The 6th International Conference on Mining Science & Technology

Study of the stress relief and gas drainage limitation of a drilling and the solving mechanism

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Abstract

The stress relief mechanism and the limitation of a borehole drilling are pointed out by theoretical and numerical analysis. The stress is relieved around the borehole wall, and the gas can be drained out easily, but the periphery of the stress relief area generates annularity stress concentration to embay around the boreholes, and forms the “Bottle Neck Effect” (BNE) which restricts the gas drainage ability. Jetting high pressure water in the boreholes to form several slots can break the BNE, which makes the stress above and below the slots relieve sufficiently. The stress relief area is nearly 200 times larger than the stress concentration area under the same condition. The slots around a borehole improve the borehole’s stress relief ability, drain out more gas, and enlarge the drainage range, which can reduce the number of the boreholes to achieve the same aim.

Keywords: drilling; stress relief; slot; BNE; coal and gas outburst

China is rich in coal, poor in oil and lacks gas. Coal provides 70\% of the energy, and it will take a half in 2050. But with the coal mine depth becoming deeper and the exploitation intensity increasing, the high ground stress and high gas pressure appear, which makes the coal and gas outburst become severer and severer and affects the safety in production\textsuperscript{[1]}. At present, gas drainage is the main method to prevent coal and gas outbursts. By draining out the gas and limiting the pressure and ground stress, stress relief zone with a certain length will be made to withstand the coal and gas outburst. The traditional method is using the borehole drilling to limit the ground stress and the gas pressure. But the engineering practice indicates that a borehole is not good enough to drain gas out in a large zone, and usually makes a lot of waste, which will lead to bad effects on production. So improving a borehole’s drainage range is very important. The High Pressure Abrasive Jet Slotting technique can create some slots around the boreholes\textsuperscript{[2,3]}, which can enlarge the stress relief zone and improve the gas drainage ability. But for a long time, the reason why a slot’s stress relief range is larger than that of a borehole has not been studied in detail. In the hope of making a contribution to the coal mine safety in production, the author studied this problem by numerical analysis, proposed the stress relief mechanism of drilling and slotting, and pointed out the essentiality of slotting at last.

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1. Theoretical analysis of the stress around a borehole

The rock is assumed to be homogeneous, isotropy and no creeping with the same original stress in every direction, and the cross section of a borehole being considered as a circle. After the borehole is drilled, the stress will redistribute around it. In the limited equilibrium area, the tangential stress $\sigma_t$ and the radial stress $\sigma_r$ from a point with a radius of $r$ to the borehole boundary can be expressed as follows $^{[4]}$:

$$\sigma_r = C \cot \phi \left[ \frac{r}{r_1} \frac{2 \sin \phi}{1 + \sin \phi} - 1 \right]$$ (1)

$$\sigma_t = C \cot \phi \left[ \frac{1 + \sin \phi}{1 - \sin \phi} \left( \frac{r}{r_1} \frac{2 \sin \phi}{1 + \sin \phi} \right) - 1 \right]$$ (2)

Where $\sigma_t$, $\sigma_r$—tangential and the radial stress in the limited equilibrium area; $C$, $\phi$ —friction and cohesion; $r_1$—radius of a borehole.

The radius of limited equilibrium area can be expressed as follow:

$$R = r_1 \left[ \frac{(yH + C \cot \phi)(1 - \sin \phi)}{C \cot \phi} \right]^{\frac{1 - \sin \phi}{2 \sin \phi}}$$ (3)

The stress of the limited equilibrium area is a horizontal static load, which can be shown in Fig.1.

![Stress around a borehole](image)

Fig. 1. Stress around a borehole

Fig. 1 shows that there is a stress concentration region around a borehole, which will limit the permeability of the rock and decrease the gas flow.

2. Numerical analysis of the stress around a borehole and the limitation in gas drainage

FLAC or FLAC3D is an explicit finite difference program for engineering mechanics computation. This program can simulate the behavior of structure of soil, rock or other materials undergoing plastic flow when their yield limits are reached. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. And this program has already been used widely in the mining field. Here, according to the actual situation, the Moore Coulomb model was chosen. Before the simulation, the density, bulk modulus, shear modulus, friction angle, cohesive strength, and tension should be given first. And the used average value is listed in Table.1$^{[5]}$.

| Parameter | Value |
|-----------|-------|
| Density   |       |
| Bulk Modulus |     |
| Shear Modulus |   |
| Friction Angle |  |
| Cohesive Strength |  |
| Tension   |       |

Table 1. Parameter values
In order to study the stress distribution around a borehole and gain the clear boundary, a three-dimensional model of 2×2×0.05 m is built. The ground stress is equal in every direction, and a borehole with the diameter of 90 mm is set in the center. The top face is defined as pressure boundary, and the others are applied as roller support boundary. The numerical model and boundary conditions are shown in Fig.2.

![Fig. 2. Numeric model and the boundary (a) Numerical model (b) Boundary](image)

The numeric results about stress distribution around the borehole are shown in Fig.3.

![Fig. 3. Stress around a borehole (a) Stress in z direction (b) Stress in x direction](image)

Fig. 3 shows that the stress concentration is generated around the borehole both in horizontal and vertical directions, and the stress is 1.33 times than that of the original, which indicates that the borehole not only relieves the stress, but also generates the stress concentration. Because the stress is equal in every direction, a stress concentration annulus is formed around the circle. The concentrated stress direction is normal to the gas flow direction. Several tests suggest that the stress concentration annulus in soft rock is larger than that in hard rock, and the borehole would become much smaller. Coal’s permeability, which is significantly affected by the stress, determines the gas drainage difficulty level. Previous studies show that coal permeability becomes lower when the
ground stress increases, and when the stress increases to some extent, there will be no gas flowing. The relationship between ground stress and permeability is shown in Fig.4[6].

![Figure 4: Relationship between ground stress and permeability](image)

Gas in the stress relief zone can be drained out easily, but the concentrated stress makes the gas flow alleyway closed or diminished, and makes the permeability become lower, which holds up the gas flowing and creates “Bottle Neck Effect” (BNE) restricting the gas drainage ability of a borehole. Besides, most of the gas around the borehole that can’t be drained out but keeps gas pressure high [7]. Previous studies show that enlarging the diameter of a borehole can enlarge the stress relief zone to some extent, but only enlarging the diameter can not improve a borehole’s drainage ability radically for the indelibility of BNE.

In low permeability coal seam, too many boreholes should be used to achieve the aim of perfect drainage, which makes this technique nearly impossible in engineering and economy aspects. So how to improve a borehole’s range is a very important problem which needs to be solved.

3. Comparing the slotting with drilling in stress relief

The High Pressure Water Jet Slotting technique creates several slots around the borehole to relieve the ground stress and improve the gas drainage ability by jetting high pressure water. If the coal is too hard, some abrasive should be applied to improve the incision ability and enlarge the depth and height of slots.

In order to study the stress relief of a slot and compare it to that of a borehole, a two-dimensional numerical model of 10×8 m was built up, and the ground stress was 8 MPa equal in every direction. A slot and a borehole were set on the same model at the same time. Pressure boundary condition was applied on the top, and roller supporting boundary condition was set on the other side. The numerical results about stress distribution are shown in Fig.5 which indicates the stress relief ability of a slot which excels that of a borehole.

![Figure 5: Comparison of a slot and a borehole in stress relief](image)

(a) Vertical stress (b) Horizontal stress
From Fig.5, we find that the slot breaks the stress concentration area and the BNE, and relieves the stress of the stress concentration area. At the same time, the slot is just like a thin protective layer in the coal seam, which makes the coal pressure above and blow the slot relieve and improves the permeability. By jetting high pressure water on the wall of the borehole, more coal is discharged from the borehole and the effect range is improved. The Fig.5 (a) and (b) show that the vertical stress and the horizontal stress are combined to make larger stress relief zone. While the high pressure water is jetted, the coal around the borehole is harassed, which will relieve the ground stress and make the gas flow out of the borehole.

In order to compare the stress relief of a slot with that of a borehole, the stress relief and concentration area are given in Table 2.

### Table 2. Comparison of the Stress relief Area of a Slot and that of a Borehole

| Stress relief area (m²) | Stress concentration area (m²) |
|-------------------------|-------------------------------|
| Relief ratio (%)        | Concentration ratio (%)       |
| Borehole    Slot Rate   Borehole Slot Rate |
| 60         0.01   2.077 208 1.6   0 0.18 / |
| 50         0.0126 2.428 193 1.5   0 0.278 / |
| 40         0.015  2.9   193 1.4   0.0008 0.439 549 |
| 30         0.019  3.62  190 1.3   0.0037 0.723 195 |
| 20         0.025  5    200 1.2   0.0086 1.4 163 |
| 10         0.046  9    196 1.1   0.023  3.6 157 |
| 5          0.094 22.52 240 1.05  0.048 7.77 162 |

In Table 2, in the relief ratio column, 60 means that the ground stress is relieved by 60%; rate, divided by the drilling area, represents the stress relief (concentration) area which is caused by the slot; in the concentration ratio column, 1.6 means the concentrated stress is 1.6 times as much as the original. It can be seen that the stress relief effect of a borehole is greatly trailed by a slot in the same condition, and the stress relief area caused by the slot is nearly 200 times than that of a borehole. However, the slot not only relieves the stress, but also causes stress concentration at the same time. The Table 5 shows that the stress relief area is far larger than the stress concentration area. The stress concentration is distributed around the end of the slot, and can’t form a closed area. The gas in the stress relief area can flow easily, and the gas in the stress concentration area can also be drained out slowly. From the analysis above, it can be seen that a slot mainly relieves the stress, and the stress relief effect excels the stress concentration. So by slotting some slots around a borehole to improve the drainage effect is possible.

### 4. Conclusion

1) Stress concentration phenomenon appears around a borehole, and forms the BNE to hold up gas flowing, which makes a borehole’s effect range much smaller.

2) By jetting high pressure water around a borehole to form some slots can break the BNE and improve the stress relief area.

3) The stress relief area caused by a slot is nearly 200 times than that of a borehole at the same condition. The stress relief area caused by a slot is far larger than the stress concentration.

### References

[1] L. Baiquan, C. Jianhua, Z. Cheng. Analysis on coal mine safety situation in China and its countermeasures. China Safety Science Journal, 16 (2006) 42-46.

[2] Z. Cheng. Rapid heading technology for mine gateway in seam with high gassy, low permeability and outburst[J]. Coal Science and Technology, 36 (2008) 62-64.

[3] L. Baoyu. Research and application of High Pressure Abrasive Jet in prevention coal and gas outburst[J]. Coal Mine Machinery. 28 (2007) 43-45.
[4] Q. Minggao. Control of rock pressure and rock[M]. Xuzhou: China University of Mining And Technology Press. 2003: 20-40.
[5] L. Shiping. Concise Guide for Rock Mechanics[M].Xuzhou: China University of Mining And Technology Press. 1986: 50-70.
[6] L. Baiquan. The impact of coal seam gas drainage and the analysis of the factors [J]. Safety in Coal Mines. 9 (1990) 30-35.
[7] W. Haijin. Numerical analysis of the pressure relief effect on slot at different stresses[J]. Journal of Mining & Safety Engineering. 26 (2009) 194-197.