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Article

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Abstract

To address the supporting difficulties of deep rockburst roadways in Inner Mongolia and Shaanxi—such as large roadway deformation, strong impact force, and severe roadway spalling—this paper analyzes the failure characteristics of surrounding rock in rock burst roadways. According to the failure characteristics, this paper proposes a cooperative support technology system featuring "high impact toughness + high strength + strong yielding + integrity" and summarizes the characteristics of this system. Through numerical simulation, the differences between this technology system and conventional support in deformation control, as well as bolt and cable stress, are analyzed. Based on the analysis of geomechanical test results, the support technology scheme for the deep 2-2 coal main haulage roadway in a mine is proposed in accordance with the cooperative support technology and verified through numerical simulation. The results show that the support scheme can effectively control the harmful deformation of roadway surrounding rock. Finally, the reliability of the cooperative support technology is further verified through the underground industrial test and field application effect evaluation.

Keywords: Deep rock burst roadway; High strength; Strong yielding; Cooperative support; numerical simulation

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1 Introduction

In recent years, with the continuous development of mining technology, equipment, and management, the number of coal mine accidents and casualties in China has decreased significantly, approaching the world's lowest level. However, due to the gradual increase of mining depth and the more complex mining conditions, the frequency and intensity of rock burst phenomenon in coal mines are rising. According to relevant statistics [1-4], over 90% of rock burst accidents occur in mining roadways. Therefore, for rock burst roadways, it is urgent to adopt effective anti-impact measures to achieve stability control of the surrounding rock.

After years of research by scholars, substantial achievements have been made in the occurrence mechanism and prevention measures of rock bursts. In the aspect of rock burst roadway support, Pan et al. [5] based on the rock burst start-up theory, proposed the anti-impact technology of timely "support" for rock burst roadway while "pressure relief"; Dou et al. [6] put forward the theory of surrounding rock strength weakening and impact reduction, mainly by means of changing the

mechanical properties of coal and rock masses, so as to reduce the elastic energy stored and transmitted, and then realize the purpose of rock burst prevention; Pan et al. [7] developed energy absorbing support equipment, such as energy absorbing bolts and cables, anti-impact hydraulic supports and energy absorbing O-shaped sheds, and established an energy absorbing support system in which all energy absorbing support components worked together, achieving the purpose of controlling roadway impact damage; He et al. [8] used the excellent performance of negative Poisson's ratio materials in shear and impact resistance, combined with the characteristics of large rock burst deformation, developed constant resistance and large deformation bolts and cables, and successfully controlled the harmful deformation of rock burst roadway; Kang et al. [9-23] systematically studied the bolt support components (from theory, material to performance), proposed the "high prestress + high strength" support theory, studied the static and dynamic load mechanical properties of the bolts, and developed a series of impact resistant support materials; Ju et al. [24-25] developed high impact toughness bolts (cables) according to the instability and failure characteristics of rock burst roadways, and studied their energy absorption and impact prevention characteristics in rock burst roadway; Gao et al. [26-28] proposed the "strong-soft-strong" theory, and based on this theory, studied the "unloading support" cooperative formation mechanism of deep impact roadways, ensuring the stability of surrounding rock to a certain extent.

Most of the above achievements focus on the failure mechanism, anti-impact technology, and support methods for rock burst roadways. Although a large number of rock burst roadway support problems have been solved, most of them are the research results for specific conditions and may not be applicable to other mining areas. The Taigemiao mining area in Xinjie is an integrated mining area to be developed. The main mining seam is deeply buried and has impact property. The roof is thick and hard sandstone, and the design capacity is large. It is expected that mining stress will induce impact phenomena in both the main roadway and other roadways during the mining process. It is necessary to put forward a reasonable rock burst roadway support system and design principles to reduce the impact damage and ensure the safe and efficient support of the roadway.

Based on the analysis of the deformation characteristics of rock burst roadways in the Inner Mongolia-Shaanxi area, this paper proposes a cooperative support technology system featuring "high impact toughness + high strength + strong yielding + integrity", and mainly analyzes the advantages of this support technology system through theoretical analysis and numerical simulation. According to the cooperative support technology, the support technology scheme of deep 2-2 coal main haulage roadway in a mine is proposed, and verified by numerical simulation. The results show that the support scheme can effectively control the harmful deformation of roadway surrounding rock. Finally, the reliability of the cooperative support technology is further verified through the underground industrial tests and field application effect evaluations.

2 Deformation and failure characteristics of surrounding rock in rock burst roadway

2.1 Engineering background

At present, the mine mainly mines the 2-2 upper coal seam and 2-2 coal seam with thicknesses of 3.1 m and 5.6 m and average buried depths of 815 m and 827 m, respectively. Both seams are near-horizontal coal seams. The average thickness of the 2-2 upper coal seam is 3.11M. The distance from the 2-2 lower coal seam is 0.86~30.14m, with an average of 10.35m. The natural thickness of the 2-2 coal seam is 0.89~8.45m, with an average of 5.68m; the beneficial thickness is 0.89~8.05m, with an average of 5.60m. The 2-2 upper coal seam and the 2-2 coal roof rock layer are mainly thick sandstone. The floor is thick sandy mudstone. The uniaxial compressive strength of 2-2 coal seam is 14.41MPa, and the uniaxial compressive strength of the strata within 20m above the roof of the coal seam exceeds 30MPa.

The 2-2 coal seam with weak impact propensity has no impact propensity on its roof and floor. 2-2 the upper coal seam and its roof and floor have no impact tendency.

After shaft excavation completion, four main roadways are arranged in the 2-2 upper coal seam and 2-2 coal seam. The main roadways is arranged in the east-west direction, from north to south are 2-2 upper coal auxiliary haulage roadway, 2-2 coal auxiliary haulage roadway, 2-2 coal main roadway and 2-2 upper coal return air roadway. Except for the 2-2 coal auxiliary haulage roadway is arranged outside the 2-2 coal floor, the other three roadways are driven along the coal floor. The clean coal pillar between each main roadway is 60m.

Based on years of production experience and field investigations of several adjacent mines in the mining area, the existing problems in roadway support and surrounding rock control are summarized as follows:

(1) Large buried depth: the buried depth is generally more than 700m, entering the category of deep mining, and the long-term deformation of roadway surrounding rock is long, showing rheological properties; The mining disturbance is strong, and the damage range of the working face dynamic pressure to the roadway is significantly larger than that of the shallow part.

(2) Impact property: the adjacent mines are rock burst mines, and some coal seams and roof and floor have impact propensity. There are clear requirements for the impact resistance of roadway support materials. At the same time, it is necessary to take anti-impact measures, which will damage the surrounding rock of roadway and bring difficulties to roadway support.

(3) Severe roadway spalling: the most obvious deformation in the process of roadway excavation in adjacent mines is spalling, which brings hidden dangers to the excavation management and roof safety.

2.2 Deformation and failure characteristics of surrounding rock

For rock burst roadway, most of them are buried deeply and accompanied by a variety of complex stresses (such as tectonic stress, mining stress, etc.), which often lead to high stress environment. Secondly, the anti-impact support measures for such roadway are often insufficient or inadequately considered. For example, the multi-level support of roadway fails to coordinate the deformation, and the unreasonable pressure relief measures lead to the damage of surrounding rock support structure to some extent, and the protection measures for both sides and floor of roadway are weak. This leads to the following deformation and failure characteristics of such roadway props:

(1) Roadway surrounding rock deformation is serious and lasts for a long time.

Through the measurement and statistics of the range of surrounding rock failure loose zone of most rock burst roadway, the results show that the failure depth of surrounding rock of such roadway is generally 5~6m, or even deeper. The deformation has a long duration. From the roadway excavation period, the surrounding rock of the roadway is gradually destroyed from the outside to the inside under the environment of high stress. For example, after the pressure relief of the roadway side drilling, most of the bolts and cables of the roadway side appear obvious breakage and failure. During this period, the two sides of the roadway move closer by about 2m. During the mining period, combined with the influence of the advance abutment pressure of the working face, the support system of the entire roadway will have a wide range of failure (mainly manifested as bolt cable breakage, steel belt breakage, serious U-shaped shed deformation, etc.), and the section of the entire roadway will shrink seriously.

(2) The surrounding rock failure of roadway is sudden and has large failure energy.

Due to the high stress environment of this kind of roadway, such as poor lithology of surrounding rock and relatively concentrated structural faults, once the structural zone in surrounding rock is induced and activated during roadway excavation or mining, it is very easy to cause extremely destructive coal and rock burst. This process is often characterized by short burst time, poor predictability and strong energy accumulation. This failure characteristic cause fatal damage to the stability of roadway surrounding rock, ranging from roadway failure and instability to roadway collapse and casualties.

(3) The phenomenon of side spalling and floor heave in roadway is serious.

When carrying out support design for such roadways, most of them are mainly concentrated in roof area and sharp corner area, and the protection treatment for both sides and floor of roadways is relatively weak. The failure and instability of roadway under high stress environment often initiate in the weak area of roadway, which leads to the obvious phenomenon of side spalling and floor heave. In this way, the roadway needs to be repaired continuously (expanding the side and floor dinting), which not only consumes a lot of manpower and material resources, but also seriously affects the high production and efficiency of the mine, and brings huge economic losses to mining enterprises.

Because of the support of roadway, people often pay attention to the support of roof and coal wall, but ignore the treatment of floor, and the complex tectonic stress field, the roadway is more prone to serious floor heave. Most coal mine roadways require repeated floor dinting to ensure normal production, which consumes massive human and material resources and causes substantial economic losses to coal mining enterprises.

3 Cooperative support principle of "high impact toughness + high strength + strong yielding + integrity"

According to the characteristics of surrounding rock stress environment and deformation and failure of the deep rock burst roadway, the traditional passive support and weak support strength have been difficult to meet the needs of roadway stability control. Therefore, the active yielding support technology is proposed to adapt to the characteristics of deep rock burst, such as sudden, strong destruction and large energy release.

3.1 Active support principle of roadway surrounding rock

The original rock stress field of deep roadway is in the state of high stress environment. With the excavation of roadway, the stress of surrounding rock free face is released rapidly, and gradually presents a bad development trend. The surrounding rock is in the post peak strength stage within a certain depth. Under the action of high stress, the cracks develop rapidly, and these cracks are easy to expand and coalesce, resulting in the reduction of surrounding rock strength. The action principle of the existing passive support system, such as bolt, steel arch and single hydraulic prop, is to drive the passive support system to produce support resistance by generating radial displacement in the surrounding rock of the roadway, which can improve the mechanical properties of the surrounding rock of the roadway to a certain extent. However, the action scope of such support resistance is mainly concentrated on the surface of the roadway wall, and it is unable to synchronously apply the active and stable radial compression force to the surrounding rock of the roadway and the deep rock mass. Because of this, the effect of passive support resistance on improving the mechanical properties of deep rock mass has significant limitations.

Compared with the passive support system, the active support mainly controls the surrounding rock of the roadway through the following mechanical mechanisms:

(1) Stress compensation function: after the roadway excavation, the surrounding rock stress is redistributed, and the stress reduction area and stress concentration area are formed around the roadway. By applying radial support force to surrounding rock, active support can compensate part of the stress loss of surrounding rock due to excavation, reduce the range of stress relief zone, reduce the stress concentration factor, and make the stress distribution of surrounding rock more uniform,

so as to improve the stability of surrounding rock.

(2) Crack closure and reinforcement: the support force applied by the active support can close the cracks in the surrounding rock and reduce the expansion of the cracks. At the same time, the bonding force and friction between the support structure and the surrounding rock can connect the broken surrounding rock blocks to form a whole and improve the overall strength and integrity of the surrounding rock.

(3) Improve the mechanical properties of surrounding rock: active support can improve the mechanical properties of surrounding rock, and improve the compressive strength, tensile strength and shear strength of surrounding rock through the constraint and reinforcement of surrounding rock. On the one hand, the support force makes the surrounding rock in the state of triaxial stress. According to the theory of rock mechanics, the strength of rock in the state of three-dimensional stress is much higher than that in the state of uniaxial stress; On the other hand, the supporting structure can prevent the surrounding rock from loosening and spalling in the process of deformation, maintain the integrity of the surrounding rock, and improve the self bearing capacity of the surrounding rock.

The characteristic curve method is adopted to analyze the interaction mechanism between support and surrounding rock, as shown in Fig. 1. In the figure, the mechanical characteristic curves of surrounding rock under active and passive support conditions are denoted by Curve 1 and Curve 2, while B1 and B2 represent two types of passive support systems. The support stiffness of B2 support system is greater than B1, Z1 is the mechanical characteristic curve of active support, and the starting point of support action is P1. The mechanical characteristics of surrounding rock under S1 and S2 based and passive support conditions are improved due to the active support effect, and the location of the failure point is changed from S1 to S2.

The starting points of the three kinds of support mechanical characteristic curves are all implemented when the surrounding rock deformation is U1. Because the support stiffness of the passive support B1 is weak, it fails to intersect with the surrounding rock mechanical characteristic curve 1 before the failure point, so the passive support cannot control the surrounding rock, and the support is invalid. By increasing the stiffness of the passive support, the surrounding rock deformation drives the passive support to increase the support resistance. The passive support B2 and the surrounding rock support characteristic curve intersect at point a, and the support is successful. The active support Z1 applies the surrounding rock prestress P1 through the active support effect of stress compensation and improving the mechanical properties of surrounding rock. Without increasing the support stiffness, it intersects with the surrounding rock characteristic curve 2 at point b, and the support is successful. Compared with the characteristic curves of active and passive support, point a is closer to the surrounding rock failure point S1, and the range of safety reserve is less. Under the action of active support, point b is far away from the surrounding rock failure point S2, and the support control safety reserve is sufficient, and the deformation of

surrounding rock at the stability control point U2 is significantly less than U3, so the surrounding rock deformation is effectively controlled, and the surrounding rock deformation is small. It can be seen that the active support can achieve the control effect of improving the stability of roadway surrounding rock and reducing the deformation without increasing the stiffness of the support system.

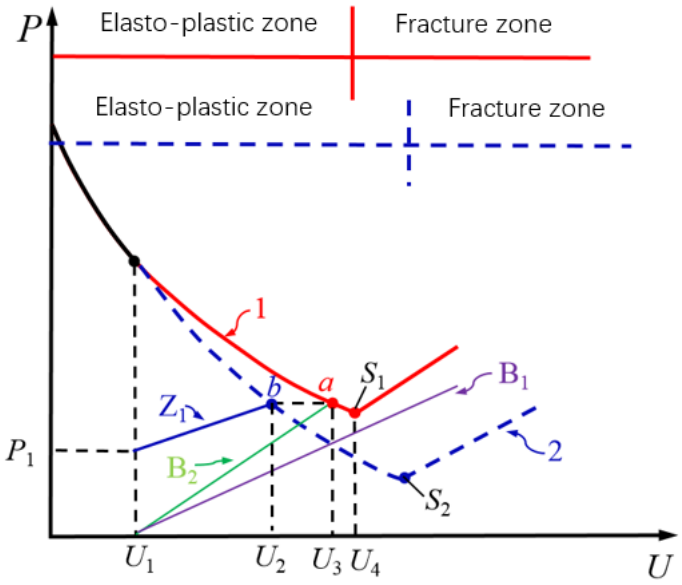


Fig. 1 Schematic diagram of surrounding rock active support

3.2 Cooperative support principle of "high impact toughness + high strength + strong yielding + integrity"

According to the failure characteristics of rock burst roadways, the support form of roadway must adapt to its failure characteristics. Therefore, in addition to the conventional roadway support function, the support design of such roadway also needs to consider some anti-impact support measures:

(1) Strong bearing capacity. Considering that the props of rock burst roadway have the characteristics of fast and strong pressure, the anti-impact support of such roadway must be able to provide sufficient support strength and stiffness. Otherwise, it is impossible to bear and effectively control the fatal deformation and damage of the roadway caused by the strong impact.

(2) Good flexibility. In view of the characteristics of long deformation duration and large deformation of rock burst roadway, the supporting equipment must be required to have sufficient expansion and deformation to ensure a certain working resistance in the process of overall deformation with surrounding rock.

(3) Good stability. Based on the characteristics of strong burst and large destruction energy of rock burst, the anti-impact support equipment or support components need good structural stability, which is not easy to lose stability in the process of severe deformation of the roadway.

(4) Good integrity. Because the failure of rock burst roadway is often broken through from the

weak part of the support system, it requires that appropriate reinforcement measures should be taken for the two sides and floor of the roadway in the support design, and at the same time, it should ensure that the entire roadway support components can form a complete and cooperative support system, rather than the traditional isolated support system.

Therefore, according to the failure characteristics of rock burst roadway and the special requirements of its support design, combined with the characteristics of coal seam bursting propensity, the cooperative support principle of "high impact toughness + high strength + strong yielding + integrity" is proposed. The principle has the following characteristics:

(1) "High impact toughness" means that the material has a high ability to absorb plastic deformation energy and fracture energy under impact load. For bolt materials, the impact toughness is generally evaluated by the impact absorption energy index. When rock burst occurs, the instability and failure of such roadway support components are mostly manifested as the breakage and failure of the bolt and cable, and the damage severity is closely related to the material toughness of the bolt and cable. Therefore, the bolt and cable support material of rock burst roadway must have high ductility to prevent a large number of "impact fracture" phenomenon.

(2) "High strength" means that the supporting material of the bolt support system has high strength, high bearing capacity in the event of impact, will not be easily damaged, and can provide high support resistance to the surrounding rock. Specifically, high-strength material, large-diameter left-hand non longitudinal rebar threaded steel anchor and large-diameter high prestressed bolt and cable are selected in the support design, and matched with high-strength support components such as tray, steel belt, metal mesh, etc., to enhance the support strength of the main support components in the whole support system.

(3) "Strong yielding" means that the support system has a strong ability to coordinate deformation and good compressibility. When the roadway is subjected to impact load, it is not a mechanical "hard resistance", but a flexible "yielding resistance", that is, it can cooperate with the surrounding rock to deform without causing the surrounding rock deformation out of control or even destabilization under the condition of providing a certain resistance, which not only meets the requirement of actively resisting part of the surrounding rock deformation energy under the condition of "hard resistance", but also realizes the natural absorption of part of the surrounding rock deformation energy under the condition of "yielding resistance", and finally achieves the goal of allowing certain deformation of the surrounding rock of the roadway without destabilization and failure.

(4) "Integrity" means that the support and the surrounding rock together form a complete supporting system.In other words, the entire support system consists of three parts: surface supports including metal mesh, steel belts and trays arranged on the surface of the surrounding rock; a shallow bearing layer formed by bolts installed in the shallow part of the surrounding rock; and a deep anchorage layer formed by cables arranged in the deep part of the surrounding rock. This

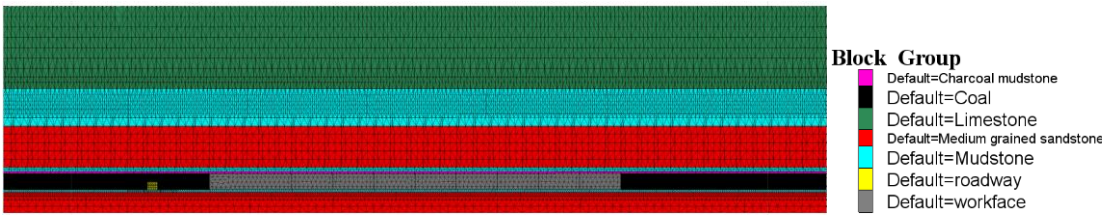
structure forms a support system that extends from the outside to the inside in space, and a "globally coordinated" deformation support combination in terms of timing, ultimately forming a complete and coordinated support system.

4 Analysis on control effect of surrounding rock with cooperative support

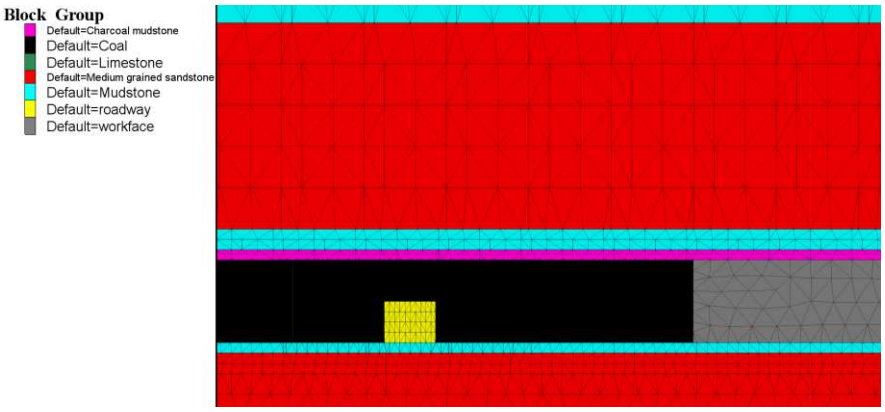
Based on the principle of cooperative support, and to further verify the anti-impact effect of this support principle under rock burst conditions, this study compared and analyzed the anti-impact effect of typical rock burst roadways under general support measures and cooperative support measures through numerical simulation.

4.1 numerical simulation scheme

Based on the actual geological conditions of a typical rock burst roadway in a mine, a corresponding calculation model is established using the 3DEC numerical simulation software. The model dimensions are 400 m × 2 m × 100 m. Horizontal displacement is constrained on the model boundaries, and vertical displacement is constrained at the model bottom. A uniform load equivalent to the gravity of the 800 m thick overburden, calculated as $2.5 \times 10^4 \times 800 = 20$ MPa, is applied on the top of the model. The roadway, which has a rectangular section, measures 5 m × 4 m. The width of the net coal pillar between the roadway and the working face is 25 m, and the average thickness of the coal seam is 8 m.The relevant mechanical parameters of the coal and rock mass used in the simulation are shown in Table 1, and the numerical calculation model is shown in Fig.2.



（a）Overall model diagram



（b）Model partial enlarged view

Fig.2 Numerical calculation model diagram

Table 1 Mechanical parameters of coal and rock mass

Name of rock strata	Density / kg/m³	Young's modulus /GPa	Cohesion/MPa	Tensile strength/MPa	Internal friction angle/°
Sandy mudstone	2400.0	6.33	2.42	0.84	30.0
Coal	1400.0	2.22	1.65	0.638	30.0
Medium grained sandstone	2700.0	22.6	8.73	3.92	42.0
Mudstone	2600.0	11.2	4.37	1.68	35.0

To facilitate distinction and comparison, this simulation keeps the row spacing and the number of bolts and cables consistent between the general support scheme and the anti-impact support scheme, with only the mechanical properties of the bolts and cables differing between the two schemes.Details are presented in Table 2. Next, the distribution of the surrounding rock plastic zone, surrounding rock deformation, and the stress of bolts and cables are simulated for scenarios where general support and anti-impact support measures are applied under two conditions: roadway excavation (general rock pressure) and working face mining (rock burst).

Table 2 Table of mechanical performance parameters for bolts and cables

Scheme	Support components	Yield strength /MPa	Tensile strength/MPa	Percentage elongation /%
General support	bolt	500	670	18
	cable	1250	1450	3.5
Anti-impact support	bolt	815	896	20
	cable	1550	1800	8

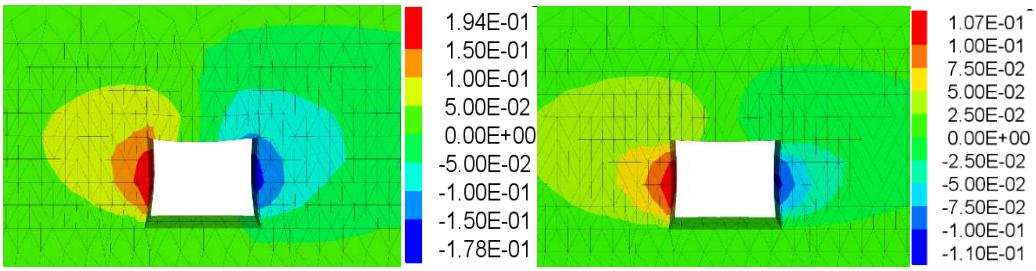
4.2 Analysis of simulation results

(1) Analysis of surrounding rock displacement field

Figure 3 and Figure 4 show the contour maps of horizontal displacement and vertical displacement of the roadway under different support measures during excavation, respectively.Figures 5 and 6 show the contour maps of horizontal displacement and vertical displacement of the roadway, respectively, under different support measures during working face

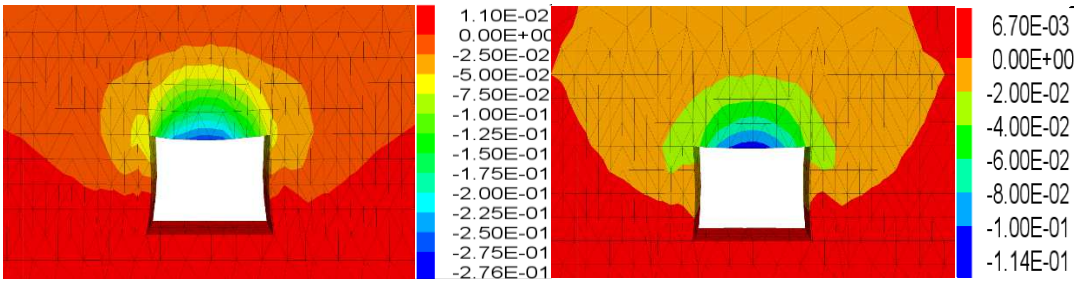
mining.

As shown in Fig. 3 to Fig. 6, the roadway surrounding rock deformation after the adoption of anti-impact support measures is significantly reduced, compared with the deformation observed when general support measures (are used, during both roadway driving and working face mining.) During driving, under general support conditions, the maximum displacement of the two sides of the surrounding rock is 372mm, and the maximum displacement of the roof and floor is 287mm; under anti-impact support conditions, the maximum displacement of the two sides of the surrounding rock is 217mm, and the maximum displacement of the roof and floor is 121mm.During working face mining, under general support conditions, the maximum displacement of the two sides of the surrounding rock is 801mm, and the maximum displacement of the roof and floor is 602mm; under anti-impact support conditions, the maximum displacement of the two sides of the surrounding rock is 490mm, and the maximum displacement of the roof and floor is 267mm.



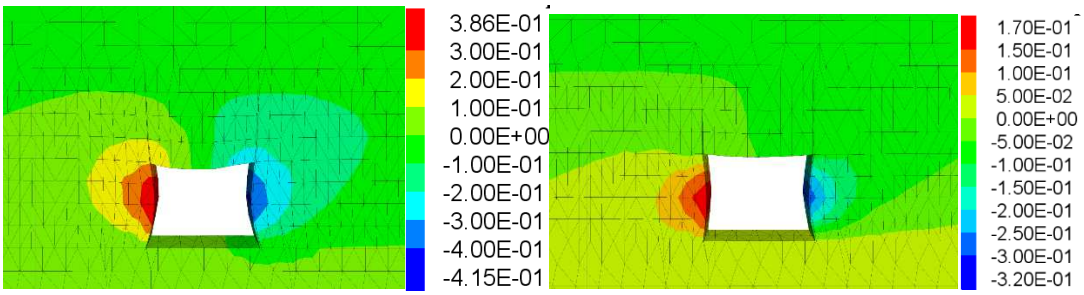
(a) general support **(b) anti-impact support**

Fig.3 Horizontal displacement contour map during roadway drivage



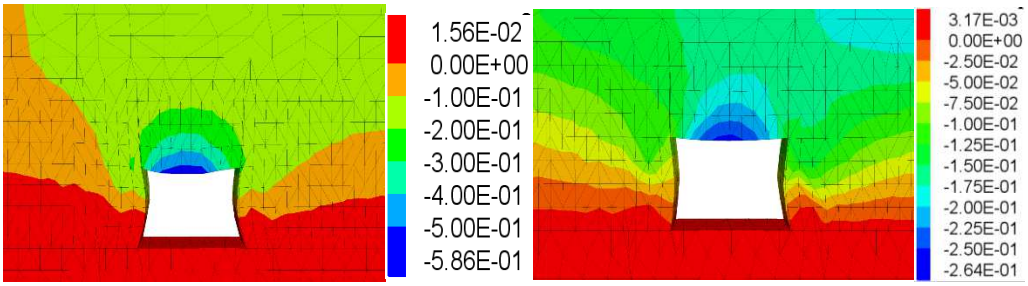
(a) general support **(b) anti-impact support**

Fig.4 Vertical displacement contour map during roadway drivage



(a) general support **(b) anti-impact support**

Fig.5 Horizontal displacement contour map during the mining of the working face

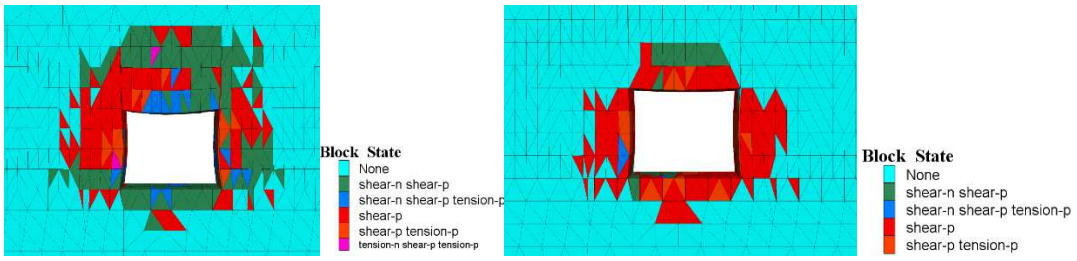


（a）general support **（b）anti-impact support**

Fig.6 Vertical displacement contour map during the mining of the working face

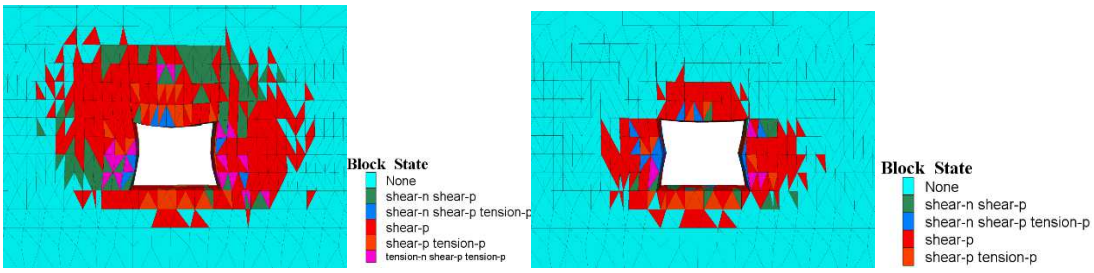
(2) Analysis of distribution range of surrounding rock plastic zone

Figure 7 and Figure 8 show the distribution of the surrounding rock plastic zone under different support conditions during roadway excavation and working face mining, respectively.Table 3 lists the statistical table of the distribution range of the roadway surrounding rock plastic zone across different working conditions.



（a）general support **（b）anti-impact support**

Fig.7 Distribution of plastic zone during roadway driving



（a）general support **（b）anti-impact support**

Fig.8 Distribution of plastic zone during the mining of the working face

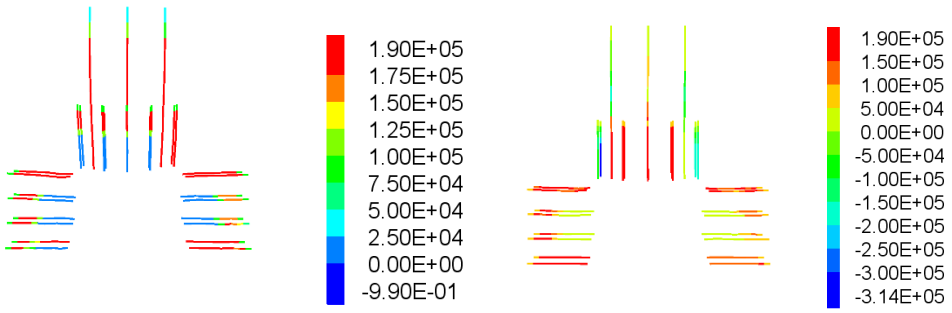
Table 3 Statistical table of distribution range of plastic zone in surrounding rock under different working conditions

Scheme	Working conditions	Damage depth of left side /m	Damage depth of right side /m	Damage depth of roof /m	Damage depth of floor /m
General support	driving	3.0	3.0	4.0	2.0
	mining	5.0	6.0	5.0	2.0
Anti-impact support	driving	2.0	2.0	2.0	2.0
	mining	3.5	4.0	2.5	2.0

Data from Fig. 7, Fig. 8 and Table 3 indicates that after the anti-impact support measures are implemented, the distribution scope of the surrounding rock plastic zone of the roadway in the period of roadway driving and working face mining is remarkably smaller than the corresponding range under conventional support measures.It can be seen that anti-impact support measures play a key role in maintaining the stability of the surrounding rock.

(3) Stress analysis of bolt and cable

Because the stress of the bolt and cable under the conditions of the two kinds of support measures during the drivage of the roadway is similar, the stress of the bolt and cable during the mining of the working face is mainly analyzed here. Fig. 9 shows the stress of bolt and cable of roadway under the condition of different support measures during the mining of working face.



(a) general support (b) anti-impact support

Fig.9 The force of bolts and cables during the mining of the working face

As can be seen from Fig. 9, during the mining of the working face, when conventional support measures are adopted for the roadway, most bolts and cables in the support system fracture and fail due to the strong impact of mining-induced dynamic pressure (that is, the axial force in the axial diagram is 0). At this stage, the support function of the entire support system can be regarded as invalid. When the roadway adopts anti-impact support measures, even under the influence of strong dynamic pressure, only a small number of bolts in the support system fracture and fail (that is, the axial force in the axial diagram is 0), while the remaining support components remain in normal working condition. In this case, the support function of the entire support system can be regarded as effective.

To sum up, for typical rock burst roadways, the traditional support system is often unable to effectively maintain the stability of roadway surrounding rock, and is prone to serious roof subsidence, obvious shrinkage of two sides, and broken bolts and cables. However, after adopting the "high impact toughness + high strength + strong yielding + integrity" cooperative support concept, the anti-impact effect is significantly improved, and the stability of roadway surrounding rock is greatly enhanced.

5 Field application of cooperative support principle

Following the cooperative support technical principle for deep rock burst roadways, a cooperative support technology plan for the 2-2 coal main haulage roadway in the mine is put forward, and the supporting effect is analyzed through field measurement.The underground industrial test shows that the cooperative support technology scheme provides effective supporting performance and achieves favorable surrounding rock control effects.

5.1 Technical scheme of cooperative support

To enable rapid drivage of the mine, the main haulage roadway of 2-2 coal mine uses a rectangular cross-section, has a drivage width of 5500mm and a drivage height of 3950mm, and employs bolt mesh cable shotcrete support.

According to the specific geological conditions, the cooperative support technology scheme suitable for the anti-impact characteristics of 2-2 coal main haulage roadway is given as follows:

The bolt body at the top and side part is a screw thread steel bolt without longitudinal ribs, the model is Φ 22×2400 mm, and the yield strength is 500MPa; The specification of bolt support plate is 150×150×10mm, and the high-strength arched support plate (with self-aligning ball pad and antifriction washer) has the same mechanical properties as the bolt body. The bolt is matched with a W steel guard plate, with the specification of 450×280×4mm. Two anchoring agents are used: one with the specification of CK2335, and the other with the specification of K2360. The designed anchoring force is not less than 186KN, and the bolt pretension torque is not less than 300N·m.Bolt arrangement: Rectangular arrangement is adopted, and the row and column spacing is 1000mm × 800mm. There are 6 top bolts per row and 8 side bolts per row (4 for each side).The roof and sidewalls are protected by single-layer welded reinforcing mesh with a 6.5mm diameter bar, a grid size of 100mm×100mm, and sheet dimensions of 5700mm×900mm and 3900mm×900mm. The mesh sheets are bound and lapped with 22# iron wire, and the lap length shall not be less than 100mm.

The roof cable uses a single 1×19 strand steel strand with the specification of Φ 21.8×7300mm, and is matched with a supporting metal support plate with the specification of 300×300×16mm (with a self-aligning ball pad) and three anchorage agents (one with the specification of CK2335 and two with the specification of K2360). The design anchoring force shall be no less than 60% of the breaking force.The spacing between rows is 1500mm×1600mm, with three units in each row. The tensioning preload shall not be less than 300KN.Top and side surfaces shall be sprayed with C20 shotcrete, with a thickness of 150mm.

The cross-section diagram of the support is shown in Fig. 10.

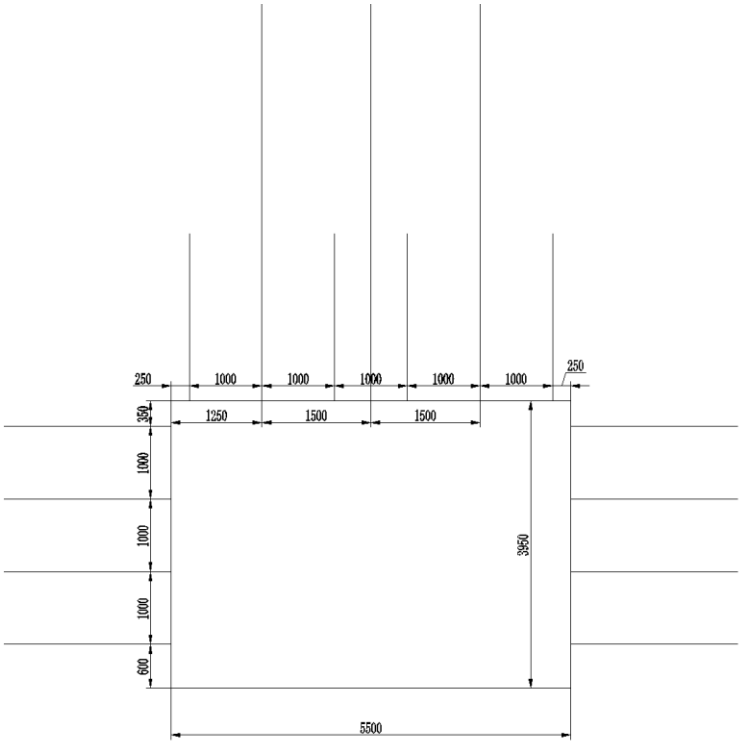


Fig. 10 Section diagram of roadway support

5.2 Field application effect evaluation

Four monitoring stations (B1, B2, B3, B4) are arranged in the 400 m long application section of the cooperative support technology scheme for the test roadway, and two monitoring stations (A1, A2) are arranged in the 200 m long non-application section. The spacing between adjacent stations is 100 m, and a monitoring cross-section is arranged at each station.The layout of the stations is shown in Table 4.

Table 4 Layout of monitoring station

Station No	Monitoring section No	Position /m
A1	1#	50
A2	2#	150
B1	3#	250
B2	4#	350
B3	5#	450
B4	6#	550

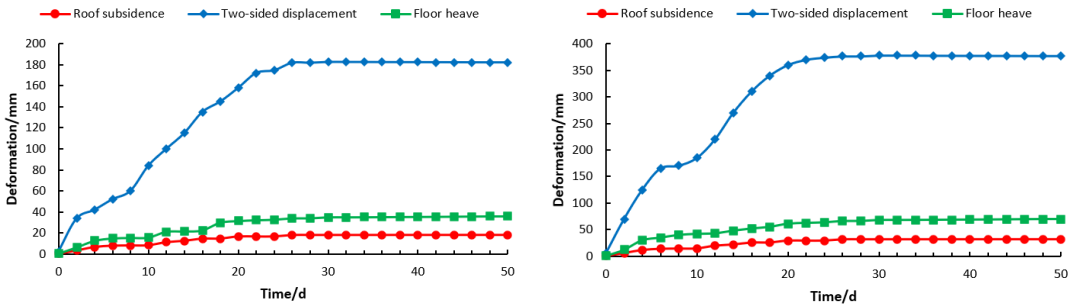
(1) Roadway surface displacement observation

To facilitate analysis and comparison, the data from the 2# monitoring section and 6# monitoring section are selected for comparison when analyzing changes in roadway surface

displacement.The statistics of surrounding rock deformation for the monitoring section are shown in Table 5, and the deformation curve of roadway surrounding rock is shown in Fig. 11.

Table 5 Statistical table of roadway surrounding rock surface deformation

Monitoring section No	Roof subsidence/mm	two-sided displacement/mm	Floor heave /mm
2#	32	376	68
6#	18	182	35



(a) 2# (b) 6#

Fig.11 Deformation curve of roadway surrounding rock

(2) Stress observation of bolt and cable in roadway roof

The stress condition of roadway roof bolt and cable is shown in Table 6.

Table 6 Statistical table of stress of roadway roof bolt and cable

Monitoring section No	Axial force value of roof cable /KN	Axial force value of roof bolt /KN
1#	342	138
2#	353	142
3#	311	112
4#	309	108
5#	306	105
6#	310	108

Based on field observation data, compared with the non-adopted control section, roadway surrounding rock deformation, roof rock separation, and roof bolt anchoring force are all significantly reduced after the cooperative support technology scheme is implemented in the test roadway.The results show that the collaborative support technology characterized by "high impact toughness + high strength + strong yielding + integrity" can not only effectively control harmful deformation of the surrounding rock, but also ensure the overall impact resistance of the

roadway.The industrial test application of the collaborative support technology is generally recognized as highly successful.

6 conclusion

(1) This paper briefly summarizes the theoretical research, related prevention and control measures, and control methods for rock burst roadways in recent years.Given the geological conditions of deep rock burst roadways and the support challenges encountered in adjacent mine roadways, this paper analyzes the failure characteristics of surrounding rock in rock burst roadways, puts forward the cooperative support principle of "high impact toughness + high strength + strong yielding + integrity", and summarizes its core technical points.

(2) Based on the cooperative support principle of "high impact toughness + high strength + strong yielding + integrity", this study used numerical simulation to compare and analyze the anti-impact support effect of roadways after adopting conventional support measures and dedicated anti-impact support measures. The results show that anti-impact support measures are more effective in maintaining the stability of roadway surrounding rock under the action of impact ground pressure.

(3) Based on the cooperative support technology principle for deep rock burst roadways, a cooperative support technology scheme is proposed for the No. 2-2 coal main haulage roadway in this mine. Numerical simulation analysis of the support effect shows that this scheme can effectively control harmful deformation of the roadway surrounding rock, and delivers satisfactory surrounding rock control performance.

(4) Industrial tests and mine pressure monitoring of the cooperative support technology scheme were carried out in the 2-2 main coal transportation roadway. Compared with the original support scheme, the roadway surrounding rock deformation, roof rock separation and roof bolt anchor force were significantly reduced, and the supporting effect is obvious.

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