Research and application of hydraulic fracturing borehole bag sealing technology

Dongping Zhou, Xuanlin Wang*, Chenye Guo, Junjie Zhou and Kai Wang
Chongqing Energy Investment Group Science & Technology Co., LTD, Chongqing 400061, China.

*Corresponding author e-mail: wangxuanlin@cumt.edu.cn

Abstract. Aiming at the problems existing in the sealing of fracturing boreholes using the regular bag sealing device in the conventional ‘two sealing and one injection’ process, this paper investigated a practical and reliable ZBQ-30/1.0 modified pneumatic grouting pump for coal mines, optimized the ‘B’ sealing material which was applied for the sealing of fracturing boreholes designed the ‘three sealing and two injection’ hole sealing device which was applied for the sealing of hydraulic fracturing boreholes, and finally carried out in Songzao Coal Mine. The results showed that the strength of the optimized ‘B’ sealing material was 14.64~15.43MPa, which was much higher than that of the regular extraction expansion sealing material. In addition, the hydraulic fracturing could withstand more than 20MPa, and the sealability was also well. This research implied the fixed-point sealing of hydraulic fracturing drilling can be carried out to save the sealing cost.

1. Introduction
With the increasing of coal mining, mining conditions are becoming more and more complex. The mines affiliated to Chongqing Energy Group are basically ‘high gas mines’ and ‘coal and gas outburst mines’, and the drainage system must be established. The sealing methods of gas drainage boreholes are mainly cement mortar and polymer foaming material presently, which have been popularized and applied in a certain period of time. However, the sealing process was complex, and the quality was poor, which was being security risks [1]. More specifically, the cement mortar was trend to shrinkage deformation after solidification, and there would be space between mortar precipitation and boreholes for the horizontal or near horizontal boreholes due to the gravity. The polymer foaming materials were mainly composed of polyurethane. As a result, the compressive strength was low, the compressibility was large, and the permeability was poor after foaming and expansion, which couldn’t prevent the creep of drilling and the formation of fracture air leakage channels. The sealing method of bag grouting was to plug two boreholes by using two bags placed on the sealing pipe. The pressure control on the grouting valve was opened, and the sealing material was injected between the two bags when the pressure reached the set value. There was a cement cylinder within a certain depth of the borehole after sealing, which provided a support for the drilling. The sealing device of bag grouting overcame the defects of the existing sealing, had high extraction efficiency, and made mining safety [2-5]. To solve the hole sealing of hydraulic fracturing drilling, this paper studied the technology of the bag-type hole sealing suitable for high-pressure hydraulic fracturing drilling, and formed an efficient and accurate sealing process, to improve
the sealing pressure capacity of hydraulic fracturing drilling and reduce the cost of hole sealing of hydraulic fracturing drilling.

2. Sealing equipment

Considering the dispersed characteristics and the variation range of sealing parameters of fracturing boreholes the equipment of a small volume, light weight, practical and reliable ZBQ-30/1.0 modified pneumatic grouting pump for coal mines (Figure 1) of Pingdingshan Antaihua Mine Safety Manufacturing Co., Ltd., was used for sealing grouting of fracturing boreholes in this study. The modified pneumatic grouting pump of ZBQ-30/1.0 were mainly composed of 1-mixing drum, 2-grouting assembly, 3-mixing device, 4-grouting pump, and 5-intake assembly. The power source of this device was the compressed air, and there was large grouting pressure with a small pressure in the grouting cylinder because of the greater area ratio between the pneumatic cylinders and grouting cylinder. The main technical parameters of ZBQ-30/1.0 modified pneumatic grouting pump were shown in Table 1.

![Structure diagram and physical picture](a) Structure diagram (b) Physical picture

**Figure 1.** ZBQ-30/1.0 modified pneumatic grouting pump for coal mine

| No. | Parameters                        | Units | Value  |
|-----|-----------------------------------|-------|--------|
| 1   | Rated intake pressure             | MPa   | 0.5    |
| 2   | Rated grout discharge pressure    | MPa   | 1.0    |
| 3   | Rated stop pressure               | MPa   | ≥1.8   |
| 4   | Discharge flow                    | L/min | 30     |
| 5   | Maximum intake pressure           | MPa   | 0.8    |
| 6   | Maximum discharge pressure        | MPa   | 3.0    |
| 7   | Rated gas consumption             | m³/min| 1.3    |
| 8   | Service temperature               | °C    | -15°C~60°C |
| 9   | Overall dimension (L×w×h)         | mm    | 1100×207×330 |

3. Sealing material ratio and optimization

In the process of drilling sealing, whether the initial solidification of cement-based expansive materials was too fast or too slow, it may lead to difficulties in grouting and insignificant expansion effect. And the expansion rate of materials was too large or too small would cause air leakage channels. The difficulty of grouting and slurry after grouting was determined by viscosity of materials. It was also difficult for expansive cement with different strength to bear the change of stress in the borehole[6, 7]. In view of the problems existing in traditional cement-based sealing materials, this paper developed a new cement-based curing expansion sealing material suitable for different fracturing drilling, as shown in Figure 2.
The new cement-based solidified expansion sealing material were mainly composed of cement-based aggregate, additives such as expansive agent, retarder, etc. and inorganic materials such as gypsum. Among them, the expansive agent which were composed of aluminum powder and CaO was mainly used to produce uniform and stable bubbles. The retarder (NaH₂PO₄) was mainly used to prolong the initial solidification time of the material and avoid the solidification of the material without expansion. The gypsum was mainly used to improve the strength of the material and adjust the fluidity of the material in the slurry state. The most significant feature of the new materials in this study was the expansion property that was markedly different from the cement materials. Therefore, this study defined a reasonable ratio of each additive of the new sealing material by researching and analyzing the changes of proportion of expansion agent, the proportion of retarder, and the ratio of water to material [8].

1) Analysis of Different Expansion Factors
(1) Analysis of expansive agent
The new sealing materials were prepared and configured with the proportion of expansive agent (mass ratio) of 0, 1.0%, 1.5% and 2.0% respectively according to the water-material ratio of 0.6. After stirring evenly, the 200mL test slurry was poured into the GB/T-12803 specification. The initial volume Vₛ of the material was read, and the initial and final solidification time were also recorded. It was defined the initial solidification when the slurry was not flowed at 45°, and the final solidification when the slurry was not flowed at 90°. The change of materials expansion rate with time with different proportion of expansion agent was shown in Figure 3. According to the requirements of borehole sealing for sealing materials, if the proportion of expansive agent was too small, it was difficult for the expansion; too large, there would be many voids in the material, reducing the strength of material. Therefore, it was considered that the cement expansion rate of 2%~6%, and the proportion of expansive agent of 1%~1.5% were reasonable expansion factor combined with Figure 3.

![](image)

(a) New materials  (b) Serous state  (c) Solidification state

**Figure 2.** ratio test of new plugging material

**Figure 3.** Effect of proportion of expansive agent on expansive properties of cement materials
(2) Effect of retarder

There was a direct effect between the initial solidification time of the sealing material and the borehole sealing, that was, the too long initial solidification time would lead to the loss of the slurry along the cracks in the borehole, and the too short initial solidification time would lead to the solidification of the slurry without full filling, and it would also cause a leakage channel between the material and the borehole wall. Therefore, the change of the expansion rate of materials with different proportions of retarders with time was researched through experiments, as shown in Figure 4. It could be seen from Figure 4 that the material expansion rate was a negative value without retarder and the material expansion rate increased to a small extent with the increase of the proportion of retarder. By observing the initial solidification and final solidification time, it could be found that the initial solidification and final solidification time of cement materials were prolonged with the increase of retarder, that was to achieve the retarding effect. The retarder had a little effect on the expansion rate of the material, but the strength of the material decreased with the increase of the retarder. According to the mechanical requirements of borehole sealing materials, it was appropriate to select the retarder with 1%~2%.

![Figure 4. Effect of the proportion of retarder on cement material](image)

2) Ratio of sealing material

It was required that the expansion rate of the material was less than 1.5% after solidification, and the compressive strength reached to 40% of the design strength after solidification for 24h, not less than 25MPa, and reached to 60% of the design strength after 3~5days as well without shrinkage under high pressure. For this reason, the type A (No.631) and type B (No.451) of micro-expansion high strength sealing materials were configured, and the relevant compressive strength tests of standard specimens were also carried out which was shown in Table 2. Meanwhile, it was found in the process of configuration that the type A and type B materials began to solidify and thicken after 15 minutes and 30 minutes, respectively.

| Sample | Size         | F/kN    | S          | P/MPa | Calculated strength /MPa |
|--------|--------------|---------|------------|-------|--------------------------|
| A-1    | 46.03*97.06  | 17.476  | 1664.07    | 10.50 | 21.00                    |
| A-2    | 46.36*99.76  | 18.542  | 1688.02    | 10.98 | 21.97                    |
| B-1    | 46.19*99.70  | 24.532  | 1675.66    | 14.64 | 29.28                    |
| B-2    | 46.70*93.31  | 26.434  | 1712.87    | 15.43 | 30.87                    |

From the Table 2, it could be seen that the compressive strength of type B was greater than that of type A which was between 325 cement and 425 cement, and the type B was much greater than that of the regular drainage borehole sealing material (9~10MPa). Therefore, type B sealing material was preferred. And the bonding force between type B sealing material and borehole wall and fractured steel pipe can meet the hydraulic fracturing strength of 30 MPa. When the sealing length is more than 28m by the pullout test.
4. Development and process design of sealing device

1) Development of Sealing Device

The existed technical problems in the application of fracturing borehole sealing in the regular bag sealing device according to the 'two sealing and one injection' process. First, the sealing length was large, causing a high pressure for the grouting pump and a reversed multiplied pressure in the pipe during grouting. As a result, the requirements for the bag, grouting pipe and blasting valve were higher. Second, the fracturing hole was built-in steel pipe with heavy material, the hole wall was irregularly smooth, and the conventional bag was easy to slide and break; Third, the traditional sealing materials cannot meet the strength requirements under high water pressure. Aiming at the above technical problems, the further improvement and optimization were made. First, the grouting pipe adopted aluminum plastic pipe (2.5MPa), the bag adopted pressure bearing design (2.5MPa), and the opening pressure of the pressure limiting blasting valve was designed to 2.0MPa to improve the pressure bearing capacity of the hole packer. Second, to solve the air displacement efficiency when the hole sealing section was long, three bags were designed and arranged to divide the hole sealing section into two sequential grouting sections, and the sieve holes were pre-processed fracturing steel pipes of the two middle grouting sections and the filter cloth was added. Third, anti-breaking wear-resistant bags with double-layer were designed to solve the anti-breaking problem of bags. Fourth, the special clamp fixed bag was used to solve the problem of bag sliding. Fifth, the necessary air or water pressure test with the grouting pressure less than 0.8MPa was carried out before the formal grouting, which was used to detect whether the device in the hole was intact.

The 'three sealing and two injection' bag sealing device suitable for hydraulic fracturing drilling was designed according to the improvement and optimization, as shown in Figure 5.

![Diagram](image)

**Figure 5.** ‘three plugging and two injection’ bag sealing device for fracturing hole

2) Principle of hole sealing technology

As shown in Figure 5, the hole sealing device components were connected at the design position of the fracturing steel pipe after the completion of the fracturing hole construction. There were three grouting parts in the hole sealing, including the internal space A of the first grouting pipe, the grouting section B between the hole and the middle bag, and the grouting section C between the middle and the bottom bag of the hole. The grouting sequence was controlled by the pressure limiting blasting valve and the hole grouting pipe. The whole grouting process was:

① The first grouting pipe filled the three bags to play the role of seat pressure bearing firstly, during which the air in each bag and part of water in the grout were filtered out the bag through the hole of the bag. ② The blasting valve was opened, and the grout was put into the grouting section C between the central bag and the bottom bag of the hole when the pressure in the space A of the bag reached to the action pressure of the pressure-limiting blasting valve. Among them, the water and air were filtered through the filter cloth II and the fractured steel pipe. At the same time, the grout flowed into the cracks under certain pressure, and the grouting pump stoped grouting, until the design pressure was reacheded. ③ The next grouting process was to put into the grouting section B between the hole and the central bag through the second grouting pipe, which was similar to that of the previous.
3) Sealing process

The whole sealing process included: ① Hole inspection. After the completion of drilling construction, blowing and suctioning the hole wall to ensure drilling unobstructed, if necessary advance pipe. ② Joint management. As shown in Figure 5, firstly, sent the sieve tube to the predetermined position at the bottom of the hole; Secondly, sent it in the steel pipes, and then the bags at the bottom, middle and mouth of the hole, which were all connected to the steel pipes for fracturing through hoops at the design positions, and every bag was connected through a 4-point aluminum plastic grouting pipe (its diameter is 15mm). Thirdly, a certain position in the middle of the two grouting section was connected with the fracturing steel pipe with the return air sieve hole, and the single layer return air bag was clamped by the clamp. ③ Gas injection test. After completing the connection of the hole sealing device, the smoothness of the hole sealing device was tested by injecting air, which the pressure was less than 1MPa, into the grouting pump. ④ Grouting. First of all, connected the first grouting pipe, and made three bags swelled up. The pressure limiting blasting valve would open when reaching the design pressure, followed by the grouting at the bottom of the hole, until the injection could not enter, and the automatic stop pump; Secondly, connected the second grouting pipe grouting, until the injection could not enter, and the automatic stop pump. ⑤ Sealing maintenance. After completing the sealing of the fracturing hole, it needs to be maintained for at least 72h before fracturing operation. It was also necessary to determine the sealing quality to ensure safety before operation.

5. Applications in the field

The sealing technology of hydraulic fracturing borehole bag was applied to the -300S Maokou roadway of three levels and one area in Songzao Coal Mine. The total length of the roadway was 660m, and the top K1 coal seam, K2b coal seam and K3b coal seam were not mined. The original gas content of K2b coal seam in this area was 13.06 m3/t, and the original gas pressure was 1.39MPa.

5.1. Design of Sealing Parameters

1) Borehole diameter and drainage diameter

Combined with the previous drainage situation in Songzao Coal Mine, the main parameters of bag-type hole sealing of fracturing borehole were as follows: the fracturing hole diameter was 94mm, and the fracturing pipe diameter was 50mm. Besides, the bag size matching custom processing.

2) Determination of Sealing Depth

The sealing depths of the fracturing boreholes and the extraction boreholes were different. Which the main difference was that the fracturing boreholes not only needed to meet the air tightness demands like extraction, but also the pressure bearing capacity of sealing materials to match with the pressure of the designed water injection. According to the stress analysis of sealing material of hydraulic fracturing borehole, the mechanical model of hydraulic fracturing sealing was established, and the calculation formula of reasonable sealing depth of through-layer and bedding fracturing boreholes was deduced as follows [9]:

\[
L_{\text{m}} = K_s \times \max \left\{ \frac{L_{m}}{} \right\}
\]

Where, \(D_1\) is the borehole diameter; \(D_2\) is the outer diameter of the fracturing pipe; \(K\) is the correction coefficient, which is generally about 2~5 according to the model statistical data; \(p_c\) is the maximum water pressure that the sealing material itself can withstand; \(K_s\) is the safety factor. which the value of bedding drilling is 1.5~2, and the value of cross-layer drilling is 1.3~1.5 according to practical experience; \(L_{m}\) is the theoretical economic hole sealing depth calculated according to Formulas along
with a certain material; $L_c$ is the width of fracture zone; and $L_p$ is the width of plastic zone. The type of fracturing boreholes implemented in this paper was through-layer drilling with small inclination angle. The reasonable sealing depth was 28 m by using the simulation software of hydraulic fracturing safety boundary conditions.

5.2. **Design of fracturing borehole**

The boreholes implemented in this paper were 1#–5# hydraulic fracturing holes in-300S Maokou Lane in No.3 level and No.1 area of Songzao Coal Mine. The hole spacing was 34.6–99.4m and the construction aperture was $\varnothing 94$ mm which were constructed by the ZDY-750 drilling rig. The main parameters were shown in Table 3.

**Table 3.** Designed parameters of hydraulic fracturing drilling

| Borehole number | Borehole diameter /mm | Angle with the center line of the drilling field /° | Dip angle /° | Drilling depth when meeting coal seam /m | Total drilling depth /m | Horizon of final hole | Remarks |
|-----------------|-----------------------|-----------------------------------------------|--------------|----------------------------------------|------------------------|----------------------|---------|
| 1#              | 94                    | 0                                             | 17.6         | 63.8                                   | 65                     | K2b                  | The positive hole is 1.5m away from the moraine head, and the opening height is 1.3m |
| 2#              | 94                    | 0                                             | 16.9         | 62.5                                   | 63                     | K2b                  | The positive hole is 1.5m away from the moraine head, and the opening height is 1.3m |
| 3#              | 94                    | 0                                             | 18.4         | 61.0                                   | 62                     | K2b                  | The positive hole is 1.5m away from the moraine head, and the opening height is 1.3m |
| 4#              | 94                    | 0                                             | 1            | 86.5                                   | 87.6                   | K2b                  | The positive hole is 1.5m away from the moraine head, and the opening height is 1.3m |
| 5#              | 94                    | 0                                             | 1.5          | 85.1                                   | 87.2                   | K2b                  | The positive hole is 1.5m away from the lower side of the roadway, and the opening height is 1.3m |

5.3. **Effect investigation**

Every fracturing borehole was conducted by hydraulic fracturing pressure and kept for 10 days after sealing. The sealing and fracturing of each fracturing borehole were shown in Table 4.
Table 4. Sealing and fracturing conditions of each fracturing hole

| Borehole number | Dip angle /° | Sealing length | Sealing position | Situation of fracturing | Pressure after holding for 10 days /MPa |
|-----------------|--------------|----------------|------------------|------------------------|----------------------------------------|
| 1#              | 17.6         | 30             | Start from the orifice | Water inflow: 240 | Fracturing process: There is no obvious water leakage during fracturing | 2.1 |
| 2#              | 16.9         | 30             | Starting from the floor of K1 coal seam | Maximum pressure: 22.34 |                                           | 1.7 |
| 3#              | 18.4         | 30             | Start from the orifice | Fracturing process: There is no obvious water leakage during fracturing |                                           | 2.9 |
| 4#              | 1.0          | 30             | Start from the orifice | Pressure: 22.1 |                                           | 3.2 |
| 5#              | 1.5          | 30             | Starting from the floor of K1 coal seam | Pressure: 21.4 |                                           | 4.0 |

Table 4 showed that the maximum pressure of fracturing boreholes with near horizontal fracturing test boreholes and fracturing boreholes with dip angle less than 20° was more than 20 MPa when conducted by the ‘three sealing and two injection’ with microexpansion and high strength. There was no obvious leakage in the fracturing process and the pressure was greater than 1 MPa along with 10 days of pressure retention, indicating that the sealing effect was good. Furthermore, the fixed-point sealing was preliminarily realized to reduce the cost to a certain extent by comparing different sealing positions.

6. Conclusions

(1) The ‘three sealing and two injection’ bag sealing device was developed, which could be used for hydraulic fracturing borehole sealing. The 1%~1.5% expansion agent and 1%~2% retarder are suitable for the sealing material of fracturing drilling.

(2) The compressive strength of the sealing material of ‘B-type’ was 14.64~15.43 MPa, which was much higher than that of the regular extraction expansion sealing material (9~10MPa). And the bonding force between the sealing material and the borehole wall and the fractured steel pipe could meet the strength of the fracturing operation when the sealing length was greater than 28m.

(3) The bag fracturing borehole could bear pressure greater than 20MPa and the pressure in the borehole was greater than 1MPa after 10 days, and the sealing property was good when conducted by the ‘three sealing and two injection’ with ‘B-type’ sealing material.

Acknowledgments

This research was supported by the Science and technology innovation leading talent support plan of Chongqing (No.CSTCCXLJRC201916). The authors are grateful for these supports.

References

[1] Hao Ruiyun. Research and Application of Hydraulic Fracturing Sealing Technology in Soft and Thick Coal Seam [J]. Shanxi Coal, 2020, 40(3):39-42.
[2] Liu Weizhi, Li Wenbin. Application of Self-plugging on Both Ends Sealing Bag Process in Gas Bedding Drainage Boreholes [J]. Coal Geology of China, 2020,32(3):63-65.
[3] Li Tao. Application of bag sealing method in sealing of gas extraction [J]. Shandong Coal Technology, 2017(10):86-87+91.
[4] Li Hui, Guo Shaoshuai, Su Xun. Design and application of the filtered water type sealing device with pressure grouting by drilling cuttings backfilled borehole[J]. Journal of Henan Polytechnic University (Natural Science), 2017, 36(6):22-26+48.
[5] Wang Zhenfeng, Zhou Ying, Sun Yuning, et al. Novel gas extraction borehole grouting sealing method and sealing mechanism [J]. Journal of China Coal Society, 2015, 40(3): 588-595.

[6] Fang Qiancheng, Huang Yuanyue, Liu Xuefu. Study on gas drainage borehole sealing technique for Tanjiachong coal mine [J]. China Coal, 2012, 38(2): 106-108.

[7] Zhou Fubao, Sun Yuning, Li Haijian, Yu Guofeng. Research on the theoretical model and engineering technology of the coal seam gas drainage hole sealing [J]. Journal of Chinese University of Mining & Technology, 2016, 45(3): 433-439.

[8] Sun Wenbiao, Li Honghang, Dong Xinzhaor, et al. Properties and swelling mechanism of hole sealing material [J]. Nonferrous Metals, 2010, 62(6): 73-77.

[9] Chao Z, Baiquan L, Yan Z, et al. Study on "fracturing-sealing" integration technology based on high-energy gas fracturing in single seam with high gas and low air permeability [J]. International Journal of Mining Science and Technology, 2013(6): 841-846.