Research on Dust Generation Mechanism and Dust Reduction of Tidal Shotcrete in Underground Coal Mine

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Abstract. Through the research on the source and mechanism of the dust generated by the tidal shotcrete in coal mine, and the inevitability analysis of the tidal shot from the aspect of construction technology, the main influencing factors of the dust are summarized, and the tidal shot, which is the direction of concrete dust reduction and related measures.

1. Introduction
Shotcrete support is the main technical method of bolting and shotcrete support for opening up roadways in coal mines in China. After years of development, wet spraying technology has made great progress, and wet spray technology has been widely used in tunnels, buildings, large coal mine roadways and other projects [1]. Although wet spraying technology has many advantages, due to the generally poor conditions of domestic coal mines, the tide spraying technology is still the main method, and the construction equipment generally uses rotor concrete spraying machine [2]. The tide spraying technology and rotor concrete spraying machine generally have a large dust concentration [3], and more in-depth analysis and research on the tide spraying process and construction equipment are needed [4-6], and the combination of the tide spraying technology and construction technology are used to better solve the key problem of dust reduction.

2. Source and Mechanism of Dust
Through analyzing the process, equipment and environment of sprayed concrete construction in coal mines, the dust produced by sprayed concrete comes from three parts, mainly including dust near the machine, spray gun dust, and tunnel ventilation dust.

2.1. Dust Near the Machine
From the analysis of the sprayed concrete process and equipment, the dust mainly comes from the dust produced by the feeding and the dust from the sprayer.

1. Feeding dust
The shotcrete loading process is the main source of dust. Feeding mainly forms artificial throwing dust and dust falling from the feeding port.

The mixing and feeding of shotcrete in coal mines are generally manually operated, and dust will be generated throughout the process. During the feeding process, the dust particles are subjected to mechanical force, gravity, Brownian motion and air force. The air intake and return of the tunnel are all important factors influencing the generation of dust. When feeding, block and granular materials move at high speed in the air, pushing the surrounding air to flow and there is a shearing effect at the same time, including the formation of dust under the action of various airflows when the feeding port leaks and falls.
During manual mixing and feeding, the airflow forms a turbulent airflow under the action of the shovel movement, but due to the viscosity of the gas, there is a step difference between the material and the airflow speed, and the fine particles in the material are separated from the material under the action of the airflow, resulting in dust. When the material is falling, the turbulent air flow is generated as the speed increases, so that the fine dust in the material moves with it and forms flying dust.

2. Dust running from equipment

Dust running on the friction plate bonding surface and dust exhaust from the residual air port are the main sources of dust next to the rotor jet equipment.

The dust generation point of the jet equipment is mainly the joint between the rotating lining plate and the friction plate. Dust generation is mainly caused by the formation of leakage grooves between the rotating liner and friction plate of the rotor due to wear; the lack of compression between the rotating liner and the friction plate and the difference in pressure at various positions cause uneven wear and form joint air leakage and running dust.

When the rotor is running, the remaining air from the material cup drives part of the dust to be discharged, forming spray dust with a relatively large movement speed, and quickly spreading to the side of the machine and outside space. When the material cup is sealed, the internal air pressure is about 0.5 MPa, and the compressed air is in a compressed state. When rotating to the exhaust port, the pressure instantly decreases from 0.5 MPa to atmospheric pressure, and the gas volume expands sharply and quickly moves to the remaining air port, entrained in the movement material particles and dust, etc., forming jet dust.

The ventilation and irregular airflow of the tunnel blow up the dust deposited on the equipment, as well as the reciprocating motion and vibration of the jet machine to form secondary equipment dust.

The dust near the machine is mainly due to the continuous action of these two processes, which then forms the dust dispersion in the roadway.

2.2. Spray Gun Dust

Spray gun dust is the main source of sprayed concrete dust. When the mixture is ejected from the spray gun, the four-phase mixture is subjected to high-pressure gas, material segregation occurs, and the spray surface impacts and rebounds, causing a large amount of cement and other dust particles to separate and diffuse, and the dust production between the spray gun and the spray surface is sharply increased, accounting for more than 80% of the total dust produced by shotcrete operations.

1. Airflow diffusion

Cement, sand, and stones are mixed with high-pressure water in the spray gun and hydrated into concrete aggregates. The mixture is restrained by the spray gun wall in the spray gun. When the high-pressure air brings the material out of the spray gun mouth in a turbulent jet state, the compressed air pressure at the spray gun is instantaneous decreased, the concrete at the spray gun outlet and the compressed air volume expand drastically, as shown in Figure 1, which will surely cause part of the powdery mixture to spread rapidly. The high-velocity air flow of the compressed air has a destructive effect on the adhesion of concrete aggregates. When air molecules exchange momentum with the high-speed fluid, they passively generate high-speed airflow, destroy the bonding of the pellets, and form a two-phase flow of materials and gas with the dust in the air, which in turn causes spray dust pollution and increases the working dust concentration.

![Figure 1. Jet spread](image-url)
2. Granular interaction

According to the viscous fluid mechanics, when there is a speed difference between the two layers of fluid, the shear of the fluid is generated, forming a swirling flow, so that the discrete particles diffuse at a faster rate. Cement, sand, stone, and aggregates after hydration are different in particle size and quality. Under the influence of the turbulent characteristics of the circular jet, the conveying speed, suspension speed, and force are different. The interaction between the jet particles leads to direct radiation, refraction and rotate [7] to cause material agglomerates to disperse, and the airflow contains high volume of dust. Stones have large mass and kinetic energy, and are more likely to produce dust when interacting with cement.

3. The material collides with the sprayed surface

When spraying concrete, driven by high-pressure airflow, cement, sand, stones and concrete pellets hit the sprayed surface at high speed. The two-phase flow of high-speed material and gas emitted by the spray gun impacts the spray surface, forming a radial wall jet diffusion, as shown in Figure 2.

![Figure 2. Jet collision diffusion](image)

Under the action of high-speed jet, there are big differences in the size and quality of the sprayed material particles, and the movement speed, suspension speed, force direction and size, etc. are all different. Cement, gravel, and concrete pellets collide with the sprayed surface at high speed. The rebounding gravel will break up the pellets, and the fine dust will break away from the pellets to form dust again, increasing the dust concentration. Agglomerates with large masses have high kinetic energy and are more likely to be destroyed to produce dust.

In the process of spraying concrete, not only the rebound dust collides with the jet to produce small-size dust; the unbonded dust on the wall surface will form "dust" under the action of high pressure air and concrete jet. The higher the velocity of the spray gun concrete jet, the closer the distance between the spray gun and the sprayed surface, the greater the "dust".

2.3. Roadway Ventilation Dust

During sprayed concrete construction, air supply is required to ensure the breathing of personnel. The air supply in the roadway itself contains a certain concentration of dust, and under the disturbance of large flow and low pressure airflow, the fine dust adhered to the sidewall of the roadway will fall off and move with the wind to form secondary dust. This dust is generally small particle size dust, coal dust, etc., and the amount of dust is relatively small compared with that of other sources, but it is mainly respirable dust, which is also more harmful.

3. Influence of Shotcrete Technology

3.1. Tide Spray Method

Coal mines now generally use tidal mixtures, which are subject to artificial influences, poor mixing uniformity, insufficient moisture content, and easy formation of dust by themselves. The mixing time of water and mixture in the spray gun is extremely short, and the cohesiveness of the agglomerate itself is low. The tiny cement and other material particles that are not wet can easily form dust under the action of air pressure.
In the long-distance construction such as roof spraying, the measures of increasing air intake are generally adopted, which makes it easier to produce more dust. The smaller the particle size and the smaller the mass of the dust, the larger the surface area of the dust and the stronger adsorption capacity of the air. The dust with small particle size and small mass is not easy to settle and is suspended in the underground air for a long time. In the case of long-distance injection, the higher the velocity of compressed air, the more suspended dust particles and the larger the dust particles. The dust suspended in the air has the tendency of concentration uniformity, and the dust diffuses from the high concentration area to the low concentration area.

3.2. Operation Technology

During the shotcrete process, the operator controls the amount of water to directly affect the dust size. Different people and environments have different water control, which can easily lead to changes in dust production.

The ∞-shaped drawing circle and the S-shaped swing of the spray gun nozzle make the concrete and the compressed air jet form a compound motion-swirling jet. The tangential velocity of the rotating jet causes the fluid in the spray gun to rotate, and the ejected fluid has a tangential velocity. The speed of rotation produces pressure gradients in the radial and axial directions and affects the entire jet. The swirling jet expands faster than the ordinary fluid without swirling, and its entrainment capacity, mixing effect, and attenuation of the axis velocity are greater than that of the ordinary jet, which greatly accelerates the generation of dust.

In tidal sprayed concrete construction, dust production is more complicated. The uneven mixing and low viscosity of the sprayed materials are internal factors; the high flow rate and entrainment of air pressure, the self-collision of the materials and the collision of the sprayed materials with the roadway wall, and the operation technology are the main external factors. The dust concentration of tide spraying far exceeds the prescribed upper limit, and the operating conditions are harsh. In order to control the dust, it is necessary to scientifically utilize the characteristics of the dust and study effective technical measures to achieve the goal of dust reduction and improve the sprayed concrete working environment.

4. Dust Reduction Measures

In view of the tide spray support technology, research is carried out from several aspects such as construction technology, materials, and dust removal, so as to achieve the control of dust production and dust reduction from the cooperation of technology and equipment.

4.1. Construction Technology

1. Air pressure is a key parameter of shotcrete, which has a greater impact on dust concentration and rebound rate. When the working air pressure of the spray gun is greater than 0.1MPa, the material bundle speed is fast, the impact force is large, and the concrete is easy to fall off by the impact of high pressure gas. As the working air pressure of the sprayer increases, the dust concentration of the spray gun increases linearly with the air consumption. According to the conveying distance, the air pressure should be adjusted in time.

2. The distance of spraying (feeding gun) has the second effect on dust production and rebound rate. If the spray gun is close to the base surface, the concrete is easy to fall off; if the distance is long, the density of the sprayed concrete is poor, the adhesion of the concrete decreases, and the rebound and dust concentration increase. The nozzle of the spray gun is about 1 meter away from the spray surface, and the dust concentration is greatly improved.

3. The spray angle has a greater direct impact on the rebound and a significant impact on the dust. When the spray gun is perpendicular to the base surface, the dust and rebound are relatively small; when the spray angle is less than 70º, the dust and rebound of the aggregate will increase rapidly. According to the spray position, the spray gun should adjust the spray angle in time and control it at 80º~90º.

4. Water pressure has a greater impact on the hydration and wetting of cement. Low water pressure causes uneven cement mixing; high water pressure causes high spray gun pressure. The water pressure
should be slightly higher than the air pressure to ensure that the spray gun fully hydrates the material flowing at high speed. Since the air pressure needs to be adjusted every 10-20m, the water pressure should be adjusted to make the water pressure higher than the air pressure by about 0.05-0.1MPa.

4.2. Material Grading and Additives
The gradation of concrete is unreasonable, and the strength of the spray layer is reduced, which seriously affects the quality of the project. A gradation test is required for the amount of cement, etc. The unreasonable ratio will cause material waste, low concrete strength and increased dust concentration. The reasonable ratio of shotcrete material: cement: sand: stone is 1:2:1.5-2. By increasing the moisture content of the mixture, strengthening the uniformity of the mixing, while keeping the water-cement ratio at about 0.4, it has a significant effect on the reduction of dust.

In-depth research on sprayed concrete admixtures, under the condition of ensuring the performance of sprayed concrete [8], reduces dust generation and solves the dust problem of sprayed concrete. By adding admixtures, improving the wetting performance of cement, enhancing the adhesion between cement, sand and stones [9], and improving the adhesion of materials to rock surfaces are effective methods for spraying concrete to reduce dust.

4.3. Dust Collector
On the basis of improving the spray equipment's own dust reduction technology, a matching dust collector is selected to reduce dust from the outside. Common dust collectors use the characteristics of dust gravity, inertial collision, static electricity and condensation to comprehensively remove dust. The physical properties of dust are closely related to the choice of dust removal technology. The auxiliary use of chemical dust suppressants and other measures to change the physical properties of dust can greatly improve the dust removal effect.

5. Conclusion
Shotcrete support has many advantages, but there are also many technical disadvantages. Alternative support materials can be studied in some application fields. In recent years, the materials and technology of TSL thin spray support [10] developed by research institutions at home and abroad have achieved good engineering results and give full play to the advantages of spray support technology.

The generation, diffusion and movement of tidal shotcrete dust particles are more complicated. Through the research of dust generation mechanism, the direction and effective method of reducing sprayed concrete dust are proposed. In order to ensure a clean and safe coal mine shotcrete working environment, in-depth technical research to effectively reduce shotcrete dust can reduce the risk of occupational diseases such as pneumoconiosis, better protect the health of shotcrete workers, and promote the advancement of coal mine bolt and shotcrete support technology.

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