Research Article

Basic Research on Rockburst Control Technology for Deep Well Filling of Municipal Solid Waste

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Given the scarcity of raw materials for rockburst prevention in filling mining and the lack of space for disposal of large amount of municipal waste, the feasibility of preparing filling materials for rockburst mines from stale waste was investigated by laboratory tests and theoretical analysis. On this basis, the process of preparing filling materials from stale garbage was proposed, and corresponding equipment were developed to prepare stale garbage filling mass. According to the characteristics and uses of the stale waste filling materials, two processes of volume filling and strength filling are proposed, and the key technology of stale garbage filling to control rockburst was designed. The following conclusions were drawn: stale garbage can be made into mine filling material because of its composition, strength, and shape. The process of preparing mine filling materials from obsolete waste includes crushing, screening, compression, and packaging. The equipment suitable for the process includes crushing-screening, compression-forming, and sealing-packaging integrated equipment. The equipment has realized effective screening, compression, and bulk packaging of stale garbage, so that the stale garbage filling mass can meet the requirements of environmental protection and strength. Strength filling is a filling method that uses the strength of stale garbage filling mass to protect the overlying strata from or less damage, thereby reducing the stress concentration in the coal face and reducing the risk of rockburst occurring. Volume filling mainly depends on the volume of the filling mass, with the main purpose of reducing the stress concentration in the roadway surrounding rock. The rockburst mine filling technology of stale garbage is support track filling technology and bag filling technology, and the deep well sealing of stale garbage is block stacking technology. The deep well filling mining key technologies provide a new approach to against rockburst and treat large amounts of municipal waste.

1. Introduction

With the increase in mining depth, the frequency of rockburst increasing, and as of 2022, China has 123 high-risk rockburst mines [1–11]. Severe rockburst disasters can cause damage to shafts and casualties, for example: on February 22, 2020, a rockburst accident occurred in the Xinjulong Coal Mine, Shandong Province, China, resulting in roadway damage of more than 500 m [12]. On April 15, 2014, a rockburst accident occurred in the Austar Coal Mine, located west of Newcastle, New South Wales, Australia, resulting in fatal injuries to two men working as part of the mining crew at the development face [13]. In 2014, a rockburst accident occurred in a West Virginia coal mine in the United States, resulting in the death of two miners [14, 15]. Rockburst has become an important factor affecting the safe and normal production of coal mines. Filling mining can protect the overlying rock layer from less damage and thus prevent the occurrence of rockburst. However, filling mining requires a large amount of infill raw materials, and the development of filling mining is constrained by the extreme lack of cheap infill materials in mining areas (especially coal mines).

Municipal solid waste, also known as municipal household waste, is the solid waste generated by urban residents in their daily lives or in activities that provide services for
their daily lives in the city, mainly waste paper, waste metal, waste fabric, brick and slag, and food waste [16, 17]. With the rapid growth of urbanization scale, quantity, and population in China, municipal waste has increased rapidly with an average annual growth rate of 10%. But the overall capacity of municipal waste treatment is small, and the technology level is still low, about 2/3 of large and medium cities are surrounded by waste, which seriously affects the development of cities and people’s quality of life [18–20]. With the rapid growth of urbanization scale, quantity, and population in China, municipal waste has increased rapidly with an average annual growth rate of 10%. But the overall capacity of municipal waste treatment is small, and the technology level is still low. About 2/3 of large and medium cities are “surrounded” by waste, which seriously affects the development of cities and people’s quality of life. At present, the commonly used garbage disposal treatment technologies mainly include landfill, incineration, and composting, among which landfill and incineration are the main ways of municipal waste treatment in China [21–23]. Landfill treatment has the characteristics of large treatment capacity and low total cost, but landfill treatment occupies a large amount of valuable urban land, limiting the choice of landfill treatment technology in many cities. Waste incineration has the characteristics of short treatment cycle, small footprint, and flexible site selection, but waste incineration has many inputs and low public awareness, and its residues are still located on the surface and in the air, without completely eliminating the pollution potential [24–27]. Therefore, there is an urgent need for an innovative and harmless method of waste disposal that is in line with the current situation of “unsorted” waste in China.

At the same time, with the continuous development of coal resources, many coal mines are facing closure or abandonment, and it is expected that by 2030, China will have 15,000 closed/abandoned mines [28]. There is a large amount of underground space such as abandoned roadway and goaf in the closed mines. During the 13th Five-Year Plan period, the number of exiting coal mines in China is about 1019, the length of available shafts is about 7274 km, and the amount of available underground space is about 0.8 billion m³. By 2030, the volume of underground space formed by coal mining will be about 23.452 billion m³ [29].

Based on the characteristics of insufficient filling raw materials for filling mining to prevent rockburst and limited space for disposal of large amount of municipal waste, in this paper, we propose a new technology for controlling rockburst by filling deep wells with municipal waste, which is needed by both municipal governments and mining enterprises. At the same time, this paper conducts a study on the preparation of rockburst mine filling materials from municipal waste, proposes the concepts of volume filling and strength filling, and designs the corresponding processes and technologies for the deep well filling. This research idea and method has been proven by experts from the Beijing Municipal Science and Technology Commission and the Environmental Protection Bureau, and the project has been successfully accepted by the Beijing Municipal Science and Technology Commission.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Material name</th>
<th>Proportional range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight waste</td>
<td>Fabrics</td>
<td>13.4~28.2</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td>29.6~32.3</td>
</tr>
<tr>
<td>Metal type</td>
<td>Iron wire</td>
<td>0.5~8.6</td>
</tr>
<tr>
<td>Waste soil</td>
<td>Humus, sandstone</td>
<td>19.1~45.3</td>
</tr>
<tr>
<td>Filter pressing water</td>
<td>Leachate</td>
<td>11.8~13.7</td>
</tr>
</tbody>
</table>

2. Characteristics of Municipal Solid Waste

2.1. Composition Characteristics of Municipal Solid Waste. The stale waste samples were collected from municipal landfills in Qian’an and Xitian, China, and the collected samples were landfilled for more than 10 years. The samples were sorted manually and weighed electronically to obtain the composition of aged waste, as shown in Table 1.

According to the statistical results of the samples, it can be concluded that the stabilized stale waste samples mainly consisted of light waste (fabric and plastic), residue, metals, and pressed filter water. Among them, metals were low in the aged waste, while light waste and sludge together accounted for more than 80%, which is similar to the results of the literature 18. However, stale waste is closely related to urban living and eating habits and landfill sampling locations. The light weight waste in the stale waste can be prepared as the main material by packing into a square to form a filling, while the residue can be reused or mixed in the light weight waste as a raw material for packing and molding.

2.2. Municipal Solid Waste Intensity Characteristics. The uniaxial compression experiment of stale waste was designed according to the characteristics of the main composition of aged waste. The test was firstly loaded the stale waste sample into a customised tooling sleeve, and then, the experiment was carried out at a constant loading rate, and the loading was stopped when the specimen was deformed to the point that no pressurized filtrate was precipitated. The parameters such as the volume compression ratio and compressive strength of the aged waste that can be obtained during the test. The results of the experiments are shown in Figure 1.

From the experimental results, it can be seen that the process of the experiment can be divided into three periods,
3. Preparation of Municipal Solid Waste Filling Materials

The main processes for the preparation of stale waste filling materials are physical crushing, mechanical screening, compression, encapsulation, packing, storage, and transportation and also include auxiliary systems such as dust removal, deodorization, and percolation water treatment. The specific processes are shown in Figure 2.

After being excavated, the stale garbage firstly enters into the crusher, where the large diameter material and some irregular material are crushed into small diameter material. Then, the crushed material enters into the screening machine, where some metal material is recovered by magnetic separation, and the slag, stone, and other material are screened out by gravity screening. And then the remaining material enters into the compressor, where the material is compressed into block-like filling mass. Finally, the filling mass passes through the surface sealing machine and antiloosening and fastening machine for encapsulation and packing. During the process of crushing, screening, and compressing, dust removal and deodorization are required. In the process of compressing, the ooze needs to be collected and treated.

After the above process, the stale waste is transformed from a loose state into a regular shaped and strong filler. The filling mass is stored in a warehouse and transported out to the rockburst mine, where it is filled and closed by the mine filling system.

3.1. Experimental Study on the Preparation of Municipal Solid Waste Filling Materials for Crushing and Screening

One of the important elements of the stale waste crushing and screening test is the preparation and selection of crushing and screening equipment. According to the preliminary market research and related studies, it is determined that the crushing and sorting process of stale waste can be completed by developing an integrated crushing and sorting machine. The crushing-sorting integrated machine needs to have the functions of hopper, loading conveying, magnetic separation, crushing, screening, wind selection, discharge conveying, dust removal, etc. The main technical parameters are shown in Table 2, according to the required technical parameters to design and improve the equipment content.

The equipment is improved according to the existing equipment on the market and the technical parameters required for the equipment. The improvements and customisations are shown in Table 3.

Figure 3 shows the improved equipment, where Figure 3(a) shows the stale waste feed hopper, feeding belt, crushing, and screening box mainframe. The three conveyor belts in Figure 3(b) are baler light waste feeding conveyor belt, residue conveyor belt 1, and residue conveyor belt 2. The blue equipment on the left side in Figure 3(c) is the dust removal equipment, the middle white is the operation table, and the magnetically selected metal discharge port is below the conveyor belt on the right side. Figure 3(d) shows the docking state of the feeding belt and the horizontal baler.

After the equipment has been improved, the performance of the equipment is tested. According to the composition of the stale garbage to the weight of 50 kg per bucket into the loading, materials through the feeding hopper conveyor belt, and feeding belt transfer into the crushing and sorting machine, the stale waste is firstly separated from the metal by magnetic separation screen and then crushed by the crusher. After crushing, the material enters into the sieving machine, the large particle size material is conveyed to the baler inlet by the feeding belt, and the residue is conveyed to the residue discharge belt 1 and belt 2 by the sieved material belt and finally falls into the slag collection box. The test results are shown in Figure 4.
Through field test and statistical analysis of the results, the actual crushing, magnetic separation, screening, and wind screening rates of the integrated crushing-screening machine are more than 90%, and the size can meet the technical requirements. The improved crushing and screening integrated machine has achieved the purpose of crushing and screening.

### 3.2. Experimental Study of Compression Molding and Sealing Packaging for Municipal Solid Waste Filling Material Preparation

After the screening of the crushing-sorting machine, the material is compressed and shaped in the compression molding machine. On the basis of full consideration of the front-end waste feed, subsequent equipment process connection, and parameter response, the horizontal baler is

<table>
<thead>
<tr>
<th>Processing object</th>
<th>Feed particle (size/mm)</th>
<th>Discharge particle (size/mm)</th>
<th>Spindle speed/(r/min)</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastics etc.</td>
<td>&lt;1200</td>
<td>&lt;50</td>
<td>30–40 r/min</td>
<td>Metal</td>
</tr>
</tbody>
</table>

#### Table 3: Main technical modification and customization of crushing-sorting integrated machine equipment.

<table>
<thead>
<tr>
<th>Customised equipment modification content</th>
<th>Operation effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biaxial crushing spiral cutter set to replace bag breaker blades</td>
<td>Guaranteed discharge size &lt; 50 mm</td>
</tr>
<tr>
<td>Shaftless drum screen replaces traditional bouncing screening unit</td>
<td>Screening rates for slag, etc. &gt; 90%</td>
</tr>
<tr>
<td>Fully enclosed integrated box replaces open grouping equipment</td>
<td>Reduces the spread of dust and odours</td>
</tr>
<tr>
<td>Customised leachate flow water collection tank equipment</td>
<td>Leachate water collection</td>
</tr>
<tr>
<td>Customised complete pilot equipment miniaturisation</td>
<td>Meets 5-8 tonnes/hour capacity</td>
</tr>
</tbody>
</table>

![Figure 2: The process of preparing filling materials from stale refuse.](image1)

![Figure 3: Pictures of crushing and screening machine and supporting system.](image2)
selected from among the horizontal hydraulic baler, the split waste compressor, and the vertical baler after market research and function matching. The horizontal baler was technically modified to meet the waste-forming requirement to regulate the amount of residue entering about 5%. A material level sensing device was installed in the feed bin to enhance the application of the hydraulic system pressure and to guarantee the strength of the fixed postcompression sample. The results of the operation of the compression-forming equipment are shown in Table 4.

Through field tests and results analysis, the actual operating effect and compression sample parameters of the integrated compression-forming machine meet the technical requirements and can be connected to the front-end crushing-sorting integrated machine.

In view of the fact that after the stale waste has been crushed and compressed into bales, it is still fully exposed to air and water during the later transportation and filling process. In order to ensure that the bales are not accidentally crushed and leaked during the loading, unloading, transfer, and closed filling process causing secondary pollution of the surrounding soil and water environment, a secondary sealing process design is required.

The mainstream packaging materials and processes on the market are PE film winding, heat shrink packaging, and resin materials, the advantages and disadvantages of which are shown in Table 5. Combined with the requirements of stale waste compressed bales, LLDPE film was chosen as the winding film and LDPE film as the heat shrink film. Wrapping first to restrain the garbage bale block and then heat shrinkage process is used for complete sealing.

After the packaging material and process were selected, the six-sided winding packaging equipment was modified. The bales are firstly transferred to the vertical winding machine by the roller conveyor on the six-sided winding machine to complete the winding in vertical direction. After that, the package block is conveyed to the pallet winding machine by the roller conveyor to complete the full sealing packaging winding of the package block. Finally, the wrapped bales are subjected to heat shrink film packaging process. Through winding packaging and heat shrinkage sealing process, the secondary sealing of the stale garbage bales could be realized, which satisfies the basic functions of the outer packaging such as waterproof, dustproof, and odour isolation; and the equipment and test products are shown in Figures 5 and 6.

**Table 4: Operation effect of compression-forming integrated machine.**

<table>
<thead>
<tr>
<th>Equipment optimisation content</th>
<th>Equipment operation parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power of the hydraulic system</td>
<td>25–40 MPa</td>
</tr>
<tr>
<td>Volume compression ratio</td>
<td>1:2 ~ 1:4</td>
</tr>
<tr>
<td>Compacted density</td>
<td>$1.5 \times 10^3 \sim 2 \times 10^3$ kg/m³</td>
</tr>
<tr>
<td>Feeding and operational control</td>
<td>Parameter warning and completely automatic</td>
</tr>
</tbody>
</table>

**Figure 4:** The process of preparing filling materials from stale refuse: (a) stale refuse samples, (b) crushing-screening of metal, (c) crushing and screening of residue, and (d) crushing-screening of light materials.
Once the municipal solid waste filled, a suitable filling technology is needed to select in order to complete the filling. Filling mining technology has gone through dry filling, hydraulic filling, paste filling, and backfill with high water material and ultrahigh water material filling [25]. These filling technologies have different requirements on the nature of the filling material and the mode of transport. The complex composition of the stale waste filling material makes the filling technology described above no longer applicable. Two new filling technologies, volume filling and strength filling, have been proposed based on the shape of the stale waste filling material and the degree of mine high-risk rockburst hazard.

4. Technologies for Controlling Rockburst in Deep Well Filling Mining of Municipal Solid Waste

Once the municipal solid waste filling material has been prepared, a suitable filling process needs to be selected in order to complete the filling. Filling mining technology has gone through dry filling, hydraulic filling, paste filling, and backfill with high water material and ultrahigh water material filling [25]. These filling technologies have different requirements on the nature of the filling material and the mode of transport. The complex composition of the stale waste filling material makes the filling technology described above no longer applicable. Two new filling technologies, volume filling and strength filling, have been proposed based on the shape of the stale waste filling material and the degree of mine high-risk rockburst hazard.

4.1. Volume Filling Technology. Volume filling is a filling technology in which the volume of filling material is the main indicator, and the main purpose is to reduce the deformation of the roadway surrounding rock. The process prepares municipal waste into a square and voluminous filling body, which relies on the volume of the filling body to fill the mine space. The volumetric filling process does not require complete contact between the filling bodies, and gaps exist between the filling bodies. The volumetric filling technology relies on the self-control of the surrounding rock to achieve stability, and the filling body is compressed to produce deformation and play a part in supporting the role. The volumetric filling process allows a certain deformation of the surrounding rock, as shown in Figure 7.

The volume filling of stale waste needs to meet certain application conditions, and the main influencing factors are shown in Table 6.

The selection of volume filling process for roadways requires comprehensive analysis of the roadways various influencing factors and scoring of various factors according to the actual situation. The scores rated by the various factors are added up and compared with the sum of the maximum values of each factor to obtain the volume filling process coefficient $q$, as shown in Equation (1). When $q$ is greater than 0.5, it is recommended to select the volume filling process for the sealing of obsolete waste in the roadway space of the mine. When $q$ is less than 0.5, other filling processes should be considered.

\[
q = \frac{U_{ci}}{U_{c_{\text{max}}}} , \tag{1}
\]

\[
U_{ci} = \sum_{i=1}^{10} U_i , \tag{2}
\]

\[
U_{c_{\text{max}}} = \sum_{i=1}^{10} U_{i_{\text{max}}} , \tag{3}
\]

where $U_{ci}$ is the sum of the factor scores, and $U_{c_{\text{max}}}$ is the sum of the maximum values of the factors. $U_i$ is the score of the $i$th influencing factor, and $U_{i_{\text{max}}}$ is the maximum score of the $i$th influencing factor.

4.2. Strength Filling Technology. Strength filling is a filling technology in which the strength of the filling material is the main indicator. The process prepares the stale waste into block-like and high strength filling mass and uses the strength of the filling body and the strength of the surrounding rock to form a support structure to achieve the stability of the surrounding rock. The surrounding rock of the strength filling process is not deformed or has small deformation, which can protect the overlying rock layer from or less damage and reduce the degree of stress concentration in the coal face.
Strength filling is aimed at reducing the risk of rockburst occurrence and is characterized by high strength of the filling body and good filling effect and stability of the filling body, as shown in Figure 8.

Strength filling can be divided into two types: complete filling and partial filling. Among them, the complete filling method is generally used in the strong rockburst hazard area of the coal face. The complete filling method has good filling

### Table 6: Influence factors of volumetric filling technology.

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Identification of influencing factors</th>
<th>Index (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_1$ Whether rockburst has occurred</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>$U_2$ Bursting tendency of coal seams</td>
<td>Strong</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Weak</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>$U_3$ Bursting tendency of roof and floor</td>
<td>Strong</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Weak</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>$U_4$ Depth of roadway burial</td>
<td>$&lt; 400 \text{ m}$</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>$400 ~ 600 \text{ m}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$&gt; 600 \text{ m}$</td>
<td>2</td>
</tr>
<tr>
<td>$U_5$ Main transport systems such as the main and auxiliary wells of the mine are in order</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>$U_6$ Types of roadways</td>
<td>Coal roadway</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Rocky roadway</td>
<td>2</td>
</tr>
<tr>
<td>$U_7$ Shape of the roadway cross-section</td>
<td>Rectangular</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Semicircular arches</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Rounded arches</td>
<td>2</td>
</tr>
<tr>
<td>$U_8$ Methods of roadway support</td>
<td>Single support</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Bolt net support</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Concrete masonry support</td>
<td>2</td>
</tr>
<tr>
<td>$U_9$ Presence of water-bearing layer in the vicinity of the roadway</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>$U_{10}$ Whether the roadway is in a tectonic concentration area</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
</tr>
</tbody>
</table>
effect and the surrounding rock is in a stable state after filling, but the amount of filling material is large and the filling speed is relatively slow. Partial filling method is generally used for medium rockburst hazard area in the working face and is characterized by less material consumption and relatively fast filling rate.

Therefore, the filling technology with the volume or strength of the filling material as the main indicator is referred to as volume filling or strength filling. Both the volume and strength filling processes have the main objective of reducing the risk of rockburst occurrence, but their characteristics and conditions of use are different, as shown in Table 7.

5. Processes for Municipal Solid Waste Sealing and Filling

The prepared stale waste filler is transported from the production site to the main-shaft entrance of the coal mine by vehicles. The filler is then transported via shaft cages to the underground yard. Finally, depending on the application, the filler is transported to the coal mining face for filling or to the roadway for sealing, as shown in Figure 9 [31–33].

5.1. Technology for Filling Mining with Municipal Solid Waste in Coal Face. The purpose of filling mining is to protect the overlying rock layer from damage and reduce the degree of stress concentration at the working face, thus achieving the purpose of reducing the risk of rockburst. The filling mining of stale waste is designed with strength filling mining technology, using support-rail filling method and bag filling technology.

The support rail filling utilizes a special hydraulic support to fill while mining. The filler is transported to the underground through the vice-well, and the filler is transported to the track under the back cover beam of the hydraulic support at the working face by the platform vehicle. The unloader is followed by the flatbed truck, and the unloader lifts the filling mass on the flatbed truck and fills the mining area from bottom to top layer by layer through a ninety-degree rotation. Grouting of the mining area is carried out at each distance of filling, so that the scattered block fillers are glued together to form a whole, enhancing the overall strength while better controlling the stability of the filler. Figure 10 shows the strength filling arrangement of the working face.

Bag filling is the technology of filling material into the prepared filling bag and filling with the filling bag as the main mass. The filling bag is generally made of impermeable plastic, in which the shape of the filling belt is supported by pillars. The filled filling bags are transported by the flatbeds to the track under the hydraulic support cover beam, followed by the unloader after the flatbeds, which lifts the filling bags on the flatbeds and turns ninety degrees to fill the goaf. At the same time, the filling area is injected with

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**Table 7: Technology comparison of volume filling and strength filling of filling mass.**

<table>
<thead>
<tr>
<th>Filling process</th>
<th>Characteristics of the filler</th>
<th>Filling index</th>
<th>The way of control the surrounding rock</th>
<th>Applicable locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume filling</td>
<td>Large volume</td>
<td>Volume of filler</td>
<td>Relying on the surrounding rock itself</td>
<td>Weak rockburst hazard area</td>
</tr>
<tr>
<td>Strength filling</td>
<td>High strength</td>
<td>Strength of filler</td>
<td>Strength structure composed of fill and surrounding rock</td>
<td>Strong and medium rockburst area</td>
</tr>
</tbody>
</table>

---

**Figure 8: The filling process depends on the strength of the filling mass.**

---

[Figure showing the filling process]
cement mortar and other impermeable materials according to a certain ratio, and multiple scattered filling bags are wrapped with slurry to make the filling bags form a whole. Both support rail filling method and bag filling technology can meet the intensity of working face filling and mining and achieve the purpose of controlling the amount of surface collapse and protecting the ground buildings. The support rail filling technology is simple and convenient to operate with higher efficiency. While the bag filling technology can better fix the flow of the filling body, keep the stability of the filling body and achieve higher strength requirements.

5.2. Technology for Filling with Municipal Solid Waste in Roadway. The technology for filling roadway with municipal solid waste refers to the sealing of stale waste in the roadway space, which is designed with volume filling technology.
When filling a closed space in a roadway, the filler is transported by forklift to the sealing roadway. Then, the filling mass is placed in the way of stacking, the height of the stack should fill the filling space as much as possible, and the middle of the filling body should be isolated.

The specific operation process is as follows: stage I, forklift trucks stack the block filling mass from the bottom of the roadway to half the height of the roadway in turn. In stage II, laying isolation layer and forklift ramp, forklift ascends to the middle of the roadway through the ramp to continue filling until the height of the whole roadway is stacked, and forklift adopts backward filling method from back to front. In stage III, walling isolation treatment is carried out at intervals, and the closure wall should be left with observation and pressure holes to monitor the stability of the filling mass and the roadway, as shown in Figure 11 [31].

6. Conclusion

In view of the shortage of raw materials for rockburst prevention in filling mining and the limited space for disposal of large amount of municipal waste, this paper studies the preparation process of stale waste as filling material for rockburst mines and the key technology of deep filling to control rockburst and draws the following conclusions.

(1) The feasibility of preparing mine filling materials from stale waste was experimentally studied, and it was concluded that stale waste has meet the requirements of composition, strength, and shape of rockburst mine filling materials and can be made into rockburst mine filling materials.

(2) The process of preparing mine filling materials from stale waste is proposed, including crushing, screening, compression, and encapsulation, and the corresponding integrated equipment are developed. The experiments of mine filling materials from stale waste are carried out, so that the stale waste filling mass meets the requirements of environmental friendliness and strength in the process of preparation, storage, transportation, and filling.

(3) In view of the characteristics and uses of the stale waste filling materials, two processes of volume filler and strength filler are proposed. Strength filling uses the strength of the filling mass to protect the overlying rock from damage or less damage and is mainly used in areas of strong and moderate rockburst hazard. Volume filling relies on the volume of the filling mass to control the deformation of the roadway and is mainly used in weak rockburst hazard areas.

(4) Technologies of stale waste for deep well filling were designed. Mine filling technologies for stale waste include support rail filling and bag filling technologies, and deep well space closure technologies for stale waste include block stacking technologies.

The deep well mine filling of municipal solid waste to control rockburst is a comprehensive research content. In addition to the research mentioned in this paper, it also includes the site selection in the prefilling period, the multilevel closure technology of the filling area during the filling process, and the secondary pollution prevention, monitoring, and evaluation methods after filling and closure, all of which have been studied in this research group [34–36]. At the same time, due to the complex composition of municipal waste, the disposal technology is difficult and restricted by the special production process of mines and environmental protection policies. In this paper, only basic experimental research...
has been conducted on the obsolete waste in municipal waste, and no research has been conducted on primary waste. The next step is to carry out research on the resourceful and harmless treatment of these wastes and to conduct corresponding industrialized tests of mining filling to control rockburst.

Data Availability

The datasets generated during and/or analysed during the current study are available in the corresponding author.

Conflicts of Interest

The authors have no relevant financial or nonfinancial interests to disclose, and the authors have no conflicts of interest for the publication of this paper.

Authors’ Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Sitao Zhu, Jiujie Li, Fuxing Jiang, Yongtao Gao, Xiaocheng Qu, Maowei Ji, and Quande Wei. The first draft of the manuscript was written by Zhou Chao, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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