

Effects of water saturation time on energy dissipation and burst propensity of coal specimens

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Abstract. Water infusion has long been taken as an effective way to eliminate coal burst risk as coal properties can be loosen and soften by water infusion. However, not all industrial trials of water infusion for coal burst prevention have been necessarily effective in all situations as the effectiveness of this method can be affected by water infusion time, coal properties and the parameters of water injection. Hence, some fundamental issues including the effects of water infusion time on burst propensity and energy evolution need to be further discussed. In this paper, four groups of coal specimens with 0 day, 5 days, 10 days, and 15 days water saturation time are tested under uniaxial compression load with the application of AE monitoring. To comprehensively compare the burst behavior of coal specimens under different water saturation time, stress-strain curves, AE counts, fragmentation characteristics and burst propensity of these groups are analyzed. It was found by this research that sufficient water saturation can mitigate the burst behavior of coal samples while insufficient water infusion might cannot reach the burst mitigation aims.

Keywords: coal burst; mining geomechanics; water saturation; burst propensity; acoustic emission; coal fragmentation

1. Introduction

With the increase of mining depth, coal body generally is under complicated geological conditions and supercritical stress, which may lead to catastrophic failure of coal hence causing personal casualties and economic losses (Shen and Barton 2018, Moayedifar *et al.* 2019). The catastrophic of coal, also called coal burst, can release large amount of stored energy in the forms of loud sounds, coal ejection, and even seismic events (Wang *et al.* 2017, Yang *et al.* 2018, Liu and Li 2020). Coal burst now has become one of the major safety concerns faced by future mining as both the coal burst frequency and severity increase with mining depth (Ning *et al.* 2017, Zhang *et al.* 2017, Genis *et al.* 2018). Poland started the research of coal burst along with Czechs in 1912 and firstly proposed the coal burst propensity measurement method for coal burst risk evaluation (Shen and Luo 2016, Konicek *et al.* 2019). Coal burst caused 401 fatalities from 1949 to 1982 in Poland (Dou and He 2001). Coal burst had long history in the U.S. as well. From 1936 to 1993, 172 burst accidents caused 83 fatalities and 163 injuries in the U.S. (Mark 2017). In China, research into coal burst was initially carried out in the early 1960's and more than 147 coal mines experienced coal burst at the end of 2014 (Shen and Luo 2016, Zhang *et al.* 2017). After decades of research and engineering

practice of coal burst controlling, these major coal mining counties have a good understanding of coal burst phenomenon and made great achievements in forecasting methods and solving technics of coal burst. In Australia, coal burst is a new challenge for mining researchers and technicians as the first coal burst accident was occurred in 2014. However, considering the increasing coal burst risk with mining depth and intensity going forward, the controlling and mitigation measures of coal burst in Australia need more research.

Water infusion method was primarily developed and applied in European coal mines, mainly for dust control (Ren *et al.* 2011). This method typically involves the pre-mining injection of water into the coal seam to increase its moisture content and therefore reduce dust generation during mining. Water infusion has long been taken as an effective way to eliminate coal burst risk as coal properties can be loosen and soften by water infusion (Lee *et al.* 2017). This method has been applied in the Ruhr Coalfield (Germany) since the 1960's and achieved great success in coal burst mitigation. As reported by Bräuner, the uniaxial compression strength and elastic modulus of Ruhr coal was reduced by 60-70 % and 40-70 % respectively by increasing the moisture content from 1 to 5 % (Brauner 1994), which means the elastic energy scale stored in coal can be reduced by water infusion. In Colorado, the pillar infusion used at the Elk Creek Mine demonstrated that infusion increased the yielding of the pillar, reducing the occurrence of damaging bumps (Varley and Whyatt 2008). Water infusion is recommended as a coal burst mitigation method in the coal burst prevention rules published by Chinese mining authority in 2018 (National Coal Mine Safety Administration 2018). Besides, water infusion has been

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successfully used for preventing coal and gas outburst as well (Aguado and Nicieza 2007). Theoretically, water infusion can decrease the strength of coal by increasing pore pressure (Frid 2000, Gu *et al.* 2018, Maruvanchery and Kim 2019). The increasing of moisture content can soften coal and mitigating coal burst risk by consuming more energy plastically (Kim *et al.* 2018). However, not all industrial trials of water infusion for coal burst prevention has been necessarily effective in all situations as the effectiveness of this method can be affected by water infusion time, coal properties and the parameters of water injection. Hence, some fundamental issues including the effects of water infusion time on burst propensity and energy evolution need to be further discussed.

The aim of this paper is to investigate the influences of water saturation time on energy dissipation and burst propensity of coal specimens through experimental study, hence providing better understanding of water influence on the mechanical behaviour and burst characteristics of the coal body during underground infusion process. Four groups of coal specimens with 0 day, 5 days, 10 days, and 15 days water saturation time were tested under uniaxial compression load with the application of AE monitoring. Stress-strain curves of all coal specimens were introduced to demonstrate the average strength change of coal specimens after different water infusion time. AE was analysed to demonstrate the influence of water infusion on plastic energy dissipation in the forms of crack and fracture propagation. Fragmentation characteristic of coal specimens, which is seldom touched by previous research, was analysed based on image processing technics to demonstrate the energy dissipation during brittle failure of coal specimens. The burst propensity of every group was also calculated in this paper.

2. Material and methodology

2.1 Specimen preparation

Coal blocks taken from local coal mines were cored and processed into 54 mm diameter and 108 mm length cylindrical coal specimens before test. The drilling direction of all coal specimens was oriented perpendicular to the joint direction of coal blocks. To maintain the original moisture content of coal and avoid damage during delivery, all blocks taken from the underground were fully wrapped with aluminium and plastic membranes. All other conditions (parallelism, flatness, and verticality) of the coal specimens met the standards for the application of uniaxial compression strength method published by International Society of Rock Mechanics guidelines. All coal specimens were well wrapped before the test with plastic membranes and stored in the laboratory with relatively constant temperature and humidity.

2.2 Test apparatus and procedure

As shown in Fig. 2, the tests were all conducted on a 500-tonne digital hydro-powered Instron-8033 universal rock resting machine. The axial displacement and applied



Fig. 1 Sample coring process

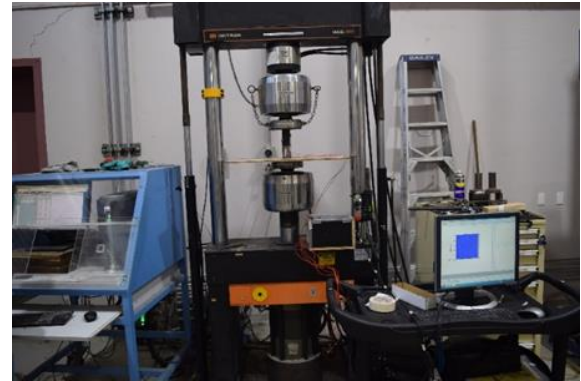


Fig. 2 Apparatus set-up for the uniaxial compression test



Fig. 3 Water saturation of coal specimens

load of the coal specimens were automatically recorded by the testing system. All specimens were loaded with a displacement control loading rate of 0.5 mm/min, which is the loading rate of coal burst propensity test. To obtain the effect of saturation time on energy dissipation and burst propensity of coal specimens, four test schemes were designed based on saturation time. The saturation time of coal specimens was designed 0 day (natural water content), 5 days, 10 days, and 15 days. As shown in Fig. 3, coal specimens were saturated with designed time in the container before the tests.

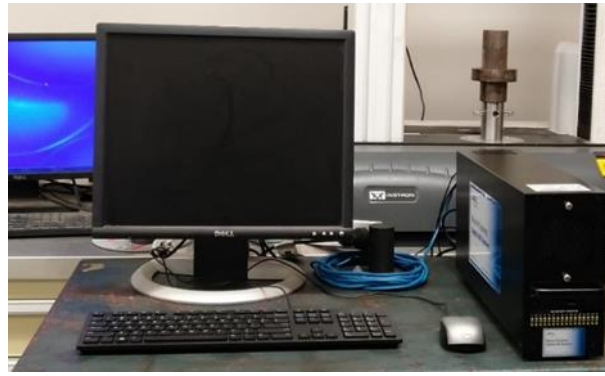


Fig. 4 AE monitoring system

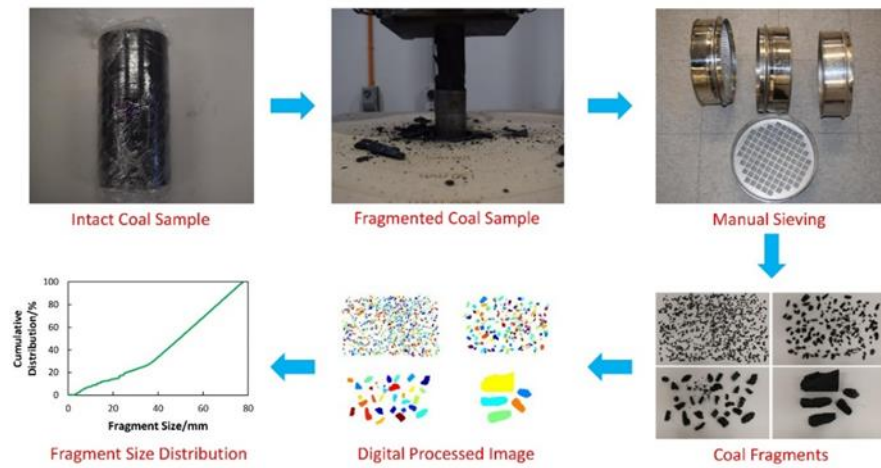


Fig. 5 Fragment size distribution analysis process

Table 1 Coal burst propensity index and risk classification of Australian coal

Index	R_C /MPa	DT /s	K_E	W_{ET}
Test Method		Uniaxial Loading		Uniaxial Loading-Unloading
Schematic Diagram				
High	$R_C \geq 15$	$DT \leq 10$	$K_E \geq 5$	$W_{ET} \geq 5$
Moderate	$10 \leq R_C < 15$	$10 < DT \leq 15$	$3.5 \leq K_E < 5$	$3.5 \leq W_{ET} < 5$
Low	$5 \leq R_C < 10$	$15 < DT \leq 20$	$2 \leq K_E < 3.5$	$2 \leq W_{ET} < 3.5$
None	$R_C < 5$	$DT \geq 20$	$K_E < 2$	$W_{ET} < 2$

2.3 AE monitoring

As an important non-destructive evaluation and monitoring methods, AE (Acoustic Emission) monitoring has been widely adopted to study the damage mechanics of

coal caused by crack initiation and propagation under applied stresses (Yang *et al.* 2020). It has been well proved by previous research that the AE event counts can reflect the stress change and fracture intensity inside the coal body (Lou, Song *et al.* 2019). During the test, AE sensors were

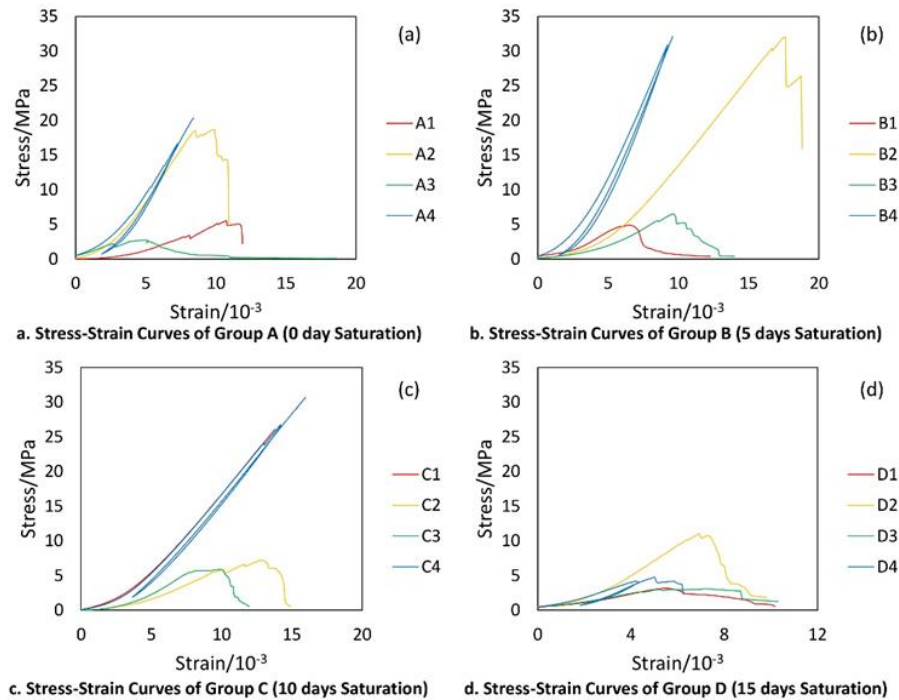


Fig. 6 Stress-strain curves of all coal specimens

attached to the surface of coal specimens to continuously acquire AE data generated inside coal specimens. As shown in Fig. 4, the AE system adopted in this test was Express-8 AE system, which can achieve 10 kSPS sampling rate with 1 kHz to 1.2 MHz bandwidth. AE monitoring was started at the same time with uniaxial compression loading. All the data including event counts, amplitude distributions and frequency characteristics was automatically recorded in the computer for analysis.

2.4 Fragment analysis

Fragmentation is a common mechanical phenomenon that exists in the brittle failure of coal subjected to static, impact, and dynamic loads, during which coal fragments with difference sizes can be generated. The analysis of fragment size distribution (FSD) of coal, which has rarely been studied by previous research, is important for the understanding of energy dissipation characteristics and fracture activities of coal specimens (Yang *et al.* 2020). FSD analysis of fragmented coal specimens was carried by a combination of manual sieving method and image processing technique (Yang *et al.* 2020). Coal fragments generated by uniaxial compression test were sieved into several regimes and then digitally analysed through image processing in Matlab software. The sieve adopted in this study has four sieve sizes including $d=2.5, 5, 10$ and 20 mm. The image processing operations include image acquisition, image reading, image binarization, watershed segmentation and statistical measurements. Every step of the fragment analysis and its results are shown in Fig. 5.

2.5 Burst propensity

Coal burst propensity index method, which includes the

uniaxial compressive strength (R_C), elastic strain energy index (W_{ET}), bursting energy index (K_E) and dynamic failure time (DT), is a widely used method for burst risk evaluation (Guo *et al.* 2017). Russian and Polish coal mines adopted W_{ET} and K_E to evaluate the burst risk of coal (Kidybiński 1981). Zhang *et al.* and Qi *et al.* proposed DT and R_C , respectively for coal burst propensity evaluation (Zhang *et al.* 1986, Qi *et al.* 2011). In 2010, China Coal Industry Association summarizes these four indices as the burst propensity index method and published the measurement standard of these four indices. Based on the previous research and the Chinese standard, as shown in Table 1, Yang *et al.* proposed the burst propensity measurement method and risk classification form of Australian coal (Yang *et al.* 2018). The burst propensity levels of coal specimens with different water saturation time were all determined based on the calculation of these four indices.

3. Results and discussion

3.1 Stress-strain curves

Elastic and mechanical weakening from water saturation are widely known to occur in sedimentary rocks including sandstone, limestone and coal (Pimienta *et al.* 2014). Fig. 5 demonstrates how water saturation affects the strength and elastic behavior of coal specimens. As shown in Fig. 6, both strength and elastic modulus of group D are obviously lower than those of group A, B and C, which means the strength of coal specimens has been weakened with long term water saturation. The explanation of strength reduction after water saturation can be given by exiting research as water molecules react easily with clay and mineral contents

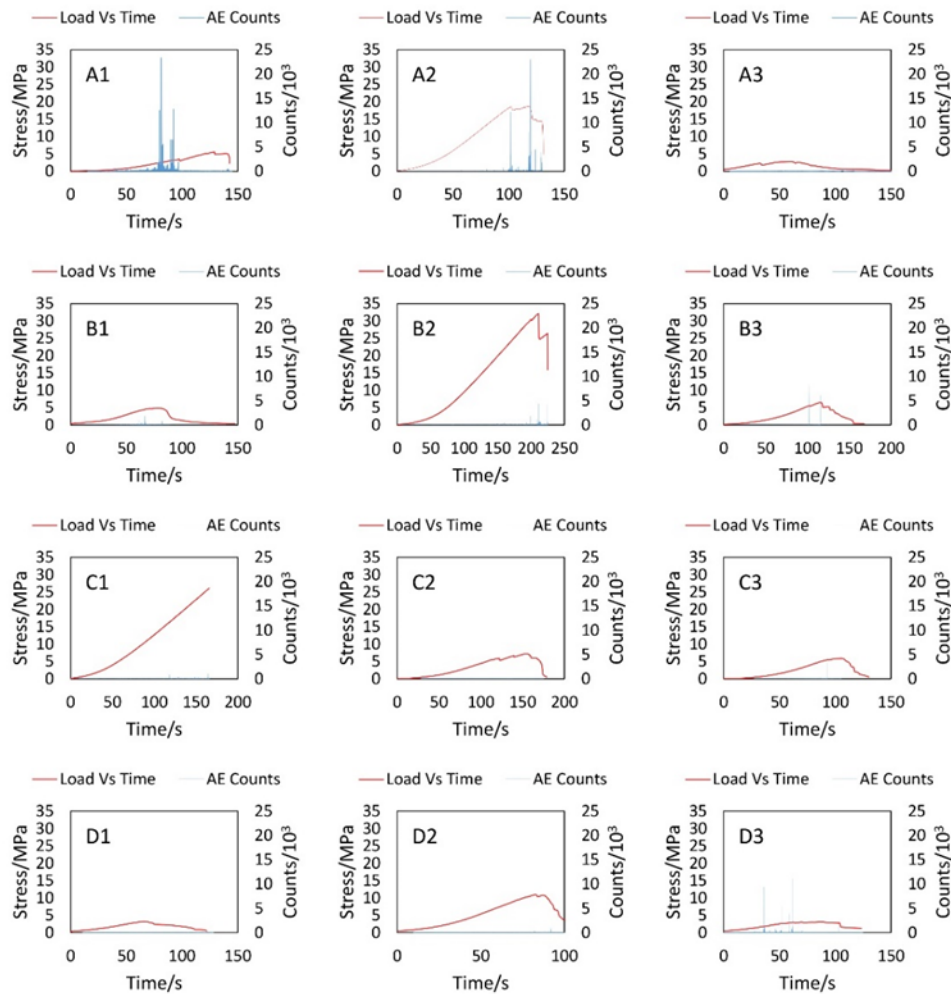


Fig. 7 AE counts of uniaxial loading coal specimens

in coal and consequently softens its bond structure (Perera *et al.* 2011). However, the strength of B2 and C1, specimens with 5- and 10-days water saturation respectively, are unreasonably high. Considering the natural weaknesses and inhomogeneous properties of coal specimens, it is possible that the strength of coal specimens is in a very wide range during laboratory uniaxial compression tests. The increase of pore pressure contributes to the reduction of strength as well. Besides, the elastic behavior of coal specimens has been obviously weakened by water infusion as the stress-strain curves is gentler with longer water infusion time.

3.2 AE features

AE data given by the AE system for each uniaxial loading specimens were examined, and the results are shown in Fig. 6. It has been widely accepted by researchers that the counts of AE can be used to identify the fracture propagation inside coal (Perera *et al.* 2011). According to Ranjith *et al.* (2010), the pre-failure stress curve of coal specimens can be divided into three crack propagations periods: crack closure period with very few AE counts, stable crack propagation period with a linear increment of AE counts and unstable crack propagation period with exponential increment of AE counts. It can be seen from

Fig. 6 that the magnitude of AE counts has been significantly decreased by water infusion, which indicates the low intensity of crack activities inside water saturated coal specimens during uniaxial loading process. The observed effects of water saturation on AE counts is consistent with previous research done by Perera *et al.* (2011). The SEM observation of coal microstructure has demonstrated that the surface area and total volume of the internal micro structures of coal specimens can be greatly increase by saturation (Liu *et al.* 2017). That is, the fracture tips of coal microstructure have been weakened, which explains the reduction of AE counts after water saturation.

3.3 Fragmentation characteristics

The fragmentation characteristics, which have been rarely touched by previous research, are important to understand the energy dissipation characteristic and burst mechanism of coal specimens (Liu *et al.* 2014). It has been found by previous research that the ejection velocity can be estimated based on the energy dissipation and coal fragmentation (Yang *et al.* 2020). To provide a comprehensive understanding of the water saturation effect on the failure behavior of coal specimens, the FSD of selected coal specimens were analyzed with the

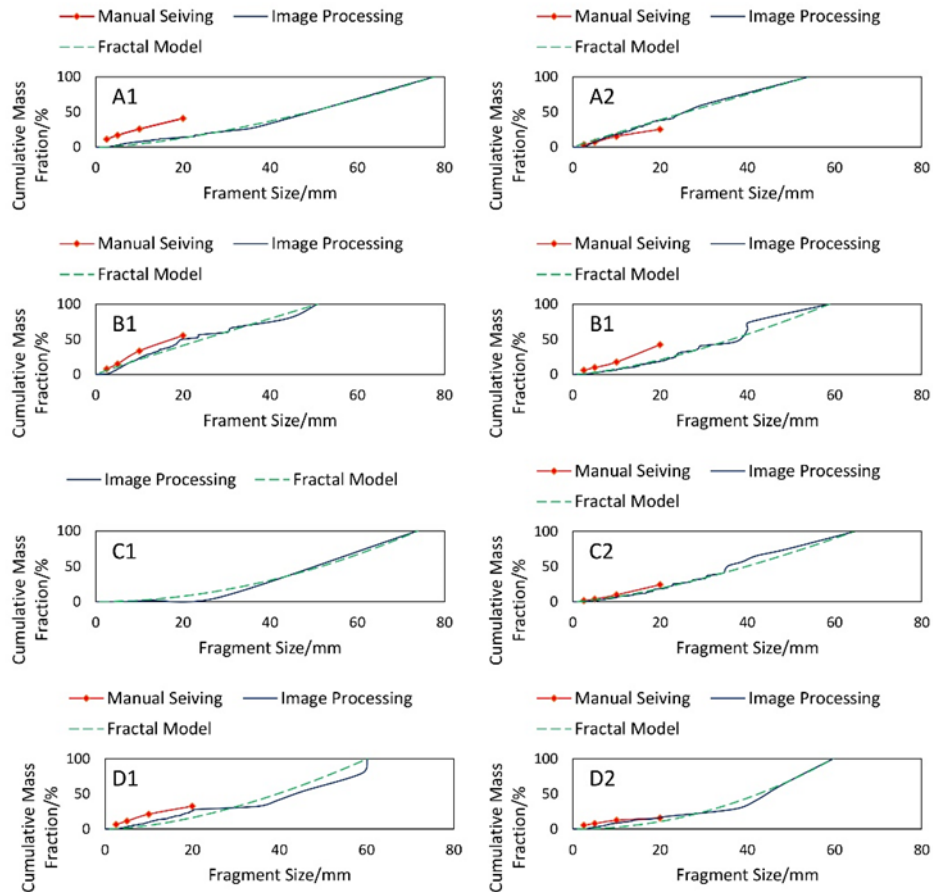


Fig. 8 Fragment size distribution of coal specimens acquired by manual sieving, image processing and fractal model

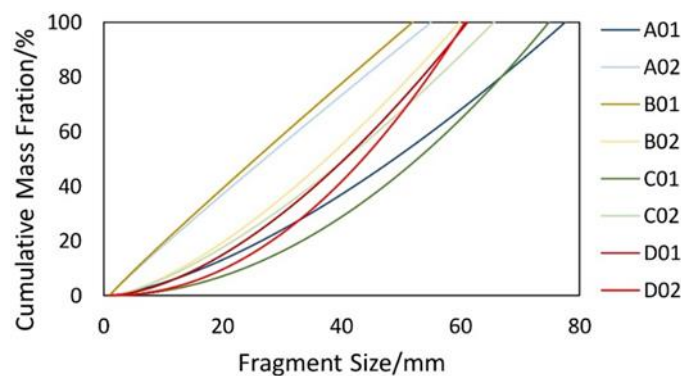


Fig. 9 Fractal size distribution of coal specimens

combination of manual sieving and image processing techniques introduced in Section 2.4. It has been well-documented by previous research that the FSD of coal can be statistically described by the fractal model (Peng *et al.* 2015). The fractal dimension of the model was adjusted based on the image processed curve.

Fig. 8 shows the cumulative size distribution of selected coal specimens obtained by manual sieving, imaging processing and fractal model. It can be seen from Fig. 8 that the similarity of the curves generated from different methods is very high, that is, the fractal model and image processed curves are both suitable to characterize the FSD of coal specimens. The fractal size distributions of coal specimens are compared in Fig. 9 to demonstrate the water

saturation influence on fragmentation characteristics of coal. Generally, sufficient water saturation can make the fragmentation mode more stable as the curves of D1 and D2 in Fig. 8 have high coincidence. However, coal specimens with insufficient water saturation (Specimen B1 and C1) may have more random fragmentation pattern than those without water saturation. This phenomenon might result from the uneven water distribution inside coal specimens as water needs more time to penetrate into the core part of the specimens (Zhou *et al.* 2016).

3.4 Burst propensity

It has been mentioned in literature that the strength and

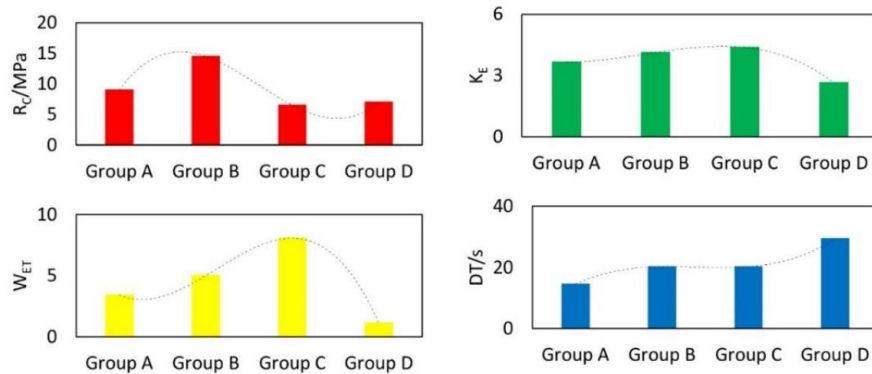


Fig. 10 Burst propensity of coal specimens

burst propensity of rock and coal decrease with moisture content (Meng *et al.* 2009). Burst propensity indexes method has been widely used to evaluate the burst risk of coal seams in many countries (Yang *et al.* 2018). The burst propensity indexes of these four groups of coal specimens were calculated based on Fig. 6 and Table 1 and the results are shown in Fig. 10. According to Fig. 10, the burst propensity of group D is the lowest as the coal specimens of group D have been saturated with the longest time. The burst propensity of group B and C are even higher than group A, although group B and C have been saturated for 5 and 10 days, respectively. It has not been indicated by previous research that in-sufficient water saturation may increase the burst propensity of coal. Both experimental and numerical studies suggested that the burst propensity should decrease with water saturation time (Guo *et al.* 2017, Liu *et al.* 2017). It is unclear that whether this phenomenon is caused by the difference between coal specimens. Different correlation between saturation time and burst propensity may be obtained if more specimens were tested.

4. Conclusions

Water infusion was taken as an effective way to mitigate coal burst risk by many researchers. However, the effect of water saturation time on burst propensity and energy dissipation of coal need more scientific research to provide better understanding of water influence on mechanical behavior and burst characteristic of coal body during underground infusion process. In this paper, coal specimens taken from local coal mines were tested under natural and different saturation time. To comprehensively compare the burst behavior of coal specimens under different water saturation time, stress-strain curves, AE counts, fragmentation characteristics and burst propensity of these groups were analyzed. The following conclusions can be drawn based the on the test results:

1. Sufficient water infusion can decrease the strength of coal specimens. However, the natural weaknesses and inhomogeneous properties of coal specimens can make the strength of some saturated specimens higher than unsaturated coal specimens.

2. The magnitude of AE counts has been significantly decreased by water infusion, which indicates the low

intensity of crack activities inside water saturated coal specimens during uniaxial loading process.

3. Sufficient water saturation can make the fragmentation mode more stable while in-sufficient water saturation can make fragmentation pattern more random. This phenomenon might result from the uneven water distribution inside coal specimens when coal specimens are in-sufficiently saturated.

4. Different with previous research, the burst propensity has not been mitigated by water saturation when the saturation time is 5 or 10 days. It is unclear that whether this phenomenon is caused by the difference between coal specimens. The burst propensity of group D is much lower than other groups as it is saturated with the longest time. However, this is the preliminary conclusion based on the test results of limited specimens taken from single coal seam. More specimens from different coal seams need to be tested to verify the findings proposed in this paper.

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Declarations

Authors declare no conflict of interests.

References

- Aguado, M.B.D. and Nicieza, C.G. (2007), "Control and prevention of gas outbursts in coal mines, Riosa-Olloniego coalfield, Spain", *Int. J. Coal Geol.*, **69**(4), 253-266. <https://doi.org/10.1016/j.coal.2006.05.004>.
- Brauner, G. (1994), *Rockbursts in Coal Mines and Their Control*, DMT, Essen, Balkema, Germany.
- Dou, L.M. and He, X.Q. (2001), *Theory and Technology of Rock Burst Prevention*, China University of Mining and Technology Press, Xuzhou, China.
- Frid, V. (2000), "Electromagnetic radiation method water-infusion

- control in rockburst-prone strata”, *J. Appl. Geophys.*, **43**(1), 5-13. [https://doi.org/10.1016/S0926-9851\(99\)00029-4](https://doi.org/10.1016/S0926-9851(99)00029-4).
- Genis, M., Akcin, H., Aydan, O. and Bacak, G. (2018). “Investigation of possible causes of sinkhole incident at the Zonguldak Coal Basin, Turkey”, *Geomech. Eng.*, **16**(2), 177-185. <https://doi.org/10.12989/gae.2018.16.2.177>.
- Gu, H., Tao, M., Wang, J., Jiang, H., Li, Q. and Wang, W. (2018), “Influence of water content on dynamic mechanical properties of coal”, *Geomech. Eng.*, **16**(1), 85-95. <https://doi.org/10.12989/gae.2018.16.1.085>.
- Guo, W.Y., Tan, Y.L., Yang, Z.L., Zhao, T.B. and Hu, S.C. (2017), “Effect of saturation time on the coal burst liability indexes and its application for rock burst mitigation”, *Geotech. Geol. Eng.*, **36**(1), 589-597. <https://doi.org/10.1007/s10706-017-0300-2>.
- Kidybiński, A. (1981), “Bursting liability indices of coal”, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, **18**(4), 295-304. [https://doi.org/10.1016/0148-9062\(81\)91194-3](https://doi.org/10.1016/0148-9062(81)91194-3).
- Kim, E., Garcia, A. and Changani, H. (2018), “Fragmentation and energy absorption characteristics of Red, Berea and Buff sandstones based on different loading rates and water contents”, *Geomech. Eng.*, **14**(2), 151-159. <https://doi.org/10.12989/gae.2018.14.2.151>.
- Konicek, P., Ptacek, J., Waclawik, P. and Kajzar, V. (2019), “Long-term Czech experiences with rockbursts with applicability to today’s underground coal mines”, *Rock Mech. Rock Eng.*, **52**(5), 1447-1458. <https://doi.org/10.1007/s00603-018-1489-y>.
- Lee, H.B., Oh, T.M., Park, E.S., Lee, J.W. and Kim, H.M. (2017), “Factors affecting waterproof efficiency of grouting in single rock fracture”, *Geomech. Eng.*, **12**(5), 771-783. <https://doi.org/10.12989/gae.2017.12.5.771>.
- Liu, D., Li, D., Zhao, F. and Wang, C. (2014), “Fragmentation characteristics analysis of sandstone fragments based on impact rockburst test”, *J. Rock Mech. Geotech. Eng.*, **6**(3), 251-256. <https://doi.org/10.1016/j.jrmge.2014.04.001>.
- Liu, F. and Li, L. (2020), “Study on the propagation mechanism of stress wave in underground mining”, *Comput. Concrete*, **25**(2), 145-154. <https://doi.org/10.12989/cac.2020.25.2.145>.
- Liu, X., Xu, G., Zhang, C., Kong, B., Qian, J., Zhu, D. and Wei, M. (2017), “Time effect of water injection on the mechanical properties of coal and its application in rockburst prevention in mining”, *Energies*, **10**(11), 1783. <https://doi.org/10.3390/en10111783>.
- Liu, X., Xu, G., Zhang, C., Kong, B., Qian, J., Zhu, D. and Wei, M. (2017), “Time effect of water injection on the mechanical properties of coal and its application in rockburst prevention in mining”, *Energies*, **10**(11), 1783. <https://doi.org/10.3390/en10111783>.
- Lou, Q., Song, D., He, X., Li, Z., Qiu, L., Wei, M. and He, S. (2019), “Correlations between acoustic and electromagnetic emissions and stress drop induced by burst-prone coal and rock fracture”, *Safety Sci.*, **115**, 310-319. <https://doi.org/10.1016/j.ssci.2019.02.022>.
- Mark, C. (2017), “Coal bursts that occur during development: A rock mechanics enigma”, *Int. J. Min. Sci. Technol.*, **28**(1), 35-42. <https://doi.org/10.1016/j.ijmst.2017.11.014>.
- Maruvanchery, V. and Kim, E. (2019), “Effects of water on rock fracture properties: Studies of mode I fracture toughness, crack propagation velocity, and consumed energy in calcite-cemented sandstone”, *Geomech. Eng.*, **17**(1), 57-67. <https://doi.org/10.12989/gae.2019.17.1.057>.
- Meng, Z.P., Pan, J.N., Liu, L.L., Meng, G.X. and Zhao, Z.H. (2009), “Influence of moisture contents on mechanical properties of sedimentary rock and its bursting potential”, *Chin. J. Rock Mech. Eng.*, **28**(s1), 2637-2643.
- Moayedifar, A., Nejadi, H.R., Goshtasbi, K. and Khosrotash, M. (2019), “Seismic fragility and risk assessment of an unsupported tunnel using incremental dynamic analysis (IDA)”, *Earthq. Struct.*, **16**(6), 705-714. <https://doi.org/10.12989/eas.2019.16.6.705>.
- National Coal Mine Safety Administration (2018), *Rules for Prevention and Controlling of Coal Burst in Mines*, National Coal Mine Safety Administration. Beijing, China.
- Ning, J., Wang, J., Tan, Y., Zhang, L. and Bu, T. (2017), “In situ investigations into mining-induced overburden failures in close multiple-seam longwall mining: A case study”, *Geomech. Eng.*, **12**(4), 657-673. <https://doi.org/10.12989/gae.2017.12.4.657>.
- Peng, R., Ju, Y., Wang, J.G., Xie, H., Gao, F. and Mao, L. (2015), “Energy dissipation and release during coal failure under conventional triaxial compression”, *Rock Mech. Rock Eng.*, **48**(2), 509-526. <https://doi.org/10.1007/s00603-014-0602-0>.
- Perera, M.S.A., Ranjith, P.G. and Peter, M. (2011), “Effects of saturation medium and pressure on strength parameters of Latrobe Valley brown coal: Carbon dioxide, water and nitrogen saturations”, *Energy*, **36**(12), 6941-6947. <https://doi.org/10.1016/j.energy.2011.09.026>.
- Pimienta, L., Fortin, J. and Guéguen, Y. (2014), “Investigation of elastic weakening in limestone and sandstone samples from moisture adsorption”, *Geophys. J. Int.*, **199**(1), 335-347.
- Qi, Q.X., Peng, Y.W., Li, H.Y., Li, J.Q., Wang, Y.G. and Li, C.R. (2011), “Study of bursting liability of coal and rock”, *Chin. J. Rock Mech. Eng.*, **30**(s1), 2736-2742.
- Ranjith, P.G., Jasinge, D., Choi, S.K., Mehic, M. and Shannon, B. (2010), “The effect of CO₂ saturation on mechanical properties of Australian black coal using acoustic emission”, *Fuel*, **89**(8), 2110-2117. <https://doi.org/10.1016/j.fuel.2010.03.025>.
- Ren, T.X., Plush, B. and Aziz, N. (2011), “Dust controls and monitoring practices on Australian longwalls”, *Procedia Eng.*, **26**, 1417-1429. <https://doi.org/10.1016/j.proeng.2011.11.2319>.
- Shen, B.T. and Barton, N. (2018), “Rock fracturing mechanisms around underground openings”, *Geomech. Eng.*, **16**(1), 35-47. <https://doi.org/10.12989/gae.2018.16.1.035>.
- Shen, B.T. and Luo, X. (2016), “Review of Chinese coal burst experience and analysis of microseismic data from Australian mines”, CSIRO Energy, CSIRO, Australia.
- Varley, F. and Whyatt, J. (2008), “Work practices to manage bump prone ground”, *Proceedings of the 27th International Conference on Ground Control in Mining*, Morgantown, West Virginia, U.S.A., July.
- Wang, Z.S., Li, Y., Zhu, W.S., Xue, Y.G., Jiang, B. and Sun, Y.B. (2017), “Field monitoring of splitting failure for surrounding rock masses and applications of energy dissipation model”, *Geomech. Eng.*, **12**(5), 595-609. <https://doi.org/10.12989/gae.2017.12.4.595>.
- Yang, X., Ren, T. and He, X. (2020), “Experimental study of coal burst risk prediction using fractal dimension analysis of AE spatial distribution”, *J. Appl. Geophys.*, 104025. <https://doi.org/10.1016/j.jappgeo.2020.104025>.
- Yang, X., Ren, T. and Tan, L. (2020), “Estimation of average ejection velocity generated by rib burst under compression load”, *Int. J. Rock Mech. Min. Sci.*, **128**, 104277. <https://doi.org/10.1016/j.ijrmms.2020.104277>.
- Yang, X., Ren, T. and Tan, L. (2020), “Size distribution measurement of coal fragments using digital imaging processing”, *Measurement*, 107867. <https://doi.org/10.1016/j.measurement.2020.107867>.
- Yang, X., Ren, T., Tan, L., Remennikov, A. and He, X. (2018), “Developing coal burst propensity index method for Australian coal mines”, *Int. J. Min. Sci. Technol.*, **28**(5), 783-790. <https://doi.org/10.1016/j.ijmst.2018.08.008>.
- Zhang, C., Canbulat, I., Hebblewhite, B. and Ward, C.R. (2017), “Assessing coal burst phenomena in mining and insights into directions for future research”, *Int. J. Coal Geol.*, **179**, 28-44. <https://doi.org/10.1016/j.coal.2017.05.011>.
- Zhang, S., Li, Y. and Xu, C. (2017), “Application of black box

model for height prediction of the fractured zone in coal mining”, *Geomech. Eng.*, **13**(6), 997-1010.

<https://doi.org/10.12989/gac.2017.13.6.997>.

Zhang, W.B., Wang, S.K., Wu, Y.K. and Qu, X.C. (1986), “To determine proneness of coal burst by dynamic failure time”, *Coal Sci. Technol.*, **14**(3), 31-34.

Zhou, Z., Cai, X., Cao, W., Li, X., and Xiong, C. (2016), “Influence of water content on mechanical properties of rock in both saturation and drying processes”, *Rock Mech. Rock Eng.*, **49**(8), 3009-3025. <https://doi.org/10.1007/s00603-016-0987-z>.

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