strata with mineable coal seams, structural characteristics of the deposit, weather patterns, environmental conditions, processing and scale of mining of the deposit, and public and private infrastructure must be considered. Future land use and water resource requirements are also important considerations. The planning and closure activities must ensure that the resultant site has the appropriate post-mining land and water resources use, and the site does not pose any future environmental and health and safety risks. These requirements suggest that closure activities should be integrated with the mining activity planning process from the start. This paper discusses mine closure issues and describes several practices for a surface coal mine in the Western USA.



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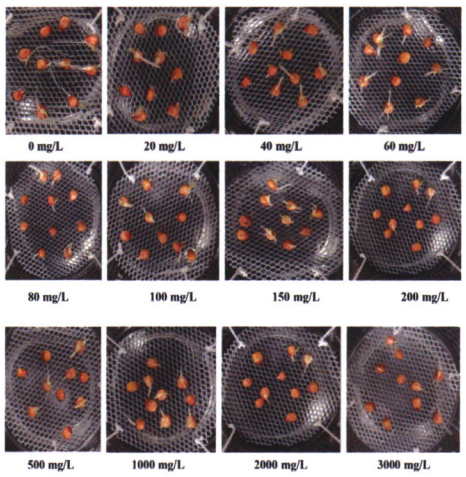

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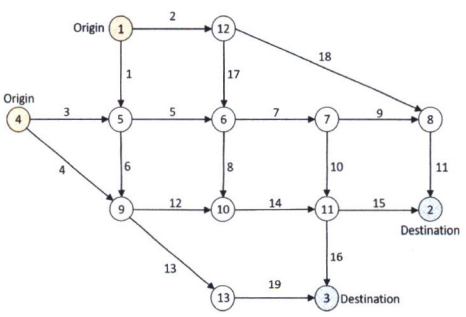
Responses of maize germination, root morphology and leaf trait to characteristics of lead pollution: a case study

Yongjian He, Ranran Jiang & Xiuli Hou

Abstract: On base of the content of Pb in the soil under different land use patterns in Lanping Lead-zinc mining area, Yunnan in southwest China, the root morphology and leaf traits of maize in different concentration Pb (20, 40, 60, 80, 100, 150, 200, 500, 1000, 2000, 3000 mg/L) were analyzed. The results showed that maize germination rate, germination vigor and growth index decreased with the increase of Pb concentration. The root length, surface area of maize increased by 0.21%–81.58%, 8.99%–73.43%, 1.50%–77.37%, respectively, under 20–500 mg/L Pb concentration. However, these parameters under 1000–3000 mg/L Pb concentration decreased by 37.86%–553.54%, 44.99%–766.16%, 55.99%–92.81%, respectively, and these lowest value appeared in 3000 mg/L Pb treatment. The root volume of maize increased by 4.57%–89.25% in 20–80 mg/L Pb concentration, and it decreased with the increase of Pb concentration when the Pb concentration was higher than 80 mg/L and decreased by 94.13% in 3000 mg/L Pb. The root surface area and length of 0.50–1.00 diameter class were higher than those of other diameter classes, and these value of maize under 500 mg/L Pb were higher than those of other concentrations. The length and perimeter of maize leaves with the highest value of 220.36 and 962.68 mm, respectively appeared in 60 mg/L Pb treatment. The leaf width and area of maize with the highest value of 15.68 mm and 2448.31 mm^2, respectively, appeared in 40 mg/L Pb treatment, which indicated that the leaf traits of maize were promoted by low concentration Pb and inhibited by high concentration Pb.



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Reducing congestion and emissions via roadside unit deployment under mixed traffic flow

Yuhao Liu, Zhibin Chen, Siyuan Gong & Han Liu

Abstract: It is expected that for a long time the future road traffic will be composed of both regular vehicles (RVs) and connected autonomous vehicles (CAVs). As a vehicle-to-infrastructure technology dedicated to facilitating CAV under the mixed traffic flow, roadside units (RSUs) can also improve the quality of information received by CAVs, thereby influencing the routing behavior of CAV users. This paper explores the possibility of leveraging the RSU deployment to affect the route choices of both CAVs and RVs and the adoption rate of CAVs so as to reduce the network congestion and emissions. To this end, we first establish a logit-based stochastic user equilibrium model to capture drivers' route choice and vehicle type choice behaviors provided the RSU deployment plan is given. Particularly, CAV users' perception error can be reduced by higher CAV penetration and denser RSUs deployed on the road due to the improved information quality. With the established equilibrium model, the RSU deployment problem is then formulated as a mathematical program with equilibrium constraints. An active-set algorithm is presented to solve the deployment problem efficiently. Numerical results suggest that an optimal RSU deployment plan can effectively drive the system towards one with lower network delay and emissions.

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