Comparison and analysis of dry mixed mortar and traditional shotcrete and equipment development scheme

Xu Li1,*, Hong li Zhu2, Wen qing Jing2 and Guo qiang Cheng4
1School of Shandong University of science and technology, Qingdao, China
2Zaozhuang Mining (Group) Co., Ltd Jujube Mining Group Co., Ltd., Zaozhuang, China
*Corresponding author: 291383041@sdust.com.cn

Abstract. In order to study the advantages and disadvantages of dry mixed mortar and traditional shotcrete in underground shotcreting operation, and improve the mechanization level of underground shotcreting operation. This paper makes a statistical analysis on the use of dry mixed mortar shotcreting machines in 10 pairs of mines, such as Fucun and Tianchen of Zaokuang group. It is found that the dust content in the feeding point and the shotcreting point is higher, and the rebound is also higher. Six pairs of coal mines, such as Fucun and Tianchen, were select to compare and analyze the shotcreting efficiency, rebound rate, dust rate and economic and technical indicators between dry mixed mortar and traditional mortar. The results showed that compared with traditional mortar, the shotcreting efficiency of dry mixed mortar was increased by 55.1%, the work efficiency was increased by 97.9%, and the rebound rate was reduced by 4.8%. Based on the above problems existing in dry mixed mortar shotcreting operation, the joint scientific research institute of Zao mining group put forward the schemes of bag feeding of finished dry mixed mortar and centralized feeding of finished dry mixed mortar, as well as the new shotcreting machine JSPB-8LX which can automatically adjust the water cement ratio, laying a foundation for the comprehensive promotion and application of dry mixed mortar under the mine.

1. Introduction
At present, there are two kinds of mortar used in coal mine roadway shotcreting: dry mixed mortar and ordinary mortar. The former refers to a kind of granular or powdery mixture produced by professional manufacturers, dried and screened fine aggregate and inorganic thickening materials, mineral admixtures and additives according to a certain proportion, which is usually transported to the site in bags and can be directly used after mixing with water[1]; the latter needs to be mixed with cement, sand and additives on site.

As one of the five natural disasters in coal mine, dust is an important factor that can not be ignored in underground safety operation. Dust will cause serious harm to the health of workers, and cause coal dust explosion accidents under certain conditions, causing casualties and property losses[2,3]. Some experts and scholars have done research and Optimization on the improvement of shotcreting operation environment. Domestic and foreign scholars have made a lot of analysis and comparison on the quality, environmental protection, performance and social benefits of the two kinds of mortar[4,5]. The results show that dry mixed mortar has obvious advantages in many aspects, and the implementation of dry mixed mortar has become an inevitable trend[6-11]. With the increasing use of dry mixed mortar[12-15], scholars at home and abroad have done a lot of research work to improve the
performance of dry mixed mortar. However, due to the late development of dry mixed mortar and the limitation of underground application scenarios, the underground construction equipment is not perfect, resulting in some unknown problems in the application of dry mixed mortar underground[16,17]. Based on the background of the shotcreting competition of Zaokuang group in 2020, through the investigation and analysis of the current situation of 10 pairs of dry mixed mortar under Zaokuang group, and selecting 6 pairs of mines for comparative analysis on the shotcreting efficiency, rebound rate and economic and technical indicators between traditional shotcreting and dry mixed mortar shotcreting, summarizes the advantages and existing problems of dry mixed mortar, and puts forward reasonable solutions.

2. Present situation and problem analysis of shotcreting in mines

| Mine name   | Net section/m² | Number of workers | Shotcreting machine to shotcreting site/(Bag / h) | Shotcrete material/(Bag / h) |
|-------------|----------------|-------------------|-----------------------------------------------|-----------------------------|
| Fu Cun      | 14.3           | 5                 | 117                                           | 10                          |
| Tian Chen   | 11.21          | 4                 | 120                                           | 32                          |
| Xin’an      | 14.2           | 4                 | 185                                           | 20                          |
| Jiang Zhuang| 17.1           | 3                 | 156                                           | 24                          |
| Gaozhuang   | 14.92          | 5                 | 210                                           | 18                          |
| Daizhuang   | 15.75          | 5                 | 139                                           | 12                          |
| Qiwu        | 17             | 5                 | 209                                           | 19                          |
| Chaili      | 16             | 5                 | 231                                           | 21                          |
| Sanhekou    | 15.3           | 7                 | 166                                           | /                           |
| Binhu       | 12.4           | 5                 | 90                                            | 9.75                        |

2.1. Analysis of shotcreting speed and efficiency

According to the analysis of the total amount of shotcreting in the table above, Chaili, the Seventh Five Year Plan and Gaozhuang are well organized and the feeding speed is fast. The shotcreting amount in one hour is more than 200 bags, among which Chaili is the highest, reaching 231 bags. From the perspective of equipment, 6 units, namely Xin’an, Gaozhuang, Daizhuang, Qiwu, Chaili and Sanhekou, use weitelibon push chain concrete shotcrete machine, with an average shotcrete volume of 185 bags (50kg / bag) per hour Zhuangzi, Tianchen and Binhu use traditional rotary shotcreting machine, with an average shotcrete volume of 139 bags; Fucun uses Tianhe pyc6z rotor concrete shotcrete machine to load 117 bags. Through the above analysis, at present, the dry mixed mortar spraying speed of finished products in mining area is faster and more widely used, or viterbon push chain concrete spraying machine.

In this shotcreting competition, 3 people spray in Jiangzhuang, 2 in feeding and 1 in operating gun head; 4 in Xin’an and Tianchen, 3 in feeding and 1 in operating gun head; 5 in other mines, 3 in feeding and 2 in gun head; among them, Jiangzhuang has the highest per capita efficiency, with 52 bags/h per capita, followed by Xin’an with 46.25 bags / h per capita; Binhu uses rotary V shotcreting machine and mixture 25kg/bag, loading 180 bags, converted to 50kg/ Bag, 18 bags/h per capita, the shotcreting efficiency was the lowest.

Through the shotcreting competition and circulation, at present, the number of shotcreting is generally 5. The finished dry mixed mortar is used to reduce the mixing link. If the feeding part and feeding mode are improved (tank truck screw feeding or box hopper feeding), the automatic feeding can be realized, and the purpose of reducing manpower and improving efficiency can be achieved.

2.2. Equipment analysis

At present, there are mainly three types of shotcreting machines in use:
Traditional VII (or V) shotcreting machine (Jining district has been completely eliminated, Zaozhuang district is widely used), viterbon pts7 push chain concrete shotcrete machine (jslt7-l improved), Shandong Tianhe pyc6z hydraulic rotor concrete spraying machine.

(1) Rotary VII shotcreting machine has high discharging speed, but poor sealing performance, and there is too much dust around the body; rotary V is evenly fed, but the feeding speed is too slow, and the body has a lot of dust, so it is not suitable to use dry mixture, so it is recommended to eliminate it.

(2) The pts7 push chain concrete shotcrete machine of viterbon pts7 has been used for a period of time, which greatly reduces the sealing performance and air leakage of the fuselage. In addition, the exhaust gas is directly discharged to the outside, resulting in a large amount of dust at the fuselage. The jslt7-l improved concrete shotcrete machine is integrated with the feeding machine and the shotcrete machine, and the exhaust gas and residual materials are discharged in the middle, but the feeding port is high, and there is no filter bag and dust collector. After the transformation, it will be the current spraying It is a mature product of Shegan mixture.

(3) Shandong Tianhe pyc6z hydraulic rotor type concrete spraying machine has the advantages of uniform feeding, adjustable speed, small rebound rate and small dust production, which is suitable for dry mixing. However, the space occupied by shotcreting machine and feeding machine is large. In addition, through the investigation of Binhu and Tianchen, the stator is easy to be damaged and the maintenance cost is high (once a month, the stator is coated with glue, the cost is about 10000 yuan, and the cost of replacing the stator is 20000 yuan).

2.3. Dust concentration analysis

| name       | Feeding point | Shotcreting site |
|------------|---------------|------------------|
| Tian Chen  | 144.67        | 122.83           |
| Xin'an     | 12.19         | 10.63            |
| Jiangzhuang| 13.35         | 17.20            |
| Gaozhuang  | 13.90         | 79.70            |
| Daizhuang  | 15.20         | 13.10            |
| Chaili     | 104.30        | 99.90            |
| Binhu      | 36.18         | 14.04            |

The dry mixed mortar is used by all units in this shotcreting. Through the comparison and analysis with the cycle, the largest dust emission is still at the loading site. The dust concentration of Xinan, Jiangzhuang, Gaozhuang and other mines with good ventilation is about 13mg/m³. The dust in Tianchen, Chaili and other units with poor equipment condition is too high to see people. However, through the upgrading of equipment and the sealing of equipment in the future The dust concentration in the shotcreting site is closely related to the water cement ratio, material outlet pressure and aggregate particle size. The water cement ratio is relatively large when spraying in Xin'an, Daizhuang and Binhu (water seepage can be seen obviously after spraying), and the dust concentration is basically controlled at about 13mg/m³; in addition, through the comparative analysis of the length and outlet diameter of the gun head, Fucun and Xin'an guns are selected The head length is 700mm, the outlet diameter is 40mm, and the dust produced on the spraying surface is small; Daizhuang gun head is 800mm, outlet diameter is 30mm, Binhu gun head is 700mm, outlet diameter is 30mm, feeding speed is slow, although the water cement ratio is large, but the field visual inspection dust is still large; after the Chaili shotcreting, the gun head with 1.2m long and 40mm outlet diameter is used for test, the rebound rate is reduced, but the change of dust concentration is unknown In addition, the gun head is long and bulky, and the workers are not flexible in operation.

3. Comparative analysis of dry mixed mortar and traditional mortar

In order to study the problems existing in the application of dry mixed mortar in underground coal mine, we investigated six pairs of coal mines under Zaokuang group, including Fucun, Tianchen, Xin'an, Jiangzhuang, Gaozhuang and the seventh five-year plan, and recorded the shotcreting efficiency, rebound amount and labor cost of traditional shotcreting and dry mixed mortar in a group of six coal mines of these six pairs of coal mines, as shown in Table 3.
### Table 3. Comparison table of labor efficiency and rebound rate.

| Mine name | Dry mixed mortar | Conventional Mortar |
|-----------|------------------|---------------------|
|           | Shotcreting efficiency (bag / person · h) | Rebound rate /% | Shotcreting efficiency (bag / person · h) | Rebound rate /% |
| Fu Cun    | 23.4             | 8.55                | 17                  | 12.75               |
| Tian Chen | 30               | 26.67               | 14                  | 22.62               |
| Xin'an    | 46.25            | 10.81               | 21                  | 15.20               |
| Jiang Zhuang | 52               | 15.38               | 25                  | 14.40               |
| Gaozhuang | 42               | 8.57                | 22                  | 15.45               |
| seven five | 41.8             | 9.09                | 41.8                | 9.09                |

#### 3.1. Analysis of shotcreting efficiency

Through the investigation and analysis of the actual data of dry mixed mortar and traditional shotcrete materials used in 6 coal mines, such as Xiaocun and Tianchen, it is found that the average time of using traditional shotcreting materials is 107 bags (25 bags per vehicle, 50kg / bag); the dry mixed mortar is 166 bags per hour, and the efficiency is improved by 55.1%; during the shotcreting competition, the number of participants in each mine is 3-5, with an average of 4.8 The efficiency is 39.2 bags / person · h, while the traditional shotcreting materials generally need 5-6 people, with an average of 5.5 people. The shotcreting efficiency is 19.8 bags / person · h, and the work efficiency is increased by 97.9%. With the implementation of automatic feeding and other measures, the next shotcreting operation can reduce 1-2 people, and the work efficiency is improved more significantly.
3.2. Analysis of rebound rate

Figure 2. Comparison table of rebound rate between dry mixed mortar and traditional shotcrete.

Through the comparative analysis of the rebound rate of dry mixed mortar and traditional sand cement, the average rebound rate of this shotcreting competition is 11.9%, while the average rebound rate of traditional sand and cement is 16.7%. During this shotcreting competition, the particle size of dry mixed mortar in Jiangzhuang is larger and the control of water cement ratio is not good, which leads to the rebound rate of dry mixed mortar slightly higher than that of traditional sand mortar. Comprehensive comparative analysis shows that the rebound rate of finished dry mixed mortar is far lower than that of traditional sand mortar. With the continuous improvement of shotcrete hand proficiency and the scientific and reasonable aggregate ratio, the rebound rate of each mine can be further reduced.

3.3. Analysis of economic indicators

Table 4. Cost comparison table of dry mixed mortar and traditional shotcrete.

| Project       | traditional shotcrete | dry mixed mortar |
|---------------|-----------------------|------------------|
| Unit price of proportioned mortar (yuan / T) | 220.7                | 370              |
| Rebound rate  | 16.7%                 | 11.9%            |
| Number of workers | 6                    | 4                |

Material cost calculation:

Taking the semi-circular arch roadway with net width of 3.6 m, wall height of 1.2 m and shotcrete thickness of 100 mm as an example, the concrete volume required by linear meter theory is as follows:

\[ V = \left( 3.14 \times 1.9 + 1.3 \times 2 \right) \times 0.1 \times 1 = 0.857 \text{m}^3 \]  

The accelerator dosage is 5% of the cement dosage, the accelerator: cement: river sand: Stone nitrate = 0.05:1:2:2 (weight ratio), the concrete density is calculated as 1.6 t / m³.

The rebound rate of traditional sand mortar shotcreting is considered as 16.7%, and the unit price of linear meter material is:

\[ \left( 0.0136 \times 850 + 0.272 \times 520 + 0.543 \times 133.1 + 0.543 \times 137.5 \right) \times 1.167 = 350.0 \text{RMB} \]  

The rebound rate of dry mixed mortar is 11.9%, and the unit price of linear meter material is:

\[ 0.857 \times 1.6 \times 370 \times 1.119 = 567.7 \text{RMB} \]  

Using traditional aggregate shotcreting, the average labor force is 6 people, and the labor cost is paid per linear meter:

\[ \left( 0.667 \times 1.13 \times 1.69 \right) \times 10000 / 30 = 424.4 \text{RMB} \]  

The finished dry mixed mortar is used for shotcreting, and the shotcreting efficiency is calculated as 1.6 times of the labor force, and the labor cost is paid for each linear meter:
Traditional aggregate shotcreting, comprehensive cost per linear meter:

\[
(0.267*1.13*1.69) \times 10000/30 = 170.02 \text{RMB}
\] (5)

Comprehensive cost per linear meter of dry mixed mortar shotcreting:

\[
350.0 + 424.4 = 774.4 \text{RMB}
\] (6)

\[
567.7 + 170.2 = 737.9 \text{RMB}
\] (7)

To sum up, compared with the traditional mortar, the comprehensive cost of using the finished dry mixed mortar is basically equal to that of the traditional mortar, and the comprehensive finished product of the finished dry mixed mortar will be significantly lower than that of the traditional shotcrete material if the number of people can be reduced continuously.

3.4. Particle size analysis of aggregate

Through communication with the dry mixture manufacturer, the dry mixture ratio has been adjusted three times, as follows:

| Num | Cement /kg | fly ash /kg | additive /kg | rubber powder /kg | coarse sand /kg | medium sand /kg | fine sand /kg | Rebound amount |
|-----|------------|-------------|--------------|------------------|----------------|----------------|--------------|----------------|
| 1   | 259.3      | 20          | 0.7          | 0                | 300            | 200            | 220          | high           |
| 2   | 255        | 20          | 2            | 3                | 50             | 200            | 470          | low            |
| 3   | 268.7      | 20          | 1.8          | 4.5              | 130            | 200            | 375          | middle         |

(1) When Jiangzhuang and Tianchen tried the mixture for the first time in October last year, the particle size was large, and the rebound rate was too high; after the second adjustment, the particle size was small, and the rebound rate was greatly reduced, but the dust on the site was relatively large, and there was no person at the feeding place and shotcreting head-on.

(2) the third batch of dry mixture is used for shotcreting competition, which can basically meet the production needs, but the particle size is still relatively fine compared with the traditional mortar, and there is more floating dust. Through the comparison of rebound material and shotcrete surface sampling, the wall fabric is basically composed of materials with particle size less than 2mm, and the opposite side of Jiangzhuang shotcrete surface is full of stone chips with particle size of 3-5mm.

To sum up, the third batch of dry mixture can basically meet the production needs, but it is still necessary to reduce the proportion of fine materials and reduce floating dust.

4. Upgrading Scheme of shotcreting transformation

Aiming at the problems existing in the dry mixed mortar sprayed by shotcrete machine, the production department of Zao Mining Group conducted a technical discussion with Shandong Tianhe Technology Co., Ltd., Shandong weitelibang mining equipment Co., Ltd. and Shandong yarit Electromechanical Engineering Technology Co., Ltd. on April 25. The specific transformation and upgrading scheme and advantages and disadvantages are as follows.

4.1. Centralized feeding of finished dry mixed mortar

(1) The feeding port of the shotcreting machine is reformed. Only two ports of dry mixture and accelerator are reserved. The screw power motor is installed on the top, and the distance between the dry mixed mortar inlet and the bottom plate is not more than 300 mm.

(2) To change the current bagged feeding mode, the screw feeding of tank car is adopted (screw at the bottom of the tank car and pneumatic output is provided), and the output is directly into the feeding port through the feeding pipe.

(3) The dry mixed mortar is transported to the mine by a large tank car, and then loaded into the well through small tanks. The tank car is sealed to avoid solidification; the upper part is reserved with a filter type air exchange opening, which can be opened during use to avoid dust.
Advantages: the use of small cans for sub charging and feeding has a short R & D cycle, which is estimated to be about 3-6 months; centralized feeding is easy to realize automatic feeding and reduce the labor intensity, and one person can load.

Disadvantages: (1) the investment cost is large, so it needs to be processed and put into special tank car to replace the current Tramcar Transportation;

(2) The transportation pressure is high, the tank car is specially used, and other materials and materials cannot be loaded and transported;

(3) It is difficult to solidify the dry mixture in the tank or in the pipeline because of the high requirements on the solidification period and moisture resistance of the dry mixture.

4.2. Wet shotcreting is adopted

The long-distance concrete shotcreting machine developed by viterbon has been tested in Gaozhuang and Xin'an. Aiming at the problems of long-distance pipe plugging, uneven spraying and collapse after spraying, the equipment pulse is reduced. At present, a small-sized spb7 wet concrete spraying machine is developed, with a spraying distance of 50-100m, which is currently applied in Tangkou. The feeding adopts centralized and quantitative feeding, and shotcrete after mixing by mixer to solve the problem of water cement. The ratio can not be automatically proportioned.

Advantages: wet spray technology can effectively reduce dust concentration from the source.

Disadvantages: (1) there is still no good solution for the problem that the water cement ratio can not be adjusted automatically for continuous feeding, and the water quantity needs to be adjusted manually.

(2) Wet spraying machine and mixer are used together, and quantitative feeding. Although it can mix evenly, it takes up a large space. The overall dimension of single equipment (length × width × height): 2670mm × 910mm × 1430mm;

(3) After adjusting the pulse of the equipment, the spb7 type wet concrete shotcreting machine can meet the needs of underground shotcreting at present, but the spraying distance of 50-100m is too short and it moves frequently.

5. Conclusions

(1) The shotcreting efficiency of dry mixed mortar can reach 39.2 bags / person · h, compared with 19.8 bags / person · h, the work efficiency of dry mixed mortar is increased by 97.7%, which has obvious advantages.

(2) The average rebound rate of dry mixed mortar is 11.9%, while that of traditional sand mortar is 16.7%. The rebound rate is reduced by 4.8%, and the rebound rate is still large.

(3) The cost of dry mixed mortar per meter is 737.9 yuan, while the cost of traditional shotcrete is 744.4 yuan. Compared with traditional mortar, the cost of using finished dry mixed mortar is basically equal to that of traditional mortar. If the number of people can be reduced continuously, the comprehensive finished product of dry mixed mortar will be significantly lower than that of traditional shotcrete material.

(4) The dust content of dry mixed mortar is high, so it is necessary to adjust the aggregate size and reduce the proportion of fine materials.

(5) The upgrading scheme 3.2 for shotcreting transformation is the most mature technology with the least amount of research and development. After the technical transformation scheme of shotcrete machine and dry mixing tank car is reformed, the labor intensity can be effectively reduced and the automatic feeding can be realized, which is conducive to the promotion and use of dry mixed mortar. The design scheme has been discussed with relevant manufacturers, and the scheme is being formulated.

Acknowledgments

References

[1] Qiu Qianan. Discussion on the role and effect of dry mixed mortar in construction [J]. China new technology and new products, 2011 (22): 198
[2] Jian Jie, Xie Jianlin, Guo Yongyi. Determination and analysis of coal mine dust concentration and particle size [J]. Journal of Taiyuan University of technology, 2017, 48 (04): 592-597

[3] Shi Yongkui, Wu Jisheng, Qi Minhua, Li pengrui. Study on dust reduction effect of new low dust shotcreting system [J]. Coal mine safety, 2016, 47 (07): 37-40

[4] Niu Shengli, Yang Xueshan, Kong Fanping, Zhao Zhilin. Technical status of dust control measures in coal mines in China [J]. China Health Engineering, 2014, 13 (04): 340-343

[5] Li Jianfeng. Dust control technology in coal mine [J]. Coal mine machinery, 2012, 33 (09): 251

[6] Wu Meihua. Advantages of common dry mixed mortar over traditional mortar [J]. Guangdong building materials, 2009, 25 (08): 52-53

[7] Cheng Zhulin. Design process and experience of dry mixed mortar mix proportion [J]. Anhui architecture, 2020, 27 (09): 227-228 + 256

[8] Liu Haidong. Advantages of dry mixed mortar and development prospect of dry mixed mortar in Tianjin [J]. Wall material innovation and building energy saving, 2014 (09): 63-65

[9] Dequan Peng, Xiaohong Guan. Research Status and Prospect Analysis of Manufactured Sand Dry-mixed Mortar[J]. International Journal of Civil Engineering and Machinery Manufacture, 2020, 5(1).

[10] Shi Xueyou. Quality control of dry mixed mortar [n]. Zhonghua Jianzhu Bao, 2020-08-18 (006)

[11] Wang Peiming. Development status and Prospect of commercial mortar technology in China [J]. Concrete and cement products, 2020 (08): 1-6

[12] Testing methods for raw materials and products of dry mixed mortar [M]. China Building Materials Industry Press, Wang Peiming, 2015

[13] Shifa Shen. Study on the Dry Mixed Mortar Modified By Carborundum System Sand Cellulose Ether[J]. International Journal of Civil Engineering and Machinery Manufacture, 2020, 5(2).

[14] Study on the effect of basal rock powder on the properties of dry mixed mortar with machine made sand [J]. Civil engineering, 2020, 09 (05)

[15] Shi Yanxin. Influence of raw materials of dry mixed mortar on mortar properties [J]. Shanxi architecture, 2020, 46 (08): 100-101

[16] Zhang Chenqi. Experimental study on properties of dry mixed mortar with Carboniferous limestone manufactured sand [D]. Chongqing Jiaotong University, 2018

[17] Wang Yanli, Liu Qinfeng, Ma Xudong, Hou Diandong. Study on mechanized wet shotcreting operation line in coal mine [J]. Coal mine machinery, 2017, 38 (04): 64-66