Research on thin spray-on technology and equipment of coal mine

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Abstract. Based on the existing problems and demands of coal mine support, as well as the advantages of thin spray-on liner in coal mine support and gas sealing, the research on thin spray-on material is carried out. Two kinds of thin spray-on products are qualitatively analyzed, and the thin spray-on equipment is developed and applied. The results show that the performance of thin spray-on material meets the requirements of coal mine. The production efficiency and construction speed are improved, and the underground material transportation volume and the number of workers are reduced. At the same time, gas infiltration is reduced and the safety of the underground is improved.

1. Introduction
Every year, tens of thousands of new tunnels are dug in coal mines, which form a large-scale underground mining channel with the accumulated tunnels over the years. The stability and maintenance of tunnels are directly related to the high efficiency, safety, clean production and social and economic benefits of coal mine.

Coal mine tunnels have many types and characteristics. Different tunnel types have different support requirements[1]. There is still much space for innovation in the traditional anchor, mesh and shotcrete supporting structures.

At present, coal mine production is facing more complex geological and environmental conditions. It is necessary to solve not only the surrounding rock control technology under difficult conditions, but also new problems such as surrounding rock weathering, device corrosion, gas leakage and so on. Therefore, it is of great significance to improve the traditional support system with low efficiency, high consumption and pollution, and develop a new type of excavation and support system which is faster, safer and cleaner than traditional system[2-5].

In the traditional support and shotcreting system, shotcreting not only plays the role of sealing and supporting, but also is the main reason of low efficiency, high consumption and pollution. Hanging the net further reduces the efficiency and greatly increases the labor intensity. The practice shows that the role of Shotcrete in all kinds of tunnels is not the same, and it can be summed up as mechanical action and non mechanical action. In the actual support work, a considerable part of its mechanical and non mechanical effects exist at the same time[6-8]. Therefore, shotcrete support can be reduced or cancelled according to the situation, and more reasonable technology can be used to replace it. It is necessary to develop and apply thin spray-on technology and equipment of coal mine[9].
Thin spray-on liners (TSL) sealing and support technology is a new support technology originated from Europe and America. It has the advantages of thin spray-on liner, dense texture, good elasticity, ductility, high tensile strength, good adhesion with the sprayed surface, etc. Since 1990, the research literature of TSL has gradually increased, mostly concentrated in Canada, the United States, Australia, South Africa, Germany and other countries. Dozens of TSL products have been developed, which are used to prevent the weathering and rust of the tunnels, replace the shotcrete and metal mesh support, and used as sealant [10-11]. This technology plays an important role, and is listed as one of the important support technologies by the mining management personnel. However, the research of TSL is mostly focused on hard rock tunnels of metal mine, and the material is generally expensive, which is difficult to be accepted by the coal industry. Based on the analysis of supporting mechanism of thin spray-on liner materials, the author developed the non reactive thin spray-on liner materials, equipment and supporting technology suitable for underground coal mine tunnel, and carried out the application of thin spray-on Technology to prevent weathering, rust and gas sealing on the wall of refuge chamber. It should promote the development and application of thin spray-on technology in coal mines and other mines.

2. Research and development of non reactive TSL technology for mining

2.1. Determination of basic formula and main performance
The TSL material of Germany, the United States, Australia, Canada, South Africa and other countries with advanced technology can be divided into reactive and non reactive types. The reaction type is mainly polyurethane / polyurea two-component system [12], which has good film-forming property and high strength. However, there is a small amount of temperature rise in the film-forming process, the operation of supporting equipment is complex and the cost is high. A large part of non reactive materials are cement-based materials, which are modified by adding polymer additives into cement paste. The advantages are low cost, the disadvantages are brittleness, low adhesion and durability.

The design principle of single component non reactive type for TSL material is determined to maintain good hydration film forming, tensile strength and adhesion strength, and meet the requirements of simple construction, safety, environmental protection and economy. Based on this, measures are taken to improve related properties, such as base emulsion optimization, curing, strength, water resistance, anti pulverization, anti shrinkage, defoaming and compact and uniform mixing. Nanjing Coal Science &Technology Research Co., Ltd. has determined the finalization formula of TSL materials for coal mines and trial produced samples. The parameters are shown in Table 1 and Table 2 respectively.

2.2. Research and application of thin spray-on equipment
In order to improve the efficiency and reduce the labor intensity of workers, the automatic spraying equipment was developed. Figure 1 shows the equipment. It is divided into two parts: the front vehicle and the rear vehicle. The rear vehicle is responsible for mixing slurry and outputting slurry to the front vehicle. The front vehicle is responsible for spraying the slurry on the tunnel wall. The front vehicle mainly includes crawler chassis, hydraulic system, explosion-proof electric control system, operating arm, etc. It has the function of space distance identification, analysis and control. The arm can be retracted, rotated horizontally and swung vertically to meet the operation requirements. The whole machine meets the explosion-proof requirements of coal mine. Table 3 shows the parameters of the spraying vehicle.

2.3. Determination of thin spray-on layer thickness
Through experimental study and comparison with projects, the spraying thickness is better controlled within 10 mm at a time, generally 5 mm. For specific engineering purposes, multiple re-spraying can be carried out to increase the strength or sealing degree, but after the bottom layer is dried. In order to achieve different spraying purposes, different TSL spraying times and thickness can be set. The
experimental study shows that the spraying with the purpose of preventing weathering and rust can be done with a thickness of 2-5mm at a time. If it is used to block gas, especially in the difficult refuge chamber for gas control, it needs 3-4 times of re-spraying, and the total spraying thickness is 10-20mm.

Table 1. Performances of TSL material designed by Nanjing Coal Science &Technology Research Co., Ltd.

|                                      | anti weathering, anti rust | gas sealing |
|--------------------------------------|---------------------------|-------------|
| Type of mixture                      | white powder with uniform particle size | white powder with uniform particle size |
| Powder density (g/mL)                | 0.68 ± 0.09               | 0.68 ± 0.09 |
| Weight of 1 mm thick (kg/m2)         | 0.9                       | 0.9         |
| Applicable temperature (°C)          | 5–45                      | 5–45        |
| Tensile strength (MPa)               | 4h>0.5, 1d>1.0, 7d>2.6, 56d>3.5 | ≥5.5        |
| Bond strength(MPa)                   | 1~2                       | 1~2         |
| Flexural properties                  | ---                       | Bendable 90 degrees |
| Liner thick (mm)                     | ≤10                       | ≤10         |
| Extensibility (4h~56d)               | ≥150%                     | ≥150%       |
| Air drying time (min)                | ---                       | ≤40         |
| Sealing performance                  | ---                       | Sealable low pressure gas |
| Flame retardancy                     | Self extinguishing        | Self extinguishing |
| Environmental protection performance | qualified                | qualified   |

*a environmental protection is the test result of Chinese coating quality inspection center according to GB18582-2008 "limit of harmful substances in interior wall coating of interior decoration materials".

Table 2. Tensile strength of TSL material of Nanjing Design & Research Institute and other company product sample.

| Sample                        | Nanjing | Germany |
|-------------------------------|---------|---------|
| Thick (mm)                    | 6.0     | 6.0     |
| Width (mm)                    | 9.2     | 9.2     |
| Length (mm)                   | 79.95   | 79.95   |
| Maximum load (N)              | 419.85  | 436.86  |
| Tensile strength (MPa)        | 7.6     | 7.91    |
Table 3. The parameters of the spraying-on equipment.

| Parameter term                        | value |
|---------------------------------------|-------|
| Length (mm)                           | 2200  |
| Width (mm)                            | 1500  |
| Height (mm)                           | 1700  |
| Maximum working height of arm (mm)    | 5600  |
| Maximum working section (m²)          | 35    |
| Maximum travel speed (km/h)           | 2     |
| Maximum climbing angle (°)            | 20    |
| Swing speed of arm (mm/s)             | 150   |
| Total power (kW)                      | 22    |
| Input voltage (V)                     | 1140/660 |

Figure 1. Newly developed thin spray-on equipment of coal mine.

3. Application example of coal mine

3.1. Anti weathering and anti rust test
It has been tested in Donghuantuo Coal Mine of Kailuan Group. The length of the test tunnel is 30 m. Compared with the shotcrete, the material transportation volume is reduced to 10%. The mixing
process is subtracted, the construction speed is increased by 3-5 times, and 3 workers are employed. The spraying thickness is 5mm, the construction speed is 5 m²/min. The spraying construction can be incorporated into the driving shift, and the driving speed is increased by 50%. The dust quality concentration is less than 10 mg/m³, basically no rebound. Film formation, extension, penetration, environmental protection, flame retardant and strength are good.

3.2. Sealing test of gas seepage in refuge chamber
It has been applied in Tiandi-Wangpo coal mine. The absolute emission of gas during driving (single tunnel): CH₄ is 1.6 m³/min, CO₂ is 0.2-0.55 m³/min, the relative gas emission is 13 m³/h. This is a high gas mine. After thin spraying, the gas concentration of the refuge chamber can be reduced from 28% /h to (0.1~0.5)% / h. Figure 2 shows the gas sealing situation.

![Figure 2. Gas plugging after thin spraying.](image)

4. Conclusion
Based on the nature of bolt support and the potential advantages of TSL technology, when the application conditions is permitted, or after the bolt support design is adjusted accordingly, it is expected that the new TSL technology will partially or completely replace the traditional spray and mesh functions. It will change the low efficiency, high consumption and pollution state of traditional spray and mesh construction.

The key mechanical properties of TSL, such as tensile strength and adhesion, are significantly higher than that of shotcrete. Moreover, compared with hanging net support, it has the advantage of timely bearing.

According to the characteristics and requirements of coal mine tunnels in China, non reactive and single component TSL materials are developed, and two kinds of products are finalized, which have the functions of anti weathering, anti rust and gas sealing. They have good film-forming property, tensile strength and bonding strength. The tensile strength has reached 3.5-7.8 MPa, reaching the level of other TSL products with high tensile strength. At the same time, it can meet the requirements of simple construction, safety, environmental protection and economy.

According to the characteristics of TSL and its application in coal mine, the automatic spraying equipment is developed. It has the characteristics of continuous work, automatic walking and efficient operation.

The field application of anti weathering and anti rusting and gas sealing of refuge chamber were carried out respectively. In the first test, compared with shotcrete, it can reduce the material transportation by 90%, reduce the mixing process, increase the spraying speed by 3-5 times, and
employ only 3 people. In the second test, under the condition of wind stop, the gas concentration of the refuge chamber after construction can be reduced from 28% / h to (0.1~0.5)% / h, and the plugging effect is remarkable.

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