Research and practice of high-speed spiral composite drilling technology in complex and weak coal seams

Yubo Song
CCTEG Xi'an Research Institute (Group) Co., Ltd., Xi'an 710077, China

Abstract: In response to the difficult slag discharge and low hole formation rate encountered in the Wangpo Coal Mine, a study was conducted on high-speed spiral composite drilling technology. This study was integrated with the performance characteristics of the ZDY6000LR-type high-speed pit rig, resulting in the design of drill bits in three different specifications: Φ110/63.5 mm, Φ95/60.3 mm, and Φ88/50 mm. Additionally, the study optimized the three-wing drill pipe's feed speed, rotation speed, and airflow volume. The industrial field test, conducted on the 3206 working face of the Wangpo Coal Mine, resulted in the design of three drill bit combinations that exhibited high strength and stiffness. This design improvement led to enhanced hole integrity, elevated slag removal efficiency, and extended service life for both the drill pipe and bit. The high-speed spiral composite drilling technology, alongside the supporting equipment, effectively addresses the challenges of slag discharge and nozzle top drilling encountered during operations. It significantly improves the deep hole drilling rate, achieving a drilling depth of over 100 m with a success rate exceeding 70%. This technology provides vital support for the extraction of gas from coal seams within the mine. Notably, the Φ95/60.3 mm screw pipe and its corresponding drill bit demonstrated the optimal hole-forming effect, with an average hole depth of 111.2 m and a hole formation rate of 90.9%. These findings offer valuable insights for drilling operations under similar conditions of complex and weak coal seams.

1 Introduction

Mine gas poses a significant hazard, severely impacting the safety of mining operations [1-2]. As coal mining activities intensify, the emission of mine gas is increasing [3]. In recent years, the advancement of drilling technology and the subsequent development of drilling equipment for underground mine tunnels have become crucial in managing mine disasters, yielding positive results [4-5]. In China, high-gas mines frequently encounter complex and weak coal seams characterized by crushed coal layers, low permeability, high gas content, high gas pressure, and significant challenges in drilling [6]. Although various drilling equipment and techniques have been developed and successfully implemented [7-10], the variability in coal seam geological conditions continues to complicate drilling operations along the coal seam. Consequently, gas extraction from weak coal seams typically relies on short drilling holes for preliminary gas pumping, which suffers from limited coverage, high overall costs, and low equipment efficiency. Addressing the challenges associated with complex weak coal seams, this study explores the process and combination of spiral drilling to enhance the efficiency and success rate of hole formation in downstream drilling operations.

2 Overview of the mine

The Wangpo Coal Mine, situated in the Qinshui Basin, boasts a designed production capacity of 3 million tons per year. It is characterized by a high coal seam gas content, classifying it as a high-gas mine. The coal seams within the mine exhibit stability, with gentle inclinations and simple structures. The primary coal seam, identified as the No. 3 coal within the Shanxi Formation, has an average burial depth of approximately 500 m and an average thickness of 5.76 m. The coal seams are notably underdeveloped, resulting in a significantly reduced bearing capacity, which frequently complicates the drilling and construction process by making hole formation challenging. In response to these conditions, this study investigates high-speed spiral composite drilling techniques and designs various drilling combinations. An experimental study was conducted at the 3206 working face of the Wangpo Coal Mine to evaluate the efficacy of these techniques.

3 High-speed spiral composite drilling technology

The complex and weak coal seams encountered in high-gas mines are characterized by low mechanical strength, high gas content, and high gas pressure, which complicate
the drilling process, leading to the potential scrapping of drills and serious safety hazards. Addressing the issues of hole collapse, inadvertent hole deviation, and the inadequate slag removal capacity of the drill pipe, this study adopts a screw composite drilling technology. This technology primarily utilizes high-speed spiral slag removal, supplemented by pneumatic auxiliary powder discharge, to effectively address the challenges encountered during drilling operations in the Wangpo Coal Mine.

3.1 Spiral drilling

Spiral drilling is a drilling technique that transmits power from the drill machine to the bit at the bottom of the hole via a screw drill rod, facilitating rock-breaking drilling. The rock debris generated at the bottom and sides of the hole is transported upwards by the rotation of the screw drill rod's blade. The advantages of near-horizontal spiral drilling include: (1) The drill screw pipe makes contact only through the drill pipe blade and the wall of the drilling hole, minimizing disturbance to the wall and promoting the stability of the drilling hole wall in weak coal formations. (2) The high rotational speed of the drill screw enables timely discharge of coal powder produced within the hole, ensuring unobstructed flow and effectively reducing accidents within the hole.

3.2 Discharge analysis of high-speed screw drilling

During the drilling of near-horizontal holes in coal mines, the cinder accumulates on the lower side of the hole wall due to gravity and is transported towards the hole by the blade. In the process of high-speed spiral drilling, the cinder, constrained by the wall of the hole, experiences centrifugal force resulting from the high-speed rotation of the drill pipe. This force compacts the cinder under significant centrifugal action.

**Figure 1.** Schematic diagram of the high-speed spiral powder discharge movement

Within the coal cinder, there is no relative movement, and the motion of the coal cinder can be segmented into the traction speed $V_1$ of the drill pipe's rotation and the relative sliding speed $V_2$ between the coal cinder and the spiral groove. The resultant speed is directed axially along the drill pipe towards the hole, illustrating the slag discharge movement as depicted in Figure 1. The motor synthesis can be represented as follows:

$$V_{close} = \frac{n \pi R_0}{30} \tan \beta$$  \hspace{1cm} (1)

$R_0$: The distance from the microcore to the center of the drill rod (m);
$n$: The rotational speed of the drill (r/min);
$\beta$: The helical ascent angle at point O (°).

From Equation 1, it is evident that the speed of cinder discharge is directly proportional to the rotational speed of the drill pipe.

**Figure 2.** Cross-sectional schematic of spiral drill pipe discharging powder

As illustrated in Figure 2, the gravitational pull ensures that the drill pipe's weight remains closer to the lower side of the borehole wall. Consequently, during high-speed rotation, a portion of the material may escape from the spiral groove due to the lack of support. The disparity between the diameters of the drill bit and the drill pipe increases the annular space gap, thereby enlarging the space through which material can escape. In practical applications, the drill bit's diameter typically exceeds that of the drill pipe by merely 10 mm. This results in a
minimal escape fraction, with the majority of the debris being expelled outward by the rotational force of the drill pipe.

### 3.3 Air drilling

Air circulation drilling is a technique that employs compressed air, conveyed through the drill pipe, to generate a high-velocity airflow within the borehole, which facilitates the removal of debris. Concurrently, this process can expedite the evacuation of gases from the borehole. In the context of drilling within complex and soft coal seams, pneumatic dust extraction offers several advantages: (1) The high-velocity airflow that is directed to the bottom of the hole via the drill pipe serves to cool the drill bit, mitigating the risk of toxic and hazardous gas emissions that may arise from coal combustion during prolonged drilling operations. (2) Such airflow is also effective in clearing pulverized coal that may be suspended in the borehole, preventing blockages at the drill bit that can occur due to an excess of fine coal particles. (3) Additionally, the high-velocity airflow exerts minimal impact on the borehole walls, reducing the likelihood of wall instability.

### 3.4 High-speed spiral composite drilling

High-speed spiral composite drilling technology harnesses the high rotational speed of a drill to drive a screw drill, utilizing this primary power source for slag discharge through a high-speed rotational process and supplementing it with pressurized air to expel coal dust from the borehole. The main attributes of high-speed spiral composite drilling include: (1) It amalgamates the benefits of spiral drilling with air drilling, substantially enhancing the hole formation rate during drilling operations. (2) Through the precise management of the drill pipe's speed and airflow, the technology enables timely evacuation of rock powder from the borehole, minimizes in-hole accumulation, and significantly boosts slag removal efficiency. (3) The high-velocity airflow not only cools the drill bit but also rapidly removes toxic gases and vapors from the borehole, preventing gas build-up and subsequently reducing the incidence of drilling-related accidents.

### 4 Improvement and design of drilling tools

In alignment with the technical specifications of high-speed spiral drilling and the characteristics of the coal seam, three drilling assemblies have been engineered:

1. A Φ110/63.5mm screw drill pipe combined with a Φ120mm three-wing taper polycrystalline diamond compact (PDC) bit, as illustrated in Figures 3 and 4. This setup yields a larger borehole diameter, which is advantageous for gas extraction. The drill rod is designed with a robust, break-resistant double-head screw structure, enhancing slag removal efficiency. The three-wing cone scraper PDC drill is durable, withstanding damage in the coal seam, thus extending its service life, facilitating smooth powder discharge, and contributing to efficient hole formation.

2. A Φ95/60.3mm screw drill pipe paired with a Φ110mm three-wing taper PDC bit, as shown in Figure 5. The drill rod features a wide blade structure that lessens the impact on the borehole wall. The expansive spiral blade is capable of expelling large volumes of coal powder and chunks, ensuring clear passage within the borehole.

3. A Φ88/50mm screw drill pipe coupled with a Φ98mm three-wing taper PDC bit, presented in Figure 6. The smaller diameter of the hole is advantageous for hole formation. The drill pipe, with its double-headed screw structure, improves slag discharge efficiency.

The research demonstrates that utilizing drilling tools equipped with wide blades and a single-head spiral configuration significantly enhances drilling efficiency. The wide blade contributes to the stability of the borehole wall, while the single-head spiral design facilitates the expulsion of large and granular coal powder. Nonetheless, the combined application of these drilling tools presents challenges, notably the wear and tear of “U” type pins and nuts. Furthermore, the conventional three-wing alloy bit exhibits limited rock-breaking capabilities and is prone to rapid wear, necessitating enhancements. To address the pronounced wear issues associated with drill pipe usage, both the design and materials have been optimized. From a design perspective, while maintaining the structural
integrity of the drill pipe joint, the inner through-hole diameter is judiciously minimized, and the shoulder depth is increased. This adjustment ensures the nut is more effectively shielded by the screw groove. Material-wise, spring steel, characterized by its high tensile strength, high elastic limit, and superior fatigue resistance, has been chosen to supplant manganese steel. This selection is aimed at mitigating the swift wear experienced by the three-wing alloy bit. The introduction of the three-wing scraper PDC bit, known for its durability during drilling operations, aids in efficient hole formation. These enhancements to the drilling assembly not only minimize mechanical wear during construction but also significantly prolong the equipment's operational lifespan.

5 Control of drilling process parameters

5.1 Feed speed

Feed speed significantly impacts the efficacy of high-speed spiral drilling technology. Achieving an optimal feed speed is crucial for efficient drilling operations. The appropriate feed speed must adhere to the following equation (Equation 2):

\[ \frac{\pi D^2}{4} v \leq W \]

\[ v \leq W \]

W: Powder discharge volume (m³);
D: Diameter of the drill bit (m).

In practice, the feed speed should be adjusted to correspond with the coal rock layer's strength, preventing excessive coal dust production and accumulation within the borehole, especially when drilling through softer rock layers. An abrupt increase in drill torque is often indicative of a collapse hole burying the drill. Under such circumstances, drilling should be halted immediately, the drilling tool retracted repeatedly to facilitate the expulsion of accumulated coal dust, and drilling resumed only once the borehole is clear.

5.2 Drill pipe speed

The speed of the drill pipe significantly influences the efficiency of high-speed spiral drilling. Typically, the drill pipe's speed should be synchronized with the feed speed. If the discharge of powder within the borehole is not smooth, drilling should be immediately halted. The operator should then employ a back-and-forth sliding motion with the drill pipe's rotation to clear the coal powder before it is safe to resume drilling. In cases of coal instability, borehole collapse, the presence of large slag particles, or abnormal gas pressure — to prevent accidents — reversing the screw direction to agitate the coal within the hole, accompanied by rotational movements of the drill pipe, can effectively remove the pulverized coal and restore dynamic balance within the borehole. As the drilling progresses, the capability of the drill pipe to remove powder diminishes, leading to increased accumulation of coal debris and making the removal more challenging. To ensure effective drilling, a method involving a gradual increase in rotational speed, coupled with periodic reverse rotations and sweeping actions, is recommended to reduce borehole resistance.

5.3 Air volume

In air drilling operations, the volume of air serves as an auxiliary means for slag removal and gas expulsion from the borehole. The high-pressure airflow suspends the pulverized coal, which is then expelled from the hole when the airflow velocity exceeds the coal's free suspension speed. Empirical evidence suggests a direct correlation between the required air volume and drilling velocity. To ensure efficient removal of pulverized coal and maintain a clear path for the drill bit, airflow must adhere to non-clogging conditions. The optimal wind speed for air drilling is determined by the following equation:

\[ v > v_b = 1.3v_n m^{0.25} \]

\[ v_b \]: Critical wind speed to prevent clogging (m/s);
\[ m \]: Mass ratio of pulverized coal flow to air flow.

During high-speed spiral composite drilling, especially in soft and fragmented coal conditions that produce substantial amounts of pulverized coal, the rotational pressure is maintained between 5-18 MPa. Feed speed is adjusted to decrease as pressure increases, with rotation speeds regulated between 80-300 r/min. A stable drilling pressure necessitates a consistent speed, which should be reduced as borehole depth increases. An appropriate air volume facilitates the expulsion of pulverized material from the borehole. Insufficient air volume leads to inadequate removal of coal dust, causing accumulation, whereas excessive air volume can destabilize the borehole walls due to air turbulence. Therefore, the air volume should be maintained at 50-60% of that used in conventional air drilling.

6 Selection of drilling equipment

To address the challenges of drilling through complex and weak coal seams at Wangpo Coal Mine, specifically to enhance the drill rig's capability to navigate through zones of crushing and high-stress concentration, the ZDY6000LR drilling rig was selected for this study. This drilling rig boasts high-speed, high-power, and high-torque capabilities, with a maximum torque of 6000 Nm and a top speed of 400 r/min. It is equipped with a significant lifting pressure, which is particularly beneficial in instances of drilling and borehole collapse, as it enables the use of strong powder actuation to augment construction capabilities. The drilling rig features an amplitude variation mechanism that offers a wide range of adjustments, simplifying operations and providing strong adaptability to different drilling conditions. It is designed to automatically switch to a lifting state in response to resistance changes within the borehole, effectively preventing stuck and buried drill incidents and thereby enhancing construction efficiency. Operation of the drill rig is streamlined through a single-handle control, offering ease of use, a wide operational range, and a centralizer that
minimizes friction between the drill pipe during intense drilling activities. The hydraulic system employs constant power and pressure-variable technology to mitigate system overheating. The main technical parameters of the drilling rig are summarized in Table 1.

**Table 1 Main technical parameters of the drilling rig of ZDY6000LR**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Appellation</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall unit</td>
<td>Appearance / m</td>
<td>4.46×1.25×2.12</td>
</tr>
<tr>
<td></td>
<td>Drill mass / kg</td>
<td>8000</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Nominal torque / Nm</td>
<td>6000~700</td>
</tr>
<tr>
<td></td>
<td>Rated rotation speed / r/min</td>
<td>80~400</td>
</tr>
<tr>
<td></td>
<td>Spindle inclination / °</td>
<td>-30~+30</td>
</tr>
<tr>
<td>Feed mechanism</td>
<td>Maximum feed / pull / kN</td>
<td>140/190</td>
</tr>
<tr>
<td></td>
<td>Feed in / pull trip / mm</td>
<td>1300</td>
</tr>
<tr>
<td>Pumping station</td>
<td>Power rating / kW</td>
<td>90</td>
</tr>
</tbody>
</table>

7 Field industrial test

7.1 Overview of the test working face

The area selected for drilling construction is the 3206 working face of Wangpo Coal Mine. Located in the south of the four centralized lanes within the second mining area, the 3206 working face is characterized as an island working face. This face spans 2092 m in length and 147 m in width, with a cutting length of 153 m. The average coal seam thickness is 4.45 m, with geological reserves estimated at approximately 2.051 million tons. The working face encompasses three roadways: the 3206 transportation channel, the 3206 return air channel, and the 3206 high drainage channel, with the 3206 return air channel situated in the south wing of the second mining area.

7.2 Drilling design

The drilling site is positioned within the return air channel of the 3206 working face. Given the dimensions of the roadway and the ZDY6000LR drill, there is no necessity for a dedicated drilling site setup; drilling operations can be conducted directly within the roadway. Boreholes are planned to be drilled in parallel alignment along the roadway, extending vertically towards the 3206 working face. To account for the coal seam's stability and permeability, the drilling spacing is set at 4 meters, with an opening inclination ranging from 0 to -10 degrees relative to the coal seam dip. The design specifies hole depths of 132 m, with borehole diameters of Φ 98 mm, Φ110 mm, and Φ120 mm, Drill gap4m. The drilling design parameters are summarized in Table 2. The drilling plane layout is shown in Figure 7.

**Table 2 Design parameters of coal seam bedding drilling**

<table>
<thead>
<tr>
<th>Drill class</th>
<th>Trompil dip (°)</th>
<th>Trompil position (°)</th>
<th>Design hole depth (m)</th>
<th>Drill gap (m)</th>
<th>Trompil altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along the layer drill</td>
<td>0°~10°</td>
<td>285.35</td>
<td>132</td>
<td>4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Figure 7.** The drilling plan layout

7.3 Drilling and construction technology

7.3.1 Selection of drilling tool combination

Based on the coal seam conditions, drilling capabilities, and the designed drilling parameters for the 3206 working face, the following drilling tool combinations have been selected for this study:

For the hole section: After initiating the hole, proceed with a Φ 98 mm drill bit and active drill pipe. Following this step, employ the re-expansion bit in a step-by-step manner to widen the hole to its final diameter. If local conditions allow, utilize a Φ 300 mm drill bit coupled with...
a Φ 114/260 mm large screw drill rod for a single expansion to the final aperture.

For the bare section: Options include a Φ 98 mm triple drill bit with a Φ 88/50 mm screw drill rod, a Φ 110 mm triple drill bit with a Φ 95/60.3 mm screw drill rod, or a Φ 120 mm triple drill bit with a Φ 110/63.5 mm screw drill rod.

7.3.2 Drilling construction process

Despite the utilization of various drilling tool combinations for test drilling, the fundamental construction process remains consistent. This involves the sequence of initiating the hole, expanding it, conducting pipe grouting, installing the final hole apparatus, performing drilling operations, sealing the hole, and implementing continuous pumping.

Opening and expanding the hole: During drilling operations, strict adherence to the design parameters is maintained, ensuring the opening inclination and azimuth angle remain within ±2 degrees of the design specifications. The opening process should be characterized by stability, employing a gentle pressure and slow rotation principle. For expansion, a guided drill is used to maintain a consistent speed, ensuring a smooth borehole wall. Post-expansion, the hole is cleared to remove any accumulated rock powder. The selection of the opening point should strategically avoid areas near coal wall support anchor cables.

Installing the lower hole mouth tube: The primary objective here is to safeguard the stability of the hole section. This is achieved in conjunction with installing the hole apparatus for gas drainage and dust removal. A Φ159 mm × 1.5 m steel casing is selected for this purpose, ensuring a tight connection at the hole tube joint, which is then manually advanced into the borehole. The exposed section of the tube should measure 0.2 m, with the gap between the tube and borehole wall sealed using polyurethane.

Installing the orifice device: The device is secured using pipe hoops or flanges at the hole's four ports, which are connected to the gas drainage negative pressure pipe. The lower slag outlet links to the dust collector-steam separator, with the separator's upper end attached to the negative pressure pipe.

Normal drilling operations: During standard drilling, it is crucial to monitor slag return at the hole mouth and adhere to specified drilling parameters. In the event of any anomalies, drilling should be paused. Instead, employ the drilling tool to sweep the hole and evacuate slag, ensuring that pressure parameters are normalized before resuming drilling.

Completing the final hole and pumping: Upon reaching the designated depth, the drilling tool and orifice device are removed, the hole guard pipe is extracted, and the hole is then continuously sealed.

7.4 Test conditions

The field test encompassed 23 boreholes, achieving a total drilling length of 2022 m, with an average hole depth of 87.9 m. The deepest single borehole reached 132 m, and 73.9% of the boreholes exceeded 100 m in depth. The drilling construction outcomes are detailed in Table 3, while the comprehensive drilling plan is illustrated in Figure 8.

<table>
<thead>
<tr>
<th>Hole number</th>
<th>Inclination angle (°)</th>
<th>Orientation (°)</th>
<th>Depth (m)</th>
<th>Diameter (mm)</th>
<th>Completion reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>2</td>
<td>285.35</td>
<td>23</td>
<td>98</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>2#</td>
<td>3</td>
<td>285.35</td>
<td>107</td>
<td>98</td>
<td>Qualification met</td>
</tr>
<tr>
<td>3#</td>
<td>0</td>
<td>285.35</td>
<td>23</td>
<td>98</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>4#</td>
<td>-2</td>
<td>285.35</td>
<td>103</td>
<td>98</td>
<td>Qualification met</td>
</tr>
<tr>
<td>5#</td>
<td>0</td>
<td>285.35</td>
<td>8</td>
<td>98</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>6#</td>
<td>5</td>
<td>285.35</td>
<td>11</td>
<td>98</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>7#</td>
<td>5</td>
<td>285.35</td>
<td>100</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>8#</td>
<td>3</td>
<td>285.35</td>
<td>102</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>9#</td>
<td>0</td>
<td>285.35</td>
<td>101</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>10#</td>
<td>-2</td>
<td>285.35</td>
<td>104</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>11#</td>
<td>-4</td>
<td>285.35</td>
<td>101</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>12#</td>
<td>-3</td>
<td>285.35</td>
<td>110</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>13#</td>
<td>4</td>
<td>285.35</td>
<td>100</td>
<td>120</td>
<td>Qualification met</td>
</tr>
<tr>
<td>14#</td>
<td>0</td>
<td>285.35</td>
<td>121</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>15#</td>
<td>-5</td>
<td>285.35</td>
<td>119</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>16#</td>
<td>-1</td>
<td>285.35</td>
<td>112</td>
<td>120</td>
<td>Qualification met</td>
</tr>
<tr>
<td>17#</td>
<td>-1</td>
<td>285.35</td>
<td>40</td>
<td>120</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>18#</td>
<td>-2</td>
<td>285.35</td>
<td>115</td>
<td>120</td>
<td>Qualification met</td>
</tr>
<tr>
<td>19#</td>
<td>-2</td>
<td>285.35</td>
<td>101</td>
<td>120</td>
<td>Qualification met</td>
</tr>
<tr>
<td>20#</td>
<td>-2</td>
<td>285.35</td>
<td>122</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>21#</td>
<td>-5</td>
<td>285.35</td>
<td>132</td>
<td>110</td>
<td>Qualification met</td>
</tr>
<tr>
<td>22#</td>
<td>-4</td>
<td>285.35</td>
<td>67</td>
<td>110</td>
<td>Hole collapse</td>
</tr>
<tr>
<td>23#</td>
<td>-6</td>
<td>285.35</td>
<td>100</td>
<td>120</td>
<td>Qualification met</td>
</tr>
</tbody>
</table>
In this test, six boreholes with a diameter of $\Phi 98\text{mm}$ were drilled, achieving an average hole depth of 45.8 m and a hole formation rate of 33.3%. Additionally, eleven $\Phi 110\text{ mm}$ boreholes were completed, with an average depth of 111.2 m and a formation rate of 90.9%. Furthermore, six boreholes of $\Phi 120\text{ mm}$ were drilled, resulting in an average depth of 94.7 m and a formation rate of 83.3%. It has been determined that the rate of borehole formation is influenced not only by the conditions of the coal seam but also by the diameter of the borehole.

The substantial volume of slag generated within the coal seam boreholes highlights the limited slag discharge capacity of drills with smaller apertures, due to the narrow space between the drill rod and the borehole wall. This limitation hampers timely slag removal, especially when holes collapse or pulverized coal accumulates, potentially leading to buried drills and complicating hole formation. Drilling with larger apertures addresses this issue effectively; however, care must be taken to prevent the borehole diameter from becoming excessively large, which could destabilize the borehole wall. Based on the outcomes of these tests, selecting either a $\Phi 95/60.3\text{ mm}$ screw rod with a $\Phi 110\text{ mm}$ three-wing cone scraper PDC drill bit or a $\Phi 120\text{ mm}$ three-wing cone scraper PDC drill bit for subsequent construction activities is advisable. This choice aims to enhance the rate of hole formation and ensure the effectiveness of the construction process.

**8 Conclusion**

(1) Addressing the challenges of slag discharge and the low rate of hole formation in complex and weak coal seams, this study introduces high-speed spiral composite drilling technology. It explores critical parameters, including feed speed, drill pipe speed, and air volume, delineating the optimal range of construction parameters for the drilling process. This method leverages the high-speed rotation of the drill screw combined with pressurized air to expel the powder, enhancing the efficiency of powder discharge and reducing resistance within the borehole.

(2) To fulfill drilling requirements, three tool combinations have been developed: a $\Phi 98\text{ mm}$ three-wing drill with a $\Phi 88/50\text{ mm}$ screw drill, a $\Phi 110\text{ mm}$ three-wing cone scraper PDC drill with a $\Phi 95/60.3\text{ mm}$ drill pipe, and a $\Phi 120\text{ mm}$ three-wing cone scraper PDC drill with a $\Phi 110/63.5\text{ mm}$ screw drill. Improvements to the drill pipe material and the selection of the three-wing cone scraper PDC drill have notably extended the lifespan of drilling tools. The employment of the ZDY6000LR type drilling rig has proven to effectively meet the demands of deep-hole drilling.

(3) Field industrial testing at Wangpo Coal Mine demonstrates a hole formation rate exceeding 70%. Larger aperture holes have been shown to effectively address the issues of challenging slag removal and embedment during construction. For subsequent construction phases, it is recommended to use a combination of a $\Phi 110\text{ mm}$ three-wing cone scraper PDC drill with a $\Phi 95/60.3\text{ mm}$ screw drill or a $\Phi 120\text{ mm}$ three-wing cone scraper PDC drill with a $\Phi 110/63.5\text{ mm}$ screw drill, aiming to improve the hole formation rate.

**Acknowledgment**

This work was supported by the Shaanxi Province 2023 Key Research and Development Plan, entitled "Research on safe and efficient hole forming technology of coal mine underground roof" (Project No.: 2023-YBGY-319).

**References**


4. Cai, B. (2023) Study on the characteristics and prevention measures of geological disasters in coal


