ISSN 2095-8293 CN 10-1252/TD

INTERNATIONAL JOURNAL OF COAL SCIENCE & TECHNOLOGY

国际煤炭科学技术学报（英文）

Volume 9 Number 6 December 2022

QK2251284

Springer Open

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Vol. 9, Issue 6, December 2022

INTERNATIONAL JOURNAL OF COAL SCIENCE & TECHNOLOGY

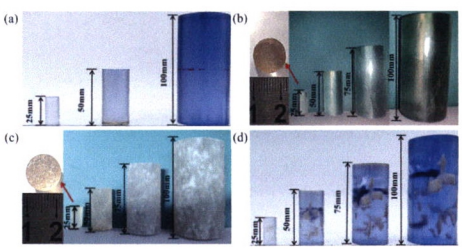
Research Articles

DOI: https://doi.org/10.1007/s40789-022-00556-3

Size effects in the uniaxial compressive properties of 3D printed models of rocks: an experimental investigation

Hao Wu, Yang Ju, Xin Han, Zhangyu Ren, Yue Sun, Yanlong Zhang & Tianyi Han

Abstract: Transparent physical models of real rocks fabricated using three-dimensional (3D) printing technology are used in photoelastic experiments to quantify the evolution of the internal stress and deformation fields of rocks. Therefore, they are rendered as an emerging powerful technique to quantitatively reveal the intrinsic mechanisms of rock failure. The mechanical behavior of natural rocks exhibits a significant size effect; however, limited research has been conducted on whether transparent physical models observe similar size effects. In this study, to make the transparent printed models accurately demonstrate the mechanical behavior of natural rocks and reveal the internal mechanism of the size effect in rock mechanical behavior, the size effect in 3D printed models of fractured and porous rocks under uniaxial compressive loading was investigated. Transparent cylindrical models with different sizes that contained different fractured and porous structures were printed using the fracture and porous characteristics extracted from natural coal and sandstone. The variation in uniaxial compressive strength and elastic modulus of fractured and porous models for increasing model sizes were obtained through uniaxial compression experiments. Finally, the influence of internal discontinuous structural features, such as fractures and pores, on the size effect pertaining to the mechanical behavior of the model was analyzed and elaborated by comparing it with the mechanical properties of the continuous homogeneous model without fractures and pores. The findings provided support and reference to analyze the size effect of rock mechanical behavior and the effect of the internal discontinuous structure using 3D printed transparent models.



DOI: https://doi.org/10.1007/s40789-022-00549-2

Determination of mining-induced stresses using diametral rock core deformations

Yizhuo Li & Hani S. Mitri

Abstract: Knowledge of ground stresses is crucial for ground control activities such as the design of underground openings, selection of support systems, and analysis for stability. However, it is a known fact that far field stresses experience changes in orientation and magnitude due to the presence of geological structures and due to the excavations created by mining activities. As a result, in-situ stresses around drifts, ramps, and stopes in underground mines are quite different from far field or pre-mining stresses. The purpose of this research is to develop a simple and practical

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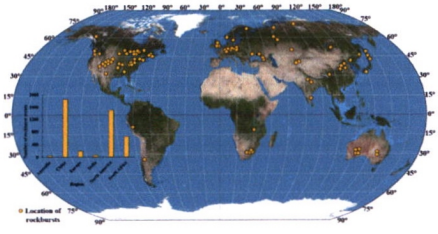
methodology for determining in-situ stresses. Stress relief occurs once the rock core is drilled off. Such relief is a function of the surrounding stress field. This study uses exploration rock cores that are drilled off for the purpose of orebody definition in the underground mine. The method measures and analyzes the diametral core deformations in laboratory. Two case studies from operating underground mines are presented for demonstration. In these case studies, rock core deformations are measured with a customized test apparatus and rock samples were prepared and tested for Young's modulus and Poisson's ratio. The differential stress, namely the difference between the local principal stresses in the plane perpendicular to the core rock axis is calculated. It is shown that this methodology is useful for determining the brittle shear ratio in the rock mass, which is of primary interest to ground control studies.

DOI: https://doi.org/10.1007/s40789-022-00537-6

Evaluation of the performance of yielding rockbolts during rockbursts using numerical modeling method

Jun Wang, Derek B. Apel, Huawei Xu & Chong Wei



Abstract: The assessment of yielding rockbolt performance during rockbursts with actual seismic loading is essential for rockburst supporting designs. In this paper, two types of yielding rockbolts (D-bolt and Roofex) and the fully resin-grouted rebar bolt are modeled via the "rockbolt" element in universal distinct element code (UDEC) after an exact calibration procedure. A two-dimensional (2D) model of a deep tunnel is built to fully evaluate the performance (e.g., capacity of energy-absorption and control of rock damage) of yielding and traditional rockbolts based on the simulated rockbursts. The influence of different rockburst magnitudes is also studied. The results suggest that the D-bolt can effectively control and mitigate rockburst damage during a weak rockburst because of its high strength and deformation capacity. The Roofex is too "soft" or "smooth" to limit the movement of ejected rocks and restrain the large deformation, although it has an excellent deformation capacity. The resin-grouted rebar bolt can maintain a high axial force level during rockbursts but is easy to break during dynamic shocks, which fails to control rapid rock bulking or ejection. Three types of rockbolts cannot control the large deformation and mitigate rockburst damage effectively during violent rockbursts. The rockburst damage severity can be significantly reduced by additional support with cable bolts. This study highlights the effectiveness of numerical modeling methods in assessing the complex performance of yielding rockbolts during rockbursts, which can provide some references to improve and optimize the design of rock supporting in burst-prone grounds.

DOI: https://doi.org/10.1007/s40789-022-00552-7

Effect of loading rate and time delay on the tangent modulus method (TMM) in coal and coal measured rocks

Zulfiqar Ali, Murat Karakus, Giang D. Nguyen & Khalid Amrouch

Abstract: Non-destructive techniques of in-situ stress measurement from oriented

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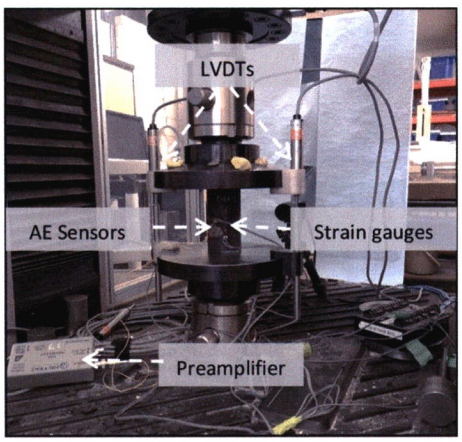
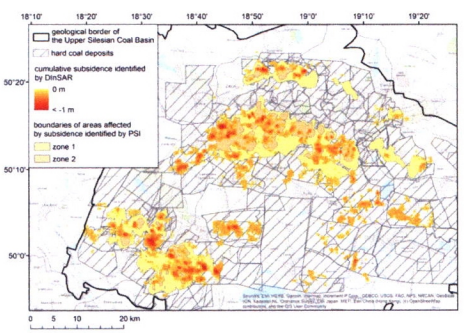
cored rocks have great potential to be developed as a cost cost-effective and reliable alternative to the conventional overcoring and hydraulic fracturing methods. The tangent modulus method (TMM) is one such technique that can be applied to oriented cored rocks to measure in-situ stresses. Like the deformation rate analysis (DRA), the rock specimen is subjected to two cycles of uniaxial compression and the stress-tangent modulus curve for the two cycles is obtained from the stress–strain curve. A bending point in the tangent modulus curve of the first cycle is observed, separating it from the tangent modulus curve of the second cycle. The point of separation between the two curves is assumed to be the previously applied maximum stress. A number of experiments were conducted on coal and coal measured rocks (sandstone and limestone) to understand the effect of loading conditions and the time delay. The specimens were preloaded, and cyclic compressions were applied under three different modes of loading, four different strain rates, and time delays of up to one week. The bending point in the stress-tangent modulus curves occurred approximately at the applied pre-stress levels under all three loading modes, and no effect of loading rate was observed on the bending points in TMM. However, a clear effect of time delay was observed on the TMM, contradicting the DRA results. This could be due to the sensitivity of TMM and the range of its applicability, all of which need further investigation for the in-situ stress measurement.



DOI: https://doi.org/10.1007/s40789-022-00541-w

Twenty years of coal mining-induced subsidence in the Upper Silesia in Poland identified using InSAR

Maria Przyłucka, Zbigniew Kowalski & Zbigniew Perski



Abstract: The paper presents the results of terrain subsidence monitoring in Poland's Upper Silesian Coal Basin (USCB) mining area using Differential Interferometry Synthetic Aperture Radar (DInSAR) and Persistent Scatterer Interferometry (PSI). The study area accounts for almost three million inhabitants where mining which started in the 19th century, has produced severe damage to buildings and urban infrastructures in past years. The analysis aimed to combine eight different datasets, processed in two techniques, coming from various sensors and covering different periods. As a result, a map of areas that have been exposed to subsidence within 3045 square kilometers was obtained. The map covers a period of twenty years of intensive mining activities, i.e. 1992–2012. A total of 81 interferograms were used in the study. The interferograms allowed not only to determine subsidence troughs (basins) formed from 1992 to 2012 but also to observe subsidence development over time. The work also included five sets of PSI processing, covering different temporal and spatial ranges, which were used to determine zones of residual subsidence. Based on InSAR datasets, an area of 521 square kilometers under the influence of mining activities were determined. Within the subsiding zones, an area of 312.5 square kilometers of the rapid increase in subsidence was identified on the interferograms. The study of combined different InSAR datasets provided large-area and long-term information on the impact of mining activities in the Upper Silesia Coal Basin.

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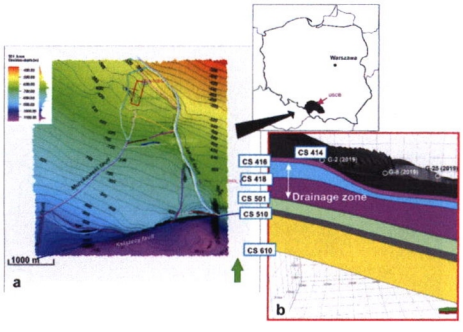
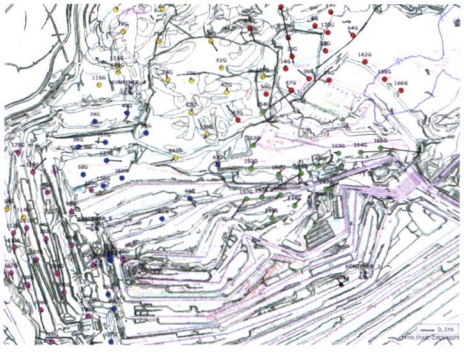


DOI: https://doi.org/10.1007/s40789-022-00553-6

Application of long-reach directional drilling boreholes for gas drainage of adjacent seams in coal mines with severe geological conditions

Grzegorz Leśniak, Daniel J. Brunner, Tomasz Topór, Małgorzata Słota-Valim, Renata Cicha-Szot, Bartłomiej Jura, Jacek Skiba, Arnold Przystolik, Ben Lyddall & Grzegorz Plonka

Abstract: This study aimed to demonstrate the application of Long Reach Directionally Drilled Boreholes (LRDD) for gas drainage of adjacent seams before and during the longwall face operations of low permeability-high gas content coals Staszic-Wujek Hard Coal Mine in the Upper Silesia Coal Basin (Poland). Five LRDD Boreholes (TM1a-TM5) with a length of 300 and 400 m were located over coal seam 501 in the fractured zone and monitored over six months of longwall face operations. LRDD Boreholes were combined with Cross-Measured Boreholes. Reservoir characterization and geological modeling supported the results obtained from gas drainage. The drainage efficiency of LRDD Boreholes was the approximately 70% level, while conventional Cross-Measured Boreholes were only 30%. The highest goaf gas quality (94% methane concentration) was reported for TM4, placed at an average elevation of 41 m above coal seam 501. The highest goaf gas production (average 6.2 m^3/min) was reported for LRDD Borehole TM3. This borehole was placed within the fracture zone (average elevation of 24.4 m) and drilled through the sandstone lithotype with the best reservoir properties, enhancing drainage performance. LRDD Boreholes TM2 and TM4 achieved similar performance. These three LRDD Boreholes were drilled close to the maximum principal horizontal stress direction, providing borehole stability during under-mining. The lowest goaf gas production was reported for LRDD Boreholes TM1a and TM5. Both Boreholes were placed in the rubble zone.



DOI: https://doi.org/10.1007/s40789-022-00555-4

The use of automatic measurement techniques in the geotechnical monitoring system of PGE GiEK S.A., KWB Turów branch

Miłosz Bąk

Abstract: Geotechnical monitoring currently plays a key role in the research of the processes taking place in the ground medium and preventing hazardous events. In the case of open-pit mining, several solutions are commonly used to monitor various geotechnical parameters. However, geotechnical situation is usually assessed based on recorded values of deep and surface displacement, which allow to accurately predict landslides. The measurements are most often carried out manually, which, due to the difficult terrain conditions in the case of open-pit mining, are often timeconsuming and complicated, especially taking into account dangerous landslide movements. Therefore, in order to ensure a higher degree of safety against the risk of landslides, modern solutions are required in the field of geotechnical monitoring. This article presents modern automatic measurement techniques, compares various solutions available on the market and illustrates the benefits of their application in open-pit mining. It also discusses the expansion and modernization of the control and measurement network at KWB Turów, carried out in recent years, as well as the observational method for controlling the efficiency of stackers, developed after the installation of automated measuring stations, with its impact on the geotechnical safety of an internal waste heap. The paper as a case study presents, what a modern and effective geotechnical monitoring system should look like, which in practice will ensure continuous observation of selected parameters and enable a quick response in the event of a landslide threat. Last but not least, the author focuses on the creation of an innovative landslide early warning system, implemented at KWB Turów.

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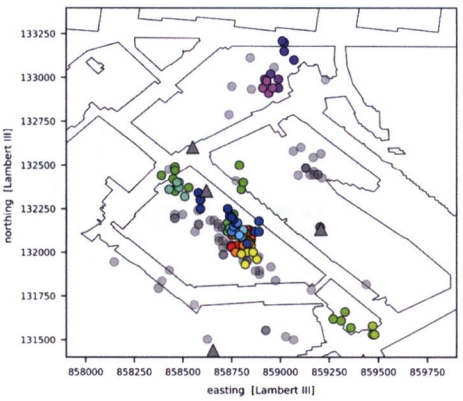
DOI: https://doi.org/10.1007/s40789-022-00558-1

Impact of past mining on public safety: seismicity in area of flooded abandoned coal Gardanne mine, France

Dalija Namjesnik, Jannes Kinscher, Isabelle Contrucci & Emmanuelle Klein

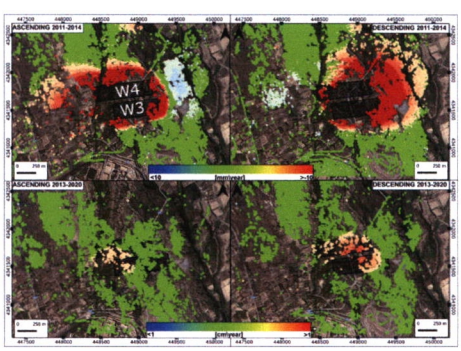


Abstract: This paper focuses on the impact of past mining on public safety. It emphasizes the need to understand the induced seismic hazard and consequently improve the post-mining management procedures and legislations, as many mining sites are located in proximity to populated areas. Due to many challenges and complexity of the post-mining environments, induced seismic hazard nowadays remains largely unknown. However, the return experience of several post-mining sites in recent decades have shown us that the mine flooding and/or degradation of mining works can lead to the stress perturbations, inducing the seismicity and the reactivation of the surrounding geological faults. Hence, it is important to advance the seismic monitoring and research of seismicity in flooded post-mining districts. As the number of mine closures worldwide is rising, it can be expected that flooding induced reactivation of the surrounding faults becomes a more often observed phenomenon. We present in this paper the experience of the abandoned flooded coal mine of Gardanne in France, which has been experiencing post-mining seismicity problems since its closure in 2010. We show the results of a recent study of seismic multiplets and clustering of seismic events, as well as their spatio-temporal activity compared to meteorological conditions. These results provide us new insights as well as lead to raising new questions on seismic sources and triggering mechanisms.

DOI: https://doi.org/10.1007/s40789-022-00559-0

Semi-real time systems for subsidence monitoring in areas affected by underground mining: the example of the Nuraxi-Figus coal district (Sardinia, Italy)

L. Ammirati, D. Di Martire, F. Bordicchia, D. Calcaterra, G. Russo & N. Mondillo



Abstract: Underground mining can produce subsidence, which can be coincident with mining activities or delayed in response to the time-dependent deformation of the rocks. Therefore, in these cases, it is essential to effectively monitor the soil deformations at different times during and after mining activity. In the present work, an integrated approach based on geotechnical numerical modeling and Advanced Differential Interferometric Synthetic Aperture Radar (A-DInSAR) method has been applied to detect, study and monitor the subsidence related to mining activity in the Nuraxi Figus coal district (Sardinia, Italy). Two datasets of high-resolution COSMO-Skymed images were acquired, respectively in two covering periods: from 2011 and 2014, and from 2013 to 2020. The cumulated satellite-based LoS displacements vary in the first period between −130 and +28 mm and −293 and +28.4 mm, while, during the second period between −6.9 and +1.6 mm and −8.72 and +4.33 mm in ascending and descending geometries, respectively. The geotechnical numerical model allowed to obtain a value for the maximum expected. By using the vertical and horizontal components it was possible to reconstruct the kinematics of the deformation considering three phases: pre-mining, syn-mining, and post-mining activity. The temporal evolution of displacements started during the mining extraction in 2011, achieved the major values in correspondence of post-mining operations, during the period from 2013 to 2014 and continued slowly until 2020. The near real-time monitoring system applied in this study proved to be very useful for detecting subsidence during the mining activity and the post-mining period.

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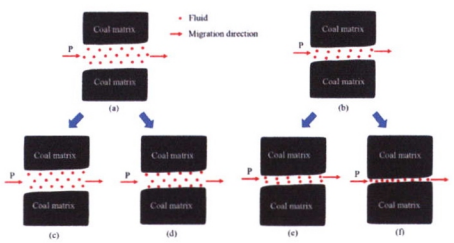


DOI: https://doi.org/10.1007/s40789-022-00545-6

Combined control of fluid adsorption capacity and initial permeability on coal permeability

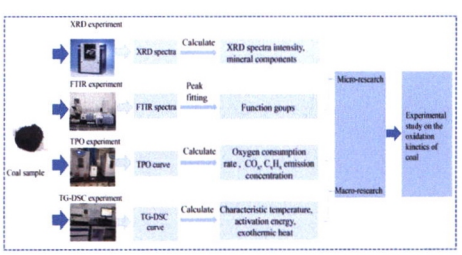
Xiaolei Liu, Jianping Wei, Guoying Wei, Caifang Wu, Cao Liu & Xiaoming Ni

Abstract: The variations of strain and permeability of coal were systematically studied through the physical simulation of N_2 and water injection. The effects of fluid adsorption capacity and initial permeability on strain, permeability and the dominant effect of pore pressure were discussed. The adsorption strain and strain rate of coal during water injection are significantly higher than those during N_2 injection. An edge of free adsorption exists in the early phase of N_2 and water injection, which is related to fluid saturation. Within this boundary, the strain rate and pore pressure are independent. Moreover, the injection time of initial stage accounts for about 20% of the total injection time, but the strain accounts for 70% of the total strain. For water injection, this boundary is about half of water saturation of coal. Besides, the influence of pore pressure on permeability is complex, which is controlled by adsorption capacity and initial permeability of coal. When the initial permeability is large enough, the effect of adsorption strain on permeability is relatively weak, and the promoting effect of pore pressure on fluid migration is dominant. Therefore, the permeability increases with increasing pore pressure. When the initial permeability is relatively low, the pore pressure may have a dominant role in promoting fluid migration for the fluid with weak adsorption capacity. However, for the fluid with strong adsorption capacity, the adsorption strain caused by pore pressure may play a leading role, and the permeability reduces first and then ascends with increasing pore pressure.

DOI: https://doi.org/10.1007/s40789-022-00542-9

Experimental study on the oxidation kinetics of coal in typical coal mining areas of the Southern Junggar coalfield, Xinjiang, China

Qiang Zeng & Li Shen



Abstract: Coal spontaneous combustion (CSC) is a disaster associated with coal mining that leads to loss of coal resources and environmental and human health issues. To investigate kinetic characteristics for oxidation of coal, three coal samples were collected from different coal mining areas in the Southern Junggar coalfield. Subsequently, the collected coal samples were ground into different particle sizes and tested using microscopic and macroscopic methods, including thermal gravimetric analysis, Fourier transform infrared spectroscopy, X-ray diffraction, and temperature-programmed oxidation. The results obtained are as follows: the sharpest absorption peak (002) indicates that graphitization is high. Furthermore, the results show that the SKS coal sample is prone to spontaneous combustion; the greater the aromatic hydrocarbon content is, the more difficult it is for CSC to occur, while the opposite is true for oxygen-containing functional groups. The SKS data confirmed this conclusion; the rate for generation of CO and CO_2 controlled the possibility of SKS oxidation at 110 °C and provided an indication of the temperature. During the dehydration stage, the WD sample had the lowest activation energy, indicating that it was most susceptible to spontaneous combustion. During the combustion stage, the lowest activation energy was found for the SKS sample with particle sizes < 0.075 mm, indicating that particle size was one of the factors affecting spontaneous combustion. The activation energy for dehydration was significantly lower than that for combustion, which showed that the coal oxygen reaction was more likely to occur in the dehydration stage. Based on DSC curves, the SKS sample had the largest exothermicity, indicating that it would ignite more readily.

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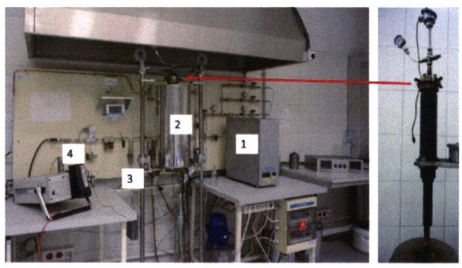
DOI: https://doi.org/10.1007/s40789-022-00550-9

Gasification of lignite from Polish coal mine to hydrogen-rich gas

Adam Smolinski, Sławomir Wochna & Natalia Howaniec

Abstract: The efforts of the world research activities involved in clean coal technologies development focus to a considerable extent on integrated hydrogen and power generation technologies based on coal gasification. As an alternative to combustion processes, gasification offers increased efficiency, lower negative environmental impact as well as wider application range of the main product—synthesis gas—in power generation and chemical syntheses. In order to select the most optimal lignite for the purpose of gasification, it is necessary to determine coal reactivity, the key parameter characterizing how fast the fuel reacts with the gasifying medium and controlling its process ability in thermochemical conversion to energy and/or energy carriers. This paper presents the experimental results of oxygen/steam gasification of lignite coal char in a fixed bed reactor under atmospheric pressure and at the temperature of 700, 800 and 900 °C; the samples come from an open pit lignite mine in the southwest of Poland. The effectiveness of the gasification process was tested in terms of the total gas and hydrogen yields, gas composition, carbon conversion rate and chars reactivity.

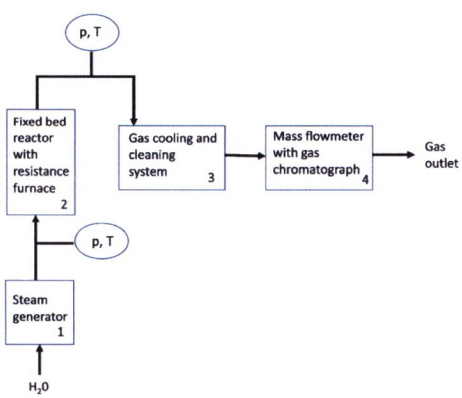


DOI: https://doi.org/10.1007/s40789-022-00548-3

Use of coals and wastes in a co-gasification process aimed at producing hydrogen rich gas

Rafał Gąsior & Adam Smoliński

Abstract: The use of low-quality coals and flotoconcentrates is currently severely limited, and the problem of managing municipal waste from anthropogenic activities is currently a challenge. The problems of reducing carbon dioxide emissions, utilizing the energy potential of waste and increasing its recycling have an impact on the costs of electricity production. Considering the abundant streams of unused fuels, they can be considered as attractive energy materials, so environmentally-friendly and cost-effective options for their utilization should be developed. A study was conducted using steam co-gasification technology on selected coals, flotation concentrates and Refuse Derived Fuel (RDF) alternative fuel. Selected low-quality coals were combined with RDF alternative fuel in a process aimed at hydrogen production. The experiments produced gas with hydrogen concentrations ranging from 67% (vol.) to 68% (vol.) with low methane concentrations. It was observed that the addition of alternative fuels helped to increase the hydrogen concentration in syngas. Attention was paid to the catalytic ability of the metal oxides contained in the fuel blend, with particular reference to K_2O and Al_2O_3 and TiO_2.



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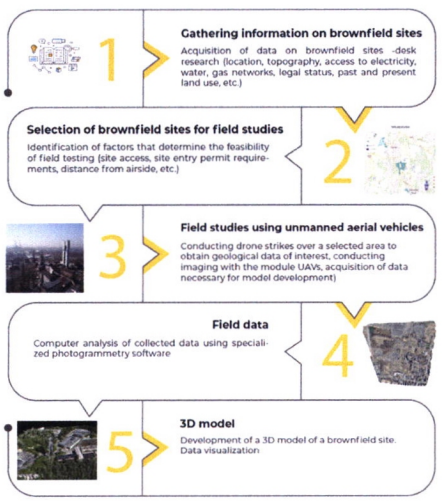


DOI: https://doi.org/10.1007/s40789-022-00551-8

Development and actualization of brownfields database with the use of unmanned aerial vehicles - the case of Upper Silesia, Poland

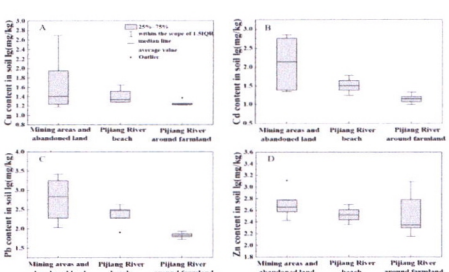
Aleksandra Zgórska, Adam Hamerla, Jan Bondaruk & Paweł Zawartka

Abstract: This paper presents the assumptions and the preliminary results of the project entitled "Extension of the system for management of post-mining areas in the Silesian province - OPI TPP 2.0". The overall objective of the project is to develop and implement a new e-service in the form of an open-access information system on post-mining areas in the Silesia Voivodeship. The range of information and tools planned to be made available is dedicated to assessing the possibilities and potential for economic and social reuse of these areas. The basic and extremely important stage of the project was to identify and collect data on post-industrial sites located in the Silesia Province. The information contained in this article illustrates the activities that were carried out in the initial phase of the project in which unmanned aerial vehicles (UAV) were used to identify and acquire information on brownfields (including post-mining sites) entered into the developed common database. The article assesses the possibility of using drones in an enterprise of such a large scale and also points out the advantages of using this method. The article describes the methodology and scope of work related to the acquisition of data that can be collected using unmanned aerial vehicle (UAV) covering surface infrastructure and land use of brownfields, allowing for the identification of negative phenomena on their site as well as monitoring of naturally occurring processes. Based on fieldworks experience and the results of numerous analyses carried out for different types of brownfields (e.g. post-mining areas, former transport bases, settling ponds, etc.), paper presents the advantages and benefits of drones (UAN) over other data sources used to monitor changes in an area. The article is based on the results of an inventory of over 600 brownfields located in Upper Silesia region (Silesia Voivodeship, Poland).

DOI: https://doi.org/10.1007/s40789-022-00538-5

Characteristics of heavy metals in soil of lead-zinc mining areas and changes of antioxidant enzyme systems in maize leaf under Pb stress

Ranran Jiang, Ping Liu, Yongjian He, Yanru Cao & Xiuli Hou



Abstract: Pb, Cu, Cd, Zn content of soil in mining areas and abandoned land, flats of the Pijiang River and farmlands were investigated. On this basis of soil heavy metal pollution, the changes of antioxidant enzyme system in maize (Qiandan 88) under different Pb concentrations (0, 20, 40, 60, 80, 100, 150, 200, 500, 1000, 2000, 3000 mg/L) stress were studied. The results show that the content of Pb, Cu, Cd, and Zn in soil is the highest in mining areas and abandoned land, followed by flats of the Pijiang River > farmlands, and that the variation range of Pb, Cu, Cd in mining areas and abandoned land are 106.40–2564.72, 14.83–490.88, 22.57–712.77 mg/kg, respectively, which are higher than that of the other land use types. When maize is under stress of 20–500 mg/L Pb concentration, T-SOD activity of maize leaves increase with the increase of Pb concentration and the highest value is 50.21 U/mg prot, but under Pb concentration > 1000 mg/L stress, T-SOD activity of maize leaves decrease gradually. The activity of POD decreases with the increases of Pb concentration, and the lowest POD activity of leaves in maize with the value of 93.24 U/mg prot is appeared in Pb 1000 mg/L concentration treatment group. MDA content in leaves of maize increases with the increase of the Pb concentration and the highest value is 101.98 nmol/mg prot, then the content of MDA decreases gradually when the Pb concentration is more than 500 mg/L, which indicates that the membrane lipid peroxidation of maize leaves under high concentration of Pb stress is serious and leads to the cell damage.

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INTERNATIONAL JOURNAL OF COAL SCIENCE & TECHNOLOGY

国际煤炭科学技术学报（英文）

(Bimonthly, Started in 2014)
Vol. 9, December 2022

Owned by China Association for Science and Technology
Sponsored by China Coal Society
Editors-in-Chief Suping Peng, Shimin Liu
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Edited by Editorial Office of International Journal of Coal Science & Technology
Address: Rm.811, Coal Tower, Block 13 Hepingjie, Beijing 100013, China
Tel: +86-10-87986415
http: //www.springer.com/40789
Email: jcst@chinacs.org.cn

Printed by Beijing LHHT Color Printing Co. Ltd.

Coverage in Abstracting & Indexing (A&I) Services: Emerging Sources Citation Index, SCOPUS, DOAJ, INSPEC, EI Compendex, Chemical Abstracts Service (CAS), Google Scholar, Geobase, OCLC, EBSCO, Dimensions, etc.

ISSN 2095-8293

CODEN IJCSQT

In China: RMB ¥58.00
Other regions: US $60.00

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