ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) https://doi.org/10.17559/TV-20220322090437
Preliminary communication

Comparative Study on Sealing Technology of Gas Drainage Borehole in Soft Coal Seam

Xiaohua JIN*, Jiyu ZHENG, Zhihao LIN, Shunheng HUA

Abstract: This paper discusses four kinds of hole sealing technologies for gas drainage in soft coal seam, which are polyurethane hole sealing, cement mortar hole sealing, full-length screen pipe hole sealing and pipe direct connection technology. Through the observation of negative pressure loss, the sealing effect of four sealing technologies is analyzed, the polyurethane sealing effect is poor, the cement mortar, the full-length screen pipe combined with cement mortar and the direct connection technology of pipe are good; through the observation of gas concentration, the gas drainage effect of four sealing technologies is analyzed, the polyurethane sealing technology is the worst, and the direct connection technology of pipe is the worst. The gas drainage effect is the best; according to the sealing effect and gas drainage effect, the traditional polyurethane and cement mortar sealing technology cannot meet the gas drainage demand of the soft coal seam. In the case of slow drilling deformation, the full-length screen pipe sealing technology can be used. In the case of rapid drilling deformation, the direct connection of pipe sealing technology should be used.

Keywords: drilling; gas drainage; hole sealing technology; soft coal seam

1 INTRODUCTION

Gas disaster is one of the main disasters in coal mines. Drilling in coal seam for gas drainage is an effective technology to solve the gas problem. After the formation of the drainage borehole, there is a stress concentration phenomenon dominated by the stress of the overlying coal strata around. For soft coal seams, due to the soft coal body and strong plasticity, with the advance of time, there is a phenomenon of shrinkage or even closure of the borehole, resulting in the stagnation of the gas drainage work [1]. After the geological tectonic movement, the firmness coefficient of coal changes greatly. The coal with firmness coefficient greater than 0.5 is called hard coal, and the coal with firmness coefficient less than 0.5 is called soft coal. Therefore, the coal seam where coal is soft coal is called soft coal seam.

In the triaxial creep test of Mishra and Verma [2], the axial stress and radial stress increase in stages. Under the condition of complex stress, the strain of coal rock will occur with the passage of time, and it will change into complete failure of the specimen. Lu and Zhao [3] have carried out triaxial creep test on outburst coal and its adjacent mudstone samples. The influence of confining pressure and axial pressure on creep test is analyzed. An accelerated creep model parallel to the nonlinear viscous and plastic components is established.

Whether it is shrinkage or collapse caused by creep, the borehole will lose its stability eventually. Haimson and Chang [4] analyzed the stability of the borehole wall based on the borehole stability model; Zhao et al. [5] established the viscoelastic model about the borehole deformation in granite; Gelet et al. [6] give the balance control equation of three-phase medium of heat flow solid, and apply it to the stability analysis of borehole. Yao et al. [7] simulated the stress field, displacement field and plastic failure area change of the coal around the borehole based on Kastner formula; Liu et al. [8] study the influence of confining pressure unloading on soft coal strength reduction, providing basis for borehole stability analysis. Yin et al. [9] used the triaxial creep test device of gas bearing coal to complete the creep test of the prefabricated shaped coal samples under different confining pressures and different gas pressures. Based on the experimental results, the change trend of axial deformation under different stress levels is studied, and the creep instability characteristics of gas bearing coal under different confining pressures are analyzed.

The study of creep law of coal and borehole instability is to better serve gas drainage engineering technology. With the progress of drilling technology, long drilling and directional drilling are more and more widely used [10], but for soft coal seam, once there is serious shrinkage phenomenon in the drilling, no matter how long the drilling is, no matter how accurate the positioning is, no gas drainage can continue. Only by adopting the technology of the combination of hole protection and gas drainage can the gas drainage work be effectively carried out. Wang and Sun [11], based on the elastic-plastic "urrounding rock support" theory, established the mechanical model of borehole wall protection, and used the numerical analysis method to analyze the change rule of stress and deformation of coal around the borehole under different internal pressure conditions. Zhai et al. [12] analyzed the instability and deformation mechanism of borehole in the soft outburst coal seam in the coal mine, and believed that after the construction of the coal seam fracturing borehole, the hole wall is easier to be damaged and unstable than the soft structure, the borehole is easy to collapse, and the borehole is difficult to form. The essential reason for these is the distribution of the rock stress around the tunnel and the borehole restress. Hao et al. [13] studied the change rule of borehole diameter and effective extraction time of different buried depth, established the gas migration model under the coupling effect of creep and seepage, and determined the effective extraction radius of different buried depth borehole. Liu et al. [14] studied the axial deformation, radial compression deformation and shear deformation characteristics of the liner. The correlation between test results and different loads is discussed. The influence of sieve density and sieve diameter on the mechanical properties of lining was studied. Liu et al. [15] studied the new technology of directional drilling, which provides a safe and reliable method for early detection of gas emission and drainage, and also provides exploration data of long drilling. Packham et al. have studied the fiber-optic induction technology, which can detect the flow of the borehole and the situation in the borehole, so as to

improve the gas drainage [16-18]. Because of the secondary distribution of stress around the hole caused by mining activities, for the soft coal seam, it is easy to cause the displacement and deformation of the coal body around the hole, and then cause the collapse of the hole [19]. Due to the soft coal seam, under the action of deep in-situ stress, the soft coal seam cannot bear the self weight of coal and rock mass in a short time, resulting in rapid borehole shrinkage and borehole collapse and closure. Therefore, it is necessary to protect the borehole. The use of large-diameter gas drainage borehole protection technology is helpful to improve the gas drainage effect [20, 21].

Although the hole protection technology in soft coal seam has made great progress, some holes in soft coal seam are shrinking too fast, or even the holes are completely closed within one or two days. In this case, the traditional hole sealing technology cannot meet the actual needs. Adopting the full-length down sieve pipe hole protection technology and the through pipe direct connection technology can solve the problem of hole sealing in soft coal seam. This paper compares four kinds of borehole sealing technologies in soft coal seam, in order to explore the applicability of borehole sealing technology to gas drainage in soft coal seam through the analysis of hole sealing effect and gas drainage effect, in order to obtain good gas drainage effect. Through the comparative analysis of hole sealing technology in soft coal seam, practitioners can choose suitable hole sealing technology for different coal seams to guide production practice, which is also its significance and value. The article mainly includes the following parts: introduction, introduction of gas drainage borehole sealing technology, hole sealing effect analysis, gas drainage effect analysis and conclusion.

2 SEALING TECHNOLOGY OF GAS DRAINAGE BOREHOLE

2.1 Polyurethane Sealing Technology

Polyurethane sealing materials are composed of isocyanate and polyether polyol. According to their proportion formula and additives, they are divided into soft foam and hard foam. The principle is that the adducts formed by various types of isocyanates and active hydrogen containing compounds expand first and then solidify in the process of chemical reaction. It is mainly used for gas drainage drilling and sealing of various hole pipes. Polyurethane sealing hole is as shown in Fig. 1. One end of the extraction pipe has a sieve hole, which can extract as much gas as possible. The sieve pipe surface is wrapped with gauze to prevent coal dust from blocking the extraction pipe. Polyurethane is injected from the liquid injection pipe. Due to the function of baffle, polyurethane expands towards the orifice, and the orifice is plugged with wooden wedge to make polyurethane expand evenly.

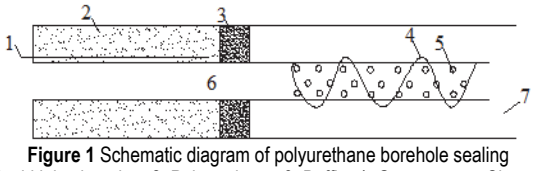

Figure 1 Schematic diagram of polyurethane borehole sealing
(1. Liquid injection pipe, 2. Polyurethane, 3. Baffle, 4. Gauze net, 5. Sieve pipe, 6. Extraction pipe, 7. Extraction hole)

2.2 Sealing Technology Of Cement Mortar

Cement mortar is a kind of mortar composed of cement, fine aggregate and water. It is a common construction material in the construction field and a common material for drilling and sealing holes. Cement mortar hole sealing is a traditional hole sealing technology (as shown in Fig. 2), which is widely used. For hard coal, the traditional cement mortar hole sealing technology can achieve better results, but for soft coal seam, due to hole collapse, the drilling failure is caused, and the pumping effect is poor. Cement mortar shall be used to seal the hole in the form of two ends blocking and middle sealing. Polyurethane or baffle shall be used to block the two ends of the hole sealing length first, and then the grouting pipe shall be injected with cement mortar. When there is liquid flowing out of the return pipe, grouting shall be stopped. After a certain time, cement mortar shall be solidified.

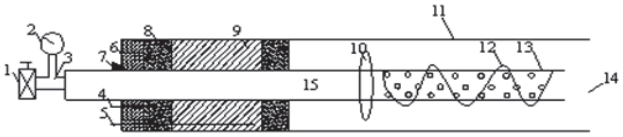

Figure 2 Schematic diagram of cement mortar hole sealing
(1. stop valve, 2. Pressure gauge, 3. three way, 4. grouting pipe, 5. slurry return pipe, 6. yellow mud, 7. wooden wedge, 8. polyurethane, 9. cement mortar, 10. baffle, 11. casing wall, 12. mesh, 13. sieve 14. drilling, 15. extraction pipe)

2.3 Sealing Technology Of Full Length Sieve Pipe

The outburst coal seam has the characteristics of large gas content and soft coal body. Drilling in the soft coal seam often occurs with the phenomenon of sticking and drilling. After the hole is formed, the hole collapses seriously, resulting in the closure of the hole and low gas extraction rate. By adopting the hole protecting device and the method of full-length sieve pipe for the soft coal seam (as shown in Fig. 3), the problems of drilling difficulty and hole collapse are solved, and the gas drainage rate can be increased.

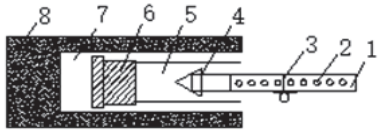

Figure 3 Schematic diagram of full-length sieve pipe
(1. Sieve pipe; 2. Sieve hole; 3. Support pulley; 4. Suspension fixture; 5. Hollow spiral drill pipe; 6. Drill bit; 7. Drilling; 8. Coal body)

After the completion of drilling construction, the drill bit and the spiral drill pipe stay in the drilling, and the drill bit and the drill pipe exit a certain distance (about 1 m), so as to reserve a fixed space for the hanging fixed device. Connect the suspension fixture with the sieve pipe, and transport it to the deep part of the borehole. After the first sieve pipe is transported into the borehole, connect the remaining sieve pipes in turn. In the process of connecting the sieve pipe, a sliding device is clamped on the sieve pipe every 10 m. When the suspension fixture is against the drill bit, stop connecting the sieve pipe, force the drill bit to open, and transport it to the deepest part of the drilling hole. Push and pull the sieve pipe repeatedly until the suspension fixture is fixed on the coal wall. After the sieve pipe is output, exit the drill bit and drill pipe.

2.4 Sealing Technology of Pipe Direct Connection

After the formation of drilling holes in soft coal seam, there are hole collapse and hole closure phenomena. Because of the rapid deformation of the drilling hole, it is too late to plug the drainage pipe into the drilling hole, so gas drainage cannot be carried out. In addition, because of the hole collapse phenomenon in the drilling hole, as long as there is local hole collapse in the drilling hole, resulting in the failure of the deep drilling hole, a kind of fast straight plug integrated gas drainage device is needed, which solves the problem of pipe route; the second problem is to solve the hole collapse failure.

Through pipe direct connection technology adopts a straight plug type integrated gas drainage. It changes the original connection mode of the extraction pipe section by section (as shown in Fig. 4 and Fig. 5). The PE material (Polyethylene material) is used to make the sectional pipe called the integrated pipe. It can be wound together at ordinary times for convenient storage and transportation. When it is used, it can be straightened. The straightening has certain strength and toughness, and can be directly plugged into the borehole. It solves the problem that the borehole is closed too fast and the extraction pipe cannot be plugged. At the same time, the full-length pipe is lowered and divided into the main body. Sieve pipe and sealing pipe solve the problem of hole collapse leading to drilling failure.

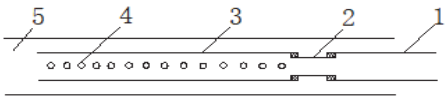

Figure 4 Schematic diagram of gas drainage device directly connected with pipe (1. Sealing pipe; 2. Connecting pipe; 3. Main pipe; 4. Sieve hole; 5. Drilling)

Figure 5 PE pipe and sealing joint

The application diagram is shown in Fig. 6. After drilling, the PE hard material gas drainage main pipe (with sieve hole) shall be straightened and plugged into the hole. According to the actual length of the hole, when there is still 10 m from the hole bottom, the main pipe shall be cut off, and the sealing pipe (without sieve hole) shall be connected with the main pipe with a connecting pipe. After that, continue to plug into the deep part of the hole. When the pipe is plugged to the hole bottom, the liquid injection pipe shall be plugged. The liquid injection pipe is located in the sealing pipe. Wrap the removable adhesive capsule around the orifice. Inflation pump is used to inflate the capsule in the hole, and then inflate the capsule in the hole until the capsule is close to the coal wall. Then, inject cement mortar around the sealing pipe with liquid injection pump to complete the sealing.

Figure 6 Application diagram

3 ANALYSIS OF SEALING EFFECT

The negative pressure loss reflects the quality of hole sealing. The negative pressure in the hole is measured by negative pressure measuring steel pipe and mercury differential pressure meter. The measuring steel pipe is a steel pipe that goes deep into a certain depth of the borehole. The deep position is to measure the negative pressure at the current position. Mercury differential pressure gauge is a device for measuring negative pressure. When polyurethane is used for hole sealing, the quality of hole sealing is poor, the negative pressure of the hole is 14.51 kPa, the negative pressure of the hole at the depth of 70 m is 11.87 kPa, and the negative pressure loss is 18.2% (as shown in Fig. 7). When cement mortar is used for hole sealing, the quality of hole sealing is good, the negative pressure of the hole is 14.45 kPa, the negative pressure of the hole at the depth of 70 m is 13.57 kPa, and the negative pressure loss is 6.1% (as shown in Fig. 8). When using the full-length sieve pipe technology to seal the hole, the negative pressure of the hole is 14.41 kPa, the negative pressure of the hole at the depth of 70 m is 13.56 kPa, and the negative pressure loss is 5.9% (as shown in Fig. 9). When using the full-length sieve pipe technology to seal the hole, the negative pressure of the hole is 14.39 kPa, the negative pressure of the hole at the depth of 70 m is 13.36 kPa, and the negative pressure loss is 7.2% (as shown in Fig. 10).

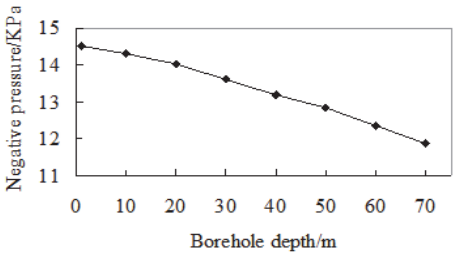

Figure 7 Negative pressure loss (polyurethane hole sealing)

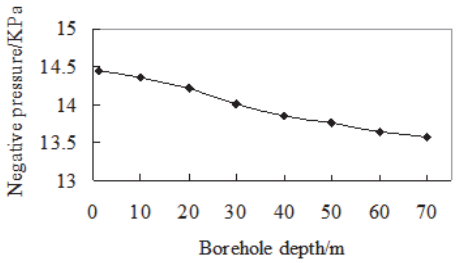

Figure 8 Negative pressure loss (cement mortar hole sealing)

Through the observation of the negative pressure of the drilling hole, the sealing effect of the full-length sieve pipe and the through pipe direct connection technology with cement mortar is good. In order to prevent the hole from shrinking and be easy to insert, the diameter of the

extraction pipe is smaller when using the pipe direct connection technology. Because the diameter of the hole is smaller than the traditional cement mortar hole sealing technology, the negative pressure of the hole has a certain loss.

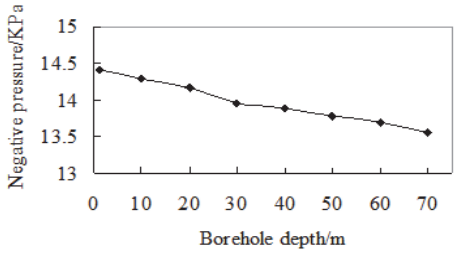

Figure 9 Negative pressure loss (full-length sieve pipe hole sealing)

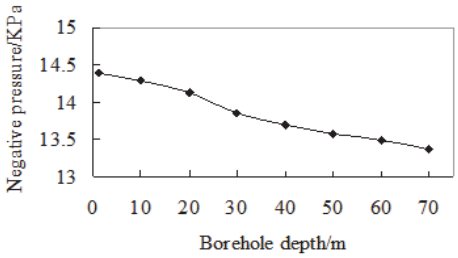

Figure 10 Negative pressure loss (direct connection of pipe)

4 ANALYSIS OF GAS DRAINAGE EFFECT

Gas concentration is an important manifestation of the effect of gas drainage. The optical gas detector (The optical gas detector is made according to the principle of light interference) is used to observe the gas concentration in the borehole, and the gas drainage concentration under different hole sealing technologies is quite different. When polyurethane is used for hole sealing, the gas concentration is not high, the highest is 18.2%, the lowest is 6.3%, the 30th day attenuation is 65.4%, and the attenuation range is large (as shown in Fig. 11). When the cement mortar is used to seal the hole, the gas concentration is 40% at the highest and 23% at the lowest, the 30th day attenuation of 42.5% (as shown in Fig. 12). When using the full-length sieve pipe technology to seal the hole, the gas concentration is 56.8% at the highest, 32.1% at the lowest and 43.5% until 30th day (as shown in Fig. 13). When the direct connection technology is used to seal the hole, the gas concentration is 64.9% at the highest, 33.4% at the lowest, and 48.5% until 30th day (as shown in Fig. 14).

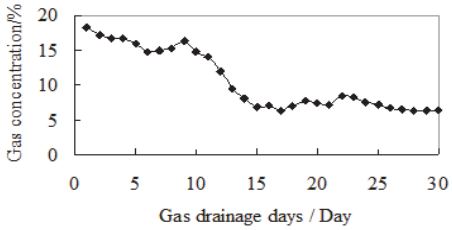

Figure 11 Gas drainage effect (polyurethane hole sealing)

Through the comparison of the effects of the four technologies through the average gas concentration (as shown in Fig. 15), the best effect is the direct connection of pipe, followed by the full-length sieve pipe, and the polyurethane sealing effect is the worst.

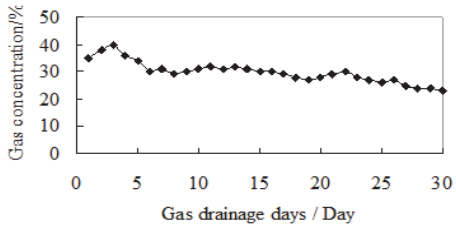

Figure 12 Gas drainage effect (cement mortar hole sealing)

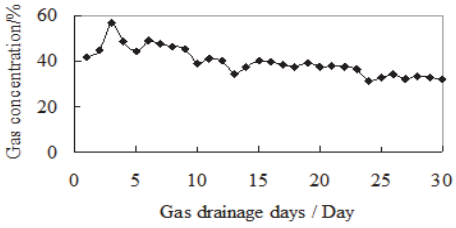

Figure 13 Gas drainage effect (full-length sieve pipe hole sealing)

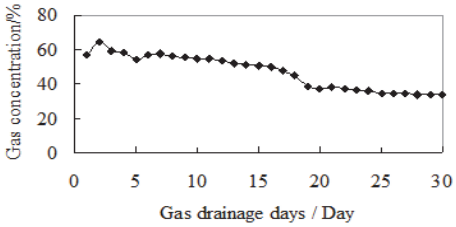

Figure 14 Gas drainage effect (direct connection of pipe)

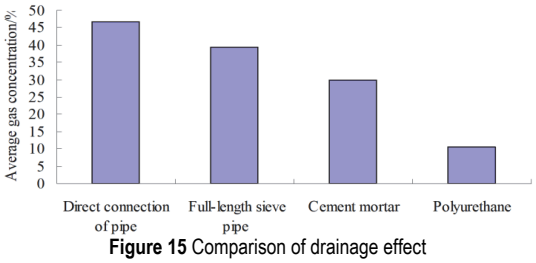

Figure 15 Comparison of drainage effect

Through the observation of gas concentration, when the pipe direct connection technology is adopted, the gas drainage effect is the best, and when the polyurethane hole sealing technology is adopted, the gas drainage effect is the worst. Therefore, for the soft coal seam, polyurethane sealing can be used as an auxiliary role, not as the main technology. Through the promotion of direct connection of pipes, the pumping concentration and attenuation have been greatly improved.

5 CONCLUSIONS

Through the above analysis, the full-length screen pipe sealing technology and pipeline direct connection technology have good hole sealing effect and gas drainage effect. In particular, the pipeline direct connection technology is more convenient for soft coal seams with fast shrinkage rate, and it is also the direction of future research. The specific conclusions are as follows:

(1) This paper discusses four kinds of hole sealing technology for gas drainage in soft coal seam, polyurethane hole sealing technology and cement mortar hole sealing technology are the traditional technology with long use time, and the hole sealing technology for under drilling sieve pipe and pipe direct connection technology are the new hole sealing technology for gas drainage.

(2) The negative pressure loss of gas extraction is used to analyze the hole sealing effect of drilling. The results show that the hole sealing effect of cement mortar, full-length screen pipe and pipeline is good, but the hole sealing effect of polyurethane is poor, and the negative pressure loss is 18.2%. Due to the small drilling diameter, the negative pressure loss is large, which is related to the diameter of PE pipe.
(3) The gas drainage effect is analyzed by using the gas drainage concentration. The results show that when the hole is sealed with the pipe direct connection technology, the gas concentration is 64.9% and the gas drainage concentration is the highest. When the full-length screen tube technology is used to seal the hole, the gas concentration is the highest 56.8%, followed by the gas drainage concentration. Polyurethane sealing technology has the lowest gas drainage concentration.

Although some achievements have been made in this paper, some new technologies affect gas drainage due to the small drainage aperture. Therefore, it is a new problem to carry out large-diameter drilling and hole sealing in soft coal seam.

6 REFERENCE

[1] Xu, B. (2019). Study on surrounding rock failure laws of three-soft coal seam mining roadway in Da'nanhu No.1 Mine. *China Coal*, *45*(2), 57-63.

[2] Mishra, B. & Verma, P. (2015). Uniaxial and triaxial single and multistage creep tests on coal-measure shale rocks. *International Journal of Coal Geology*, *137*, 55-65. https://doi.org/10.1016/j.coal.2014.11.005

[3] Lu, H. & Zhao, Z. (2016). Creep properties and a creep equation of delay outburst coal and its adjacent mudstone. *International Journal of Mining Science and Technology*, *26*(6), 1161-1167. https://doi.org/10.1016/j.ijmst.2016.09.027

[4] Haimson, B. C. & Chang, C. (2002). True triaxial strength of the KTB amphibolite under borehole wall conditions and its use to estimate the maximum horizontal in situ stress. *Journal of Geophysical Research: Solid Earth, 107*(B10), ETG-15. https://doi.org/10.1029/2001JB000647

[5] Zhao, Y., Feng, Z., Xi, B., Wan, Z., Yang, D., & Liang, W. (2015). Deformation and instability failure of borehole at high temperature and high pressure in Hot Dry Rock exploitation. Renewable *Energy*, *77*, 159-165. https://doi.org/10.1016/j.renene.2014.11.086

[6] Gelet, R., Loret, B., & Khalili, N. (2012). Borehole stability analysis in a thermoporoelastic dual-porosity medium. *International Journal of Rock Mechanics and Mining Sciences*, *50*, 65-76. https://doi.org/10.1016/j.ijrmms.2011.12.003

[7] Yao, X. R., Cheng, G. L., & Shi, B. M. (2010). Borehole instability analysis and pore forming method of gas drainage in deep surrounding rock with weak structure. *Journal of Coal Industry*, *35*(12), 2073-2081.

[8] Liu, Q., Cheng, Y., Jin, K., Tu, Q., Zhao, W., & Zhang, R. (2017). Effect of confining pressure unloading on strength reduction of soft coal in borehole stability analysis. *Environmental Earth Sciences*, *76*(4), 173.

[9] Yin, G. Z., Wang, D. K., Zhang, D. M., & Wei, Z. (2008). Study on three-dimensional creep characteristics and creep model of gas bearing coal rock. *Journal of Rock Mechanics and Engineering*, (S1), 2631-2636.

[10] Frank, H., Ting, R., & Naj, A. (2013). Evolution and application of in-seam drilling for gas drainage. *International Journal of Mining Science and Technology*, *23*(4), 543-553. https://doi.org/10.1016/j.ijmst.2013.07.013

[11] Wang, Y. L. & Sun, Y. N. (2012). Analysis of mechanical mechanism of borehole wall protection in soft outburst coal seam. *Journal of Anhui University of Science and Technology (NATURAL SCIENCE EDITION)*, *32*(4), 50-55.

[12] Zhai, C., Li, Q. G., Sun, C., Ni, G. H., & Yang, W. (2012). Borehole instability analysis and solidification pore forming method of hydraulic fracturing in soft coal seam. *Journal of Coal Industry*, *37*(9), 1431-1436.

[13] Hao, F. C., Liu, Y. W., Long, W. C., & Zuo, W. Q. (2017). Study on the effective extraction radius of different buried depth under the coupling effect of creep and seepage. *Journal of Coal Science*, *42*(10), 2616-2622.

[14] Liu, C., Zhou, F., Yang, K., Xiao, X., & Liu, Y. (2014). Failure analysis of borehole liners in soft coal seam for gas drainage. *Engineering Failure Analysis*, *42*, 274-283. https://doi.org/10.1016/j.engfailanal.2014.04.010

[15] Liu, L., Cheng, Y. P., Wang, H. F., Wang, L., & Ma, X. Q. (2009). Principle and engineering application of pressure relief gas drainage in low permeability outburst coal seam. *Mining Science and Technology (China)*, *19*(3), 342-345. https://doi.org/10.1016/S1674-5264(09)60064-8

[16] Packham, R., Cinar, Y., & Moreby, R. (2011). Simulation of an enhanced gas recovery field trial for coal mine gas management. *International Journal of Coal Geology*, *85*(3-4), 247-256. https://doi.org/10.1016/j.coal.2010.11.013

[17] Aminossadati, S. M., Amanzadeh, M., Prochon, E., Kok, J., & Adam, S. (2014). Step change approaches in coal technology and fugitive emissions research. *International Journal of Mining Science and Technology*, *24*(3), 363-367. https://doi.org/10.1016/j.ijmst.2014.03.013

[18] Aminossadati, S. M., Mohammed, N. M., & Shemshad, J. (2010). Distributed temperature measurements using optical fibre technology in an underground mine environment. *Tunnelling and Underground Space Technology*, *25*(3), 220-229. https://doi.org/10.1016/j.tust.2009.11.006

[19] Haimson, B. (2007). Micromechanisms of borehole instability leading to breakouts in rocks. International *Journal of Rock Mechanics and Mining Sciences*, *44*(2), 157-173. https://doi.org/10.1016/j.ijrmms.2006.06.002

[20] Zhang, P., Qin, Z., & Li, F. (2021). Study on hole protection technology of large diameter gas extraction boreholes in loose and soft coal seams. *Coal and Chemical Industry*, *44*(3), 92-95.

[21] Liu, P., Fan, J., Jiang, D., et al. (2021). Evaluation of underground coal gas drainage performance: Mine site measurements and parametric sensitivity analysis. *Process Safety and Environmental Protection*, *148*(4), 711-723.

Contact information:

Xiaohua JIN
(Corresponding author)
School of Energy & Environment, Zhongyuan University of Technology,
Zhengzhou 450007, China
E-mail: 6561@zut.edu.cn

Jiyu ZHENG
School of Resources and Safety Engineering, Henan University of Engineering,
Zhengzhou 451191, China
E-mail: zhengjiyu@haue.edu.cn

Zhihao LIN
School of Energy & Environment, Zhongyuan University of Technology,
Zhengzhou 450007, China
E-mail: 2020108291@zut.edu.cn

Shunheng HUA
School of Energy & Environment, Zhongyuan University of Technology,
Zhengzhou 450007, China
E-mail: 2021108309@zut.edu.cn