Improvement and application of drilling and blasting techniques of anchor net (cable) spraying in rock roadways

Zhongyi Wen
Yongcheng Coal Power Holding Group Company, Yongcheng 476600, China

Abstract. To overcome the shortcomings of the prior art of bolting net (cable) spraying technology in rock tunnels of mine engineering, based on the principle of the combined action of surrounding rock and support, improvement methods and technical requirements are formulated. Through roadway section optimization and support parameter design and improvement of technology, smooth blasting, initial shotcreting, and construction quality of the anchor net (cable) as well as controlled release of the surrounding rock stress and local reinforcement are improved, so that the surrounding rock and support can be carried out together. Finally, through thin shotcreting, the coupling effects of the anchor net (cable), shotcreting layer, and surrounding rock can be realized, and the bearing performance can be brought into play to achieve the best support effect and ensure that the net section meets the requirements with minimal investment. The test shows that the improved technology can effectively solve problems of large area cracking and convergence deformation; the effect is positive and highly recognized by the industry, and it has been popularized and applied in this area and brother units. Large economic and social benefits have also been obtained.

1. Introduction
In 1956 in China, bolting was used in rock roadways. In the early 1960s, bolting and shotcreting were used in rock roadways. In the mid-1960s, with improved shotcreting tools, shotcrete support was developed. Smooth blasting, bolting, and shotcreting technology were combined to form smooth blast bolting and shotcreting support, which then rapidly developed and gradually formed a set of smooth blasting bolting and shotcreting. The classification of surrounding rock and the corresponding parameters of bolting and shotcreting support were compiled into the Mining Design Manual, and the technical specifications of bolting and shotcreting support were established.

The designers of the Coal Design Institute can conduct the anchor mesh shotcreting design of shafts and roadways through the Mining Design Manual, and coal mine field engineers and technicians can adopt the engineering analogy method to design or optimize the design through the Mining Design Manual combined with on-site practice [1]. With increased mining depth, single anchor shotcreting or anchor net shotcreting supports cannot meet the safe use of roadway; thus, prestressed anchor cable reinforcement of roadways technology has been developed and widely used in coal mines over recent years. When adopting the drilling and blasting method of anchor net (cable) shotcreting construction, in general, the rock is
broken by blasting according to the smooth blasting chart, and after gangue is produced, the roadway arch is bolted and net is hung according to the row distance between the anchors. If an anchor cable is designed, the construction is also carried out according to these requirements. When the construction of the arch anchor net (cable) is completed, shotcrete support is first performed on the roadway arch. After 10–15 m of roadway construction, the lower two sides of the roadway will be uniformly bolted (anchor cable) and a net will be constructed; then, shotcrete support is carried out on the lower two sides of the roadway, and that month's project will be renovated and shotcreted before acceptance at the end of the month to meet the acceptance criteria.

However, with increased mining depths of mines, the defects existing in the anchor net (cable) technology of the above rock roadway are becoming increasingly obvious, and the phenomenon of deformation and destruction after roadway construction is becoming increasingly serious, especially in relation to soft and broken surrounding rock. In these situations, the mines must be expanded and strengthened numerous times, and comprehensive reinforcement measures must be taken, resulting in slow construction progress and high roadway renovation and reinforcement, and seriously affecting the normal mining replacement and economic benefits of the coal mine [3-7]. To overcome the defects of anchor net (cable) shotcreting technology and reduce the renovation rate of rock roadway bolting net (cable) shotcreting roadways to save supporting materials, reduce construction cost, improve the single entry level of the rock roadway, and ensure normal and orderly replacement of mines, improvement of bolting net (cable) shotcreting technology of rock roadways by drilling and blasting is urgently needed.

2. The main problems of the original process technology
(1) When the roadway adopts the design of a fixed cross section and support parameters, adapting to the geological conditions and the complexity, variability, and heterogeneity of the roadway force is difficult. For the sections with good overall surrounding rock stability, super strength supports may be present, resulting in waste. For the sections or stress concentration zones where the overall stability of the surrounding rock is weak, insufficient support strengths may be present; thus, it will inevitably cause roadway instability and failure, and continued renovation and reinforcement will cause more waste.

(2) From the perspective of the anchor mesh (cable) shotcrete supporting structure, the characteristics of the concrete sprayed layer being easily damaged by tension and shear was not fully considered. On the contrary, the steel mesh is arranged on the inside of the sprayed layer, so that the thicker the sprayed layer is, the easier it is to crack.

(3) Due to the complexity of geological conditions, the strata heterogeneity and implementation deviation of smooth blasting measures, the over-underexcavation caused by blasting and an uneven roadway driving profile occasionally occurs. Therefore, large errors in the row distance between anchors and the direction of the anchors are inevitable, and there is also a big discount on the effective anchoring depth and thickness of the extruded reinforcement zone formed by anchors. The uneven surface of the roadway not only causes the bolt tray to be far from the rock surface but also causes shear force at the end of the bolt in the process of bolt pretension. In addition, in the anchoring process from the completion of anchor hole construction to the anchor bolt anchoring process, if the rock around the bolt hole falls again, the bolt tray will be unable to stick to the rock surface. Therefore, the bolt role is
often reduced or bolt waste occurs from time to time.
(4) Due to the uneven surface of the roadway driving profile and even over-underexcavation, the lapping and laying quality of steel mesh is quite different from the design, and its function is reduced.
(5) To ensure that the roadway meets the requirements of the acceptance specification, constructors must repeatedly spray the roadway many times, resulting in different thicknesses of the sprayed concrete on the outside of the steel mesh, where the steel mesh is not in the tension area of the sprayed layer. Therefore, the compound-sprayed concrete layer of the roadway is easy to crack and fail.
(6) It is not conducive to the support and self-supporting capacity of surrounding rock, and deformation and failure phenomena occur in most roadways after construction; particularly, with the continuous increase of mining depths or the encountering of soft and broken surrounding rock, the damage phenomenon is becoming more serious.

3. Improvement ideas and objectives
According to the joint action principle of surrounding rock and support, through the continuous optimization of the cross section and support parameter design of anchor mesh (cable) shotcreting roadways and by ensuring the quality of smooth blasting and initial shotcreting, and then the construction of anchor net (cable), in order to ensure the construction quality of anchor net (cable), so that the role of anchor net (cable) can be brought into full play, and the stress of surrounding rock can be released and deformation measurement can be carried out at the same time. Local anchor mesh (cable) reinforcement was performed according to the cracking and deformation of the roadway after releasing the surrounding rock stress, so that the surrounding rock and support work together bear the load to its maximum extent. Through thin spraying into the roadway, so that the role of the steel mesh can be further brought into play, an anti-corrosion effect can be achieved, and ultimately, the forces of the anchor mesh (cable), spray layer, and surrounding rock can be coordinated and maximized. Achieving a support effect is the most important goal, and the net section meets these requirements with minimal investment.

4. Method and technical requirement improvements of the process
First, on the basis of on-site investigation and geomechanical S1 evaluation of roadway surrounding rock, the cross section and support parameters of anchor mesh (cable) shotcreting roadways were designed with theoretical calculation and engineering analogies according to the use of roadway. The reserved deformation must be fully considered in the cross-section design.
Next step is to formulate the smooth blasting chart according to the driving section of the roadway and the surrounding rock conditions of the working face, break the rock according to the smooth blasting chart, and ensure that smooth blasting measures are in place. Then, adjust the smooth blasting parameters in time according to the smooth blasting effects in the implementation process to ensure that the smooth blasting effect meets these requirements.
Third, complete the initial shotcreting work under strict safety and quality control measures, such as knocking the roof and checking the heading forming size and temporary support, to ensure that the initial shotcreting reaches the straight arch garden of the wall, and the thickness of the initial shotcreting should prevail on the thinnest portion covering the rock.
surface. 

Fourth, use an injection anchor (anchor cable) and lay metal mesh according to the requirements of the steel mesh lap binding.

The fifth step is to repeat the 2\textsuperscript{nd}–4\textsuperscript{th} steps to release the surrounding rock stress of the constructed initial shotcreting anchor net (cable) roadway during the normal advancement of the roadway.

The sixth step is to measure the roadway S2 deformation after initially shotcreting the anchor net (cable) roadway after the surrounding rock stresses were released for one month. The measured results are then summarized and analyzed to determine the local reinforcement scheme according to the deformation. For sections where the measured deformation of the roadway does not exceed 80\% of the reserved deformation, further reinforcement measures are not needed; for those whose measured deformation reaches 80\% of the reserved deformation, lengthened anchors should be adopted for increased reinforcement. If the measured deformation exceeds the reserved deformation, the local broken gangue net bag shall be removed and the rising gangue shall be treated and checked; after meeting the requirements, it will be leveled by spraying concrete again. Then, stronger first-class anchor net (cable) reinforcement or grouting anchor net (cable) reinforcement must be adopted. For slight roadway bottom heave, directly pull the bottom, and use stronger first-class anchor net (cable) reinforcement or grouting anchor net (cable) reinforcement. For more serious roadway bottom heave, in addition to the bottom pulling measures, a bottom angle anchor or cable should be added to strengthen the support.

The seventh step is a thin spray into an alley. After releasing the stress and taking local reinforcement measures according to the measured deformation, the long section thin shotcreting measures can be taken to form a roadway. The shotcreting thickness can then be determined according to the service scope and use of the roadway. For the development roadway, the shotcreting thickness should reach 20–40 mm of the steel mesh protective layer; for the preparation roadway, the thin shotcreting thickness should be covered with steel mesh; for the rock roadway mining roadway, such as a bottom extraction roadway and car yard, the thin shotcreting should not be conducted.

Finally, according to the feedback of the measured deformation and shotcreting roadway and summarizing the data related to the cross section of the anchor mesh (cable) shotcreting roadway, the reserved deformation and design of various support parameters can be further adjusted to ensure that the economic and technical indexes of the newly constructed rock roadway anchor mesh (cable) shotcreting roadway are better.

5. Engineering experiment

5.1. Project overview

In August 2014, a field experiment was first conducted in the track roadway of the south wing of the second level (800 m) in the outskirts of Yong Coal Group Co. The roadway was a development roadway on the south wing of the second level with a design volume of 1596 m, construction of 931 m, and a remaining engineering quantity of 665 m.

The second horizontal south wing track roadway was driven along the roof mudstone, sandy mudstone, and medium- and fine-grained sandstone of the No. 2 coal seam. The distance between the roadway floor and the roof of No. 2 coal seam was 2.2–30 m, and the rock
hardness coefficient (f) was 4–7. Medium- and fine-grained sandstone was light gray and thin-bedded, mainly comprising quartz, feldspar, and small amounts of mica and argillaceous cementation. Sandy mudstone was gray, medium-thick layered, contained plant fossils, unevenly sand distributed, locally enriched, and locally intercalated with thin mudstone, and pyrite was seen on the fracture surface.

The design section of the roadway was straight wall semicircular arch with a wall height of 1600 mm, tunneling width of 4800 mm, tunneling height of 4000 mm, spray thickness of 100 mm, net width of 4600 mm, net height of 3900 mm, $S_{\text{excavation}} = 16.72 \text{ m}^2$, and $S_{\text{net}} = 15.67 \text{ m}^2$. The bolt was made of $\Phi 22 \times 2500 \text{ mm}^3$ high-strength steel, the bolt tray size was $200 \times 200 \times 10 \text{ mm}^3$, the row distance between the bolts was $700 \times 10 \text{ mm}^2$, each bolt used two resin anchoring agents (one MSK2335 and one MSZ2335 resin anchoring agent), the designed anchoring force was 120 kN, and the length of the exposed nut of the bolt was 10–40 mm. The mesh was a steel mesh, composed of 6.5 mm steel bar by longitude and weft welding. The mesh was $70 \times 70 \text{ mm}^2$, and the mesh size was $1000 \times 2000 \text{ mm}^2$. Seven anchor cables were constructed on the main roof, shoulders, and sides of the roadway to strengthen the support; the row distance between the anchor cables was $1400 \times 1400 \text{ mm}^2$ (the distance between the anchor cables was $2100 \times 1400 \text{ mm}^2$), the anchor cable size was $\Phi 21.6 \times 4600 \text{ mm}^3$, the anchor cable tray was $250 \times 250 \times 20 \text{ mm}^3$, each anchor cable used four resin anchoring agents (two MSK2335 resin anchoring agents and two MSZ2335 resin anchoring agents), and the anchoring force was designed to be 210 kN.

Using traditional construction technology, after roadway acceptance, most of the roadways have relatively serious convergence deformation and large areas of spray layer cracking, accompanied by different degrees of bottom heave phenomenon. In the course of use, we must stop normal driving to renovate and reinforce the rear roadway and expand and reinforce some sections, which not only wastes considerable manpower and material resources but also poses great threats to the safety management of the mine. It also significantly affects normal construction progress of the roadway and restricts the standards of quality and normal mining replacement of the mine. The design and technological process of rock roadway bolting net (cable) shotcrete support with drilling and blasting methods are shown in Figure 1.
5.2. Engineering experiments

An experiment was conducted using the “smooth blasting + first shotcreting then anchor + reserved deformation pressure + local reinforcement + thin shotcreting” technology. The original design of the straight wall semicircle arch, wall height, and anchor mesh (cable) support parameters remained unchanged; the drivage width was increased by 200 mm to 5000 mm; the drivage height was increased by 100 mm to 4100 mm; the shotcreting thickness of 100 mm was changed to the initial shotcreting thickness of 50 mm; the compound shotcreting thickness was 50 mm; the reserved deformation was 100 mm; the net width of the roadway $\geq 4600$ mm; the net height of roadway $\geq 3900$ mm; and $S_{net} \geq 15.67$ m$^2$.

The experiment was conducted in strict accordance with the technical requirements of the improved technology, and the smooth blasting quality was much higher than before. The smooth shotcrete surface after the initial spraying created better conditions for the construction of the anchor net (cable). All anchor cable trays were close to the shotcrete surface, and the anchors were arranged in rows along the normal direction of the roadway, so that the force of the anchor was uniform and a regular bearing arch structure could be formed. The allowable pressure of reserved deformation not only releases the stress of the surrounding rock and creates the joint action of surrounding rock and support but also helps to check the quality of anchor mesh (cable) support, ends hidden engineering, and improves the support quality of anchor wire mesh (cable) shotcreting. After releasing the stress, the last thin shotcreting roadway is locally reinforced, which not only makes the shotcrete fully bonded with the steel mesh to play a better supporting role but also enables the steel bar mesh and exposed components of anchor rods and anchor cables to play an anti-corrosion role. Finally,
the surrounding rock and support play a vital role, and the problems of large area cracking of the slurry skin and convergent deformation of the roadway after rock roadway construction were solved to its maximum extent. Its economic and social benefits were good, and its construction effect is shown in Figures 2 and 3.

Figure 2. Bolting-wire mesh-shotcreting initial support effect

Figure 3. Effect of thin sprayed entry after pressure release and local reinforcement

6. Popularization and application

6.1. Popularization and application of the project

On August 22, 2015, Yong Coal Group held a special meeting on “smooth blasting + first shotcreting and then anchor releasing stress + local reinforcement and thin shotcreting into roadway” in a suburban coal mine, requiring all rock roadway construction faces in suburban coal mines to use this technology no matter what kind of equipment was adopted. By the end of 2018, the roadway constructed by this technology is about 15615 m, and the main unit projects and quantities were as follows:

1. 2397 m of the second horizontal south wing track lane and belt lane;
2. 609.2 m of the second level south wing return air roadway;
3. 160 m of the second section of the second horizontal south wing return air roadway;
4. 1329 m of the second level auxiliary mining area track roadway;
5. 1644 m of the second level west wing track roadway and belt roadway;
6. 593.5 m of the second level east wing return air roadway;
7. 100.4 m of the east wing return wind uphill;
8. 14 auxiliary mining area track roadways;
(9) 864.3 m of the west wing return air dark inclined shaft;
(10) 123 m of the west wing return air dark inclined shaft return air bypass;
(11) 1417.7 m of the northwest return air Shimen;
(12) 56 m of the northwest return Shimen Guanlian roadway.

Simultaneously, under the initiative of the production department of the Yongcheng Coal Group, all suburban coal mines in the Yongcheng mining area of the Yongcheng Coal Group were visited and studied, and this technology was then promoted to them. Coal companies belonging to Henan Energy and Chemical Group Co., Ltd., were also visited for study, promotion, and application.

6.2. Economic benefits

(1) Material cost savings: according to statistical calculations, the rice extension cost of construction materials in the southern wing track roadway of the second level of the suburban mine was reduced from 1860 yuan/m to 897 yuan/m, which is 33.81% lower than that of the original technology; the rice extension cost of supporting materials was reduced from 2963 yuan/m to 2720 yuan/m, which is 8.3% lower than that of the original process. According to this, we can concluded that the total saved material cost for a suburban mine in 2018 was $15615 \times (9633243) \text{ yuan/m} = 18831690 \text{ yuan}$.

(2) Lane repair cost savings: if the original technology must by renovated by at least 60%, and the unit price of renovation is calculated at 10000 yuan/m. By the end of 2018, suburban mines can save at least $15615 \times 60\% \times 10000 \text{ yuan/m} = 93690000 \text{ yuan}$.

6.3. Social benefits

(1) After the adoption of the new technology, construction labor efficiency was increased from 0.86 m/work/month to 1.09 m/work/month, an increase of 27%, which can help the mine reduce personnel and improve efficiency.

(2) The quality of roadway support has been greatly improved, and the safety conditions of the roadways have been thoroughly improved, which puts an end to the cycles of repeated destruction, instability, and expansion of roadways and lays the foundation for the essential safety of mines as well as helps enhance the social image of enterprises.

(3) The tense situation of mine replacement is greatly alleviated, and the sustainable development of coal mining enterprises is promoted.

(4) The rice extension consumption of roadway construction materials and support materials is greatly reduced, which reduces the occupation and consumption of social resources, which is beneficial in saving energy and reducing pollutant emissions.

(5) Large numbers of fines and legal costs caused by blasting and anchor net (cable) construction quality are reduced, the income of construction personnel is increased, and the profitability of coal enterprises is increases.

(6) With continuous increases of mining depth in shaft coal mines, the proportion of soft rock and engineering soft rock is increasing, and the difficulty of shaft and roadway support is becoming more difficult. In this case, popularizing and applying this technology is important.

7. Conclusions

Through the study of the defects existing in the bolt mesh (cable) shotcreting technology in rock roadways, improvements were generated according to the joint action principle of
surrounding rock and support. Through field experiments, the problems of large area cracking, convergence deformation, and influences of spray layer after the construction of original rock roadway anchor mesh (cable) shotcreting technology have been overcome, and good results have been achieved. It has become popular and has been applied in a large area in this region and brother units with huge economic and social benefits, which can provide reference experience for other similar mines.

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