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# Slicing filling principle and repeated mining key technology for extra-thick coal seams in small coal pit destroyed areas

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Aiming to solve the problems of the efficiency of repeated mining technique in small coal pit destroyed areas, the principle of slicing filling and repeated mining was applied, and techniques were proposed for slicing grouting filling in small coal pit destroyed areas and reconstruction of cutting layers, spacer layers and support layers. Grouting filling eliminates potential safety hazards in small coal pit destroyed areas. Simultaneously, a complete area which is best for normal mining was built; the thickness and intensity of each layer were determined, and the filling materials and ratio of each layer were also provided. Field application proved that slicing filling and repeated mining achieves good results in safely recycled coal seams in small coal pit destroyed areas with high efficiency. Although the cost of coal is increased by 1.21 CNY (Chinese Yuan) per ton, the approach provides an innovative method for the safe and efficient backfill mining of coal resources in small coal pit destroyed areas and waste utilization in a mining area.

**Keywords:** Extra-thick coal seam, Small coal pit destroyed area, Slicing filling, Backfill mining technology.

## INTRODUCTION

Driven by market interests, some small coal pits conduct predatory coal mining operations which destroy the integrity of the entire coalfield [1-3]. According to the second coalfield predication in our country, the coal resources in Xinjiang, Inner Mongolia, Shanxi and Shaanxi account for 81.3% of the total volume across the country. However, in most mining areas in the northwest regions, small coal pit mining is damaging mining fields especially in Shanxi and Inner Mongolia which have abundant coal resources of high quality [4-6]. As is well known, the areas in the whole coal field destroyed by small coal pit mining activities are called destroyed areas in small coal pit mining, including both mined-out areas and residual coal layer.

Restricted by regional economies and less advanced techniques, the mining technique used in small coal pits is not well developed, including room and pillar mining and alley mining with a recovery rate of less than 20% [7,8]. Accidents such as water inrush, fires, gas explosions and roof collapses are major potential hazards threatening coal mine safety production. In recent years, injuries caused by permeable small coal pits are often seen, especially in mined-out areas [9-12]. Integral coal fields are badly damaged locally by small coal pit mining which also seriously affects the normal layout of large-scale mines working face. Small coal pit destroyed areas are high-risk and inefficient in recycling coal resources and the backfill mining in small coal pit destroyed areas is still in the exploration stage without reliable mining technology and theory.

Therefore, it is necessary to study the technique of restoring small coal pit destroyed areas by grouting filling, and then employing normal mining methods that are taking conventional mining methods to exploit in the working face. Although there has been a lot of research conducted by experts from home and abroad on filling methods and materials in mined-out areas, there are few studies on the key technology of slicing filling thickness and intensity, filling materials and ratios and repeated mining technology [13-17]. The repeated mining technology is mining technology that assigns the working face in the destroyed areas of small coal pit after grouting filling the mined-out areas. This paper studies the slicing filling principle and key repeated mining technology of extra-thick coal seams in small coal pit destroyed areas, providing an innovative theory and technique for the safe and efficient backfill mining of coal resources in small coal pit destroyed areas and waste utilization in mining areas.

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## EXPERIMENTAL

### *Engineering situation in a small coal pit destroyed area*

China Coal Pingshuo Group Co., Ltd., 2# is a modernized extensive mine with an annual production capability of ten million tons. However, it has been badly damaged by small coal pit mining activity. Recoverable reserves in the second mining area 9# are 45.19 million tons, among which the fully mechanized working face B909 covers small coal pit mined-out area of 30,000 $m^2$. The length of the working face B909 is 300 m with an advance length of 1600 m and the thickness of the coal seam is 14.5 m with a dip of 1°-3°. There are 7 destroyed areas in the working face, the volume amounting to 20260 $m^3$. There are no poisonous gases or burning zones in these 7 mined-out areas, but a small amount of seepage as shown in Fig. 1. The goaf A, which is close to the open-off cut (“open-off cut” is the roadway of working face formed during the initial mining), is shown in Fig. 2. Under such geological and mining conditions, it is a challenging technical problem to operate a fully mechanized working face of ten million tons and achieve mining with safety and high efficiency.

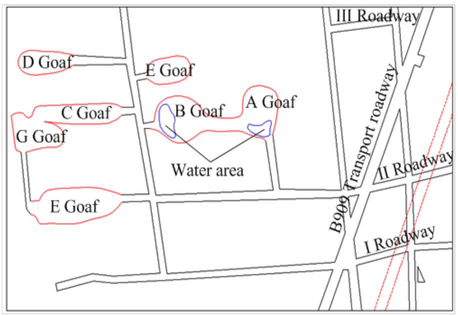



**Fig. 1**. Working face distribution of mined-out area in a small coal pit

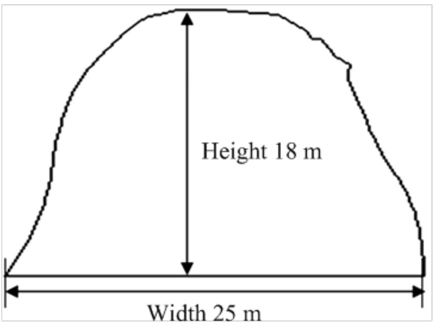



**Fig. 2.** Space form of small coal pit mined-out area A (length 25 m)

### *Slicing grouting filling principle and key technology*

As shown in Fig. 1, the working face B909 is in a small coal pit which is randomly distributed with a large area of influence. Small face mining will cause a great loss of coal resources and will not ensure stable production of a ten million tons working face and thus companies will lose economic benefits. Security cannot be guaranteed if the working face is directly pushed through the destroyed area and therefore it is proposed to adopt the slicing grouting filling method in mined-out areas in the small coal pit, then build the coal seam and roof, restore the integral mining area, assign ten million tons fully-mechanized face and conduct normal mining.

### *Slicing grouting filling principle of small coal pit destroyed area*

This technique provides guarantees for assigning working faces of repeated mining to fill small coal pit destroyed areas by grouting which eliminates potential hazards in mined-out areas and, at the same time, is one of the key technologies ensuring safe and high-efficient backfill mining in small coal pit destroyed area. Due to the large space in small coal pit mined-out areas, filling the area with some material will not only increase the cost of filling, but is also against safe and high-efficiency mining. Therefore, a slicing grouting filling technology is proposed that fills the destroyed area by grouting and then builds cutting layers, spacer layers and support layers, as shown in Fig. 3. The cutting layer is at the bottom of the mined-out area in a small coal pit. Above the cutting layer is a spacer layer, constructed by grouting filling and then the support layer, protected by the spacer layer, also ensures that filling material in the support layer and that in the cutting layer automatically separate when a shearer is passing through the cutting layer. The support layer is used to combat the impact of collapsed coal and to protect the working face to safely pass the destroyed area.

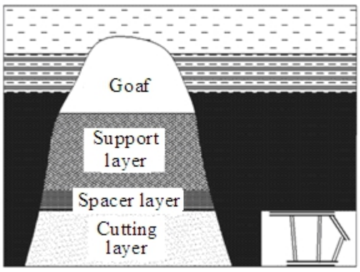



**Fig. 3.** Filling mined-out area A in a small coal pit

### *Key technology of slicing grouting filling*

The key technology of ensuring that the working face safely passes the destroyed area and thereby realizing high-efficient backfill mining of the coal seam in a small coal pit destroyed area with the lowest cost is to rationally construct a cutting layer, spacer layer and support layer, develop relevant filling materials and find out their appropriate ratio.

(1) Determination of the thickness of cutting layer, spacer layer and support layer. When normal mining commences at the working face in the complete coal seam, it can be seen that the thickness

of the cutting layer is the same as the mining height. The spacer layer protects the support layer from been damaged when the coal feeder is working and ensures that the filling material in the support layer and that in the cutting layer automatically separate. The thickness of the spacer layer is usually less than 10 cm.

The mined-out area in a small coal pit is filled by slicing grouting filling, constructing a support layer, spacer layer and cutting layer to form a comparatively complete mining area and then assigning a working face for normal repeated mining. Figs. 4 and 5 show that when the mining working face is pushed into the filling area in a small coal pit and affected by mining pressure, the roof of the mined-out area in a small coal pit may become unstable and collapse. Coal waste caused by roof collapse would impact the support layer, thus affecting safe repeated mining of the working face. Therefore, the support layer is the crucial factor ensuring safe working at the face and its thickness and intensity are strictly restricted to combat the impact and have a great loading capacity. The height and span of the unfilled space in the mined-out area in a small coal pit, the thickness of the cutting layer and the physical and mechanical parameters determine the weight of the collapsed coal seam and its impact on the support layer. The equation describing the support layer thickness is derived by establishing the mechanical model.

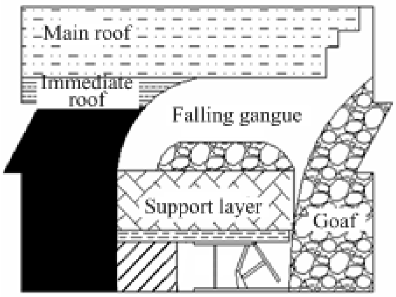



**Fig. 4.** Profile of filling area working face

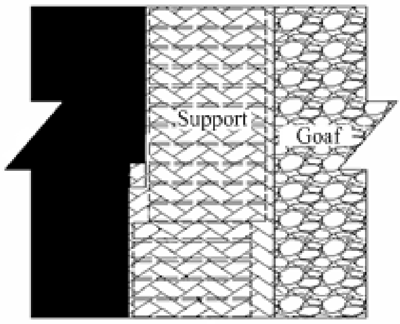



**Fig.5.** Structure of working face and roof of filling area

Impact force F of caving rock in old workings is as follows:

$$F = P(1+\sqrt{1+\frac{2H}{P}\frac{E}{M}}) \qquad (1)$$

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \sigma_z)]$$
$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_x + \sigma_z)] \qquad (2)$$
$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)]$$

According to the generalized laws of Hooke based on the elasticity theory given in Eq. (2), combining boundary conditions and Mohr Coulomb failure criteria, we get:

$$\frac{F}{2M(l+b)} = c + \frac{\mu F}{(1-\mu)lb}\tan\varphi \qquad (3)$$

If the distance between the end face andro of is not destroyed, the thickness of the sup-por t layer M should be:

$$M \ge \frac{K_d P \quad l \quad b}{2(l \quad b + c\frac{\mu}{1-\mu}K_d P \quad \varphi)\; lg(l+b)} \qquad (4)$$

where P is the height of collapsed rock; $K_d$ is the dynamic load coefficient ("dynamic load coefficient" means the impacting coefficient of roof caving rock in small coal pit mined-out areas under the influence of mining); H represents the distance between roof and support layer in the small coal pit mined-out area; E, M and F are the elastic modulus, the thickness of the support layer and the impact force of collapsed rock on the support layer, respectively; l indicates the distance between hydraulic support and coal wall; b is the hydraulic support width of not advancing support in time; the internal friction angle, the cohesion force and the Poisson's ratio are indicated by φ, c and μ, respectively.

According to B909 geomechanic parameters, combining with space conditions of each mined-out area and Eq. (4), it can be seen that the thickness of the support layer in the B909 mined-out area is more than 5 m, the cutting layer thickness is 3.8 m which is equal to the mining height and the spacer layer thickness is 10 cm.

(2) Performance requirements of filling materials in cutting layer, spacer layer and support layer. In order to ensure safe and high-efficient repeated mining of small coal mine destroyed areas, based on slicing grouting filling repeated mining theory and the function of the cutting layer, spacer layer and support layer, the performance requirements of the cutting layer, spacer layer and support layer are as follows:

Cutting layer: this has the characteristics of a brittle material with a compressive strength of 1-2 MPa, and is convenient for washing.

Spacer layer: this has the characteristics of loose

**Table 1.** Input parameters for the filling materials

| Performance parameters | Performance index | | |
|---|---|---|---|
| | Filling material I | Filling material Ⅱ | Filling material Ⅲ |
| Water-cement ratio (by weight) | 1:2 | 2:1 | 2.5:1 |
| Density (kg/cm$^3$) | 1.250-1.280 | 0.6-0.65 | 0.28-0.30 |
| Unilateral filling material (kg) | 400-430 | 300-330 | 80-100 |
| Hardening time (min) | 3-5 (Adjustable) | 3-5 (Adjustable) | 3-5 (Adjustable) |
| Final hardening uniaxial compressive strength (MPa) | 4.0-5.0 | 1.5-2.0 | 0.1-0.4 |

rock with a compressive strength less than 0.5 MPa, weak tensile and shear strengths.

Support layer: this has the characteristics of plastic materials with a compressive strength greater than 4 MPa.

(3) Performance and ratio of filling materials.

Performance requirements of filling materials: good fluidity, strong permeability, environmental friendliness and low cost.

Ratio of filling materials: basic materials are Remy filling material, fly ash and foaming agent with the ratio of 2:1:0.003 (by weight), an appropriate excipient is added together with water.

By studying material ratios, three filling materials of different performance were developed: filling material I (used to fill reconstructed support layer), filling material Ⅱ (used to fill reconstructed cutting layer) and filling material Ⅲ (used to fill reconstructed spacer layer). Relevant parameters of the filling materials are shown in Table 1.

## Repeated mining key technology of restored small coal mine destroyed area

*Parameter design of fully mechanized working face of repeated mining*

The mined-out area in a small coal pit is restored with filling technology. Parameter design of fully mechanized working face of repeated mining is the same as with a normal working face with an annual mining production capacity of ten million tons and daily production capacity of more than 30 thousand tons. Fig. 6 shows that the length of working face is 300 m with an advance length of 1600 m.

*Repeated mining technology and process of fully mechanized working face*

Taking advantage of a roadway to fill a small coal mine destroyed area by grouting, there is no need to supplement roadway support nor to alter the system after the mined-out area is filled. The original support, coal feeder and conveyor need not be changed against the filling area. After filling the mined-out areas in small coal pit destroyed areas, the working face is assigned to mining.

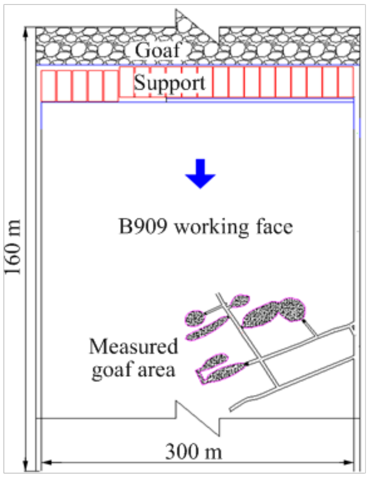



**Fig. 6.** Arrangement plan of B909 fully mechanized working face

The mining method is a fully mechanized top caving mining method, except for the filling areas. The height of the bottom slicing mining is 3.8 m and the thickness of the caving coal is 10.7 m. The mining technology remains unchanged, however, when the working face is approaching the filling area. However, the advance speed should be reduced in order to fully release the sinking deformation energy of the roof, which is the released energy caused by deformation. When the working face is passing through the filling area, advance speed should be increased in order to avoid the maximum sinking pressure of the roof. The screw type grouting pump and surface grout experiment are shown in Fig. 7, the backfilling technical system is shown in Fig. 8, and the underground construction site is shown in Fig. 9.

*Strata-pressure behavior of a fully mechanized working face when passing small coal pit destroyed area*

According to the actual measurements of strata-pressure behavior, when a fully mechanized working face is passing through the filling area in a small coal pit, the working resistance of the supports is usually lower. For example, when working face B909 is passing through a mined-out area, the resistance force of the filling section is obviously lower than the caving coal section (Fig. 10).

**Fig. 7.** Grouting pump and surface grout experiment

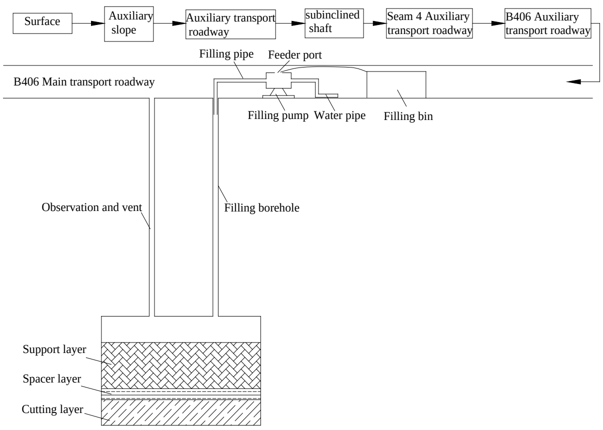
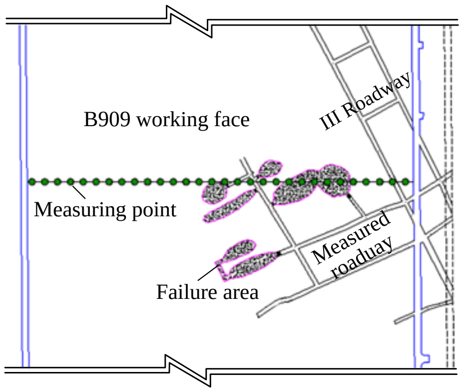



**Fig. 8.** Backfilling technical system

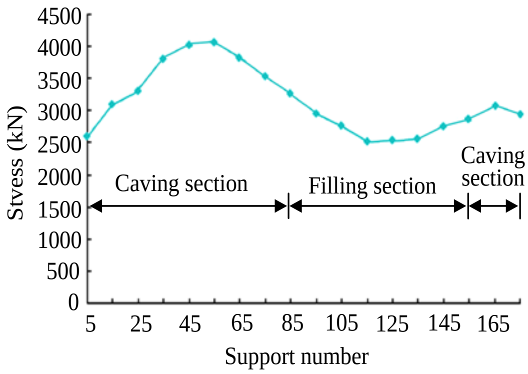
**Fig. 9.** Underground construction site

## RESULTS AND DISCUSSION

As shown in Fig. 11, the filling and cementation effects are very good and the shearer cuts normally in repeated mining. Coal production of B909 working face reaches 9.1 million tons with a mining rate of more than 87%, which is calculated by subtracting the amount of coal due to mining loss. The volume of these 7 mined-out areas in small coal pits amounts to 20260 $m^3$ using 5329 tons of filling materials which increases the cost of a ton of coal by 1.21 Yuan. The working face passes small coal mine destroyed areas at a fast speed, achieving safe and highly-efficient mining of a fully mechanized working face in an environmentally friendly manner.




(a) Measuring points arrangement of working face




(b) Stress curve of working face support

**Fig. 10.** Monitoring and stress curve of B909 fully mechanized working face support

(a) Section of working face passing through cutting layer

(b) Cementation effect of cutting layer

**Fig. 11.** Effect drawing of small coal mine destroyed area repeated mining

## CONCLUSIONS

1. This study fundamentally eliminates the major potential safety hazards of water inrush, fires and gas explosion in mined-out areas and achieves large-scale, continuous, safe and highly-efficient repeated mining of tens of millions of tons from working faces in small coal pit destroyed areas by slicing grouting filling, constructing a cutting layer, spacer layer and support layer, and then assigning the working face for repeated mining.

2. This paper provides the thickness and mechanical performance requirements of the cutting layer, spacer layer and support layer, establishes a mechanical model and derives an equation for support layer thickness. The thickness and mining height of the cutting layer are the same and the compressive strength of the cutting layer is less than 0.5 MPa. The spacer layer is 10 cm thick with a compressive strength of 1-2 MPa. The support layer is more than 5 m thick with a compressive strength of more than 4 MPa.

3. Appropriate filling materials and ratios were developed and the cutting layer, spacer layer and support layer were reconstructed in small coal mine destroyed areas to restore a ten million tons fully mechanized working face. Repeated mining by filling achieved good results with the cost of a ton of coal increasing by 1.21 Yuan and the recovery rate of coal resources increased which ensured regular production of mine and improved its safe production.

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