Green mine research and evaluation based on using solid wastes in urbanization for mine filling

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Abstract. Derived from the disposal problems of construction wastes generated by urbanization and combined with the current situations of mine gob filling, this paper, in accordance with the actual requirements of green mines, probed into the methods of using construction wastes for gob filling, whose technical and economic feasibility was also analyzed. An evaluation system of green-mine filling was established and the goals of green-mine filling were dissected as well. Simultaneously, as a new view and the ultimate evaluation index, environmental protection degree, whose abbreviation is \( H \), was proposed. As for the outcomes of green-mine filling, fuzzy comprehensive evaluation was utilized, whose results can more systematically and factually reflect the environmental protection degree of construction wastes for green-mine filling and thus have high application value.

1. Introduction
As is proposed in Report on the Work of the Government delivered in 2017, the emission of the key pollutant should uninterruptedly decrease, the eco-environmental protection and governance should be strengthened and its enhancement should be accelerated as well, which is a goal for the new period. With the continuous advancement of urbanization in China, more and more importance is attached to the disposal of the increasing number of construction waste during urban and rural reforms. As the primary energy of China at present, coal resources play an important role in the development of the national economy. On the other hand, previously, caving mining methods were widely utilized in China, thus making severe destruction on the ground surface and impacting the ecological balance. The popularization of filling mining technology provided underground mining with a new perspective that fully using the construction wastes for filling gob in coal mines is of great significance in putting forward and fulfilling the green-mine construction.

2. Construction wastes in urbanization

2.1. Sources of construction wastes
Construction wastes refer to the wastes produced by constructions (buildings and infrastructures of all types) during constructing, reconstructing, extension and demolishing [1]. City construction wastes in China are mainly originated from the wastes produced by constructions and reconstructions in urbanization and the solid wastes from major disasters. In accordance with function sources, they can
be classified into living construction wastes, communal facility construction wastes, industrial construction wastes and other types.

2.2. Disposal methods of construction wastes

The report on the research analysis and the market prospect forecast of China’s construction waste disposal industry from 2016 to 2020, which was released by China Industry Research, opined that the disposal methods of construction waste in China can be generally divided into two categories. The first one is to build some permanent sites for piling up wastes or interring wastes. And the other one is to recycle the wastes by using some recycling equipment which can smash wastes and then regenerate them to be reusable building materials.

Almost all cities adopt the first method which is simple but will take up much urban land during the disposal of the wastes, probably resulting in secondary pollution. In the meanwhile, the disposal in a cursory and coarse style will be detrimental to urban general planning and waste large amounts of resources.

3. Research on filling gob in coal mines

3.1. Current situations of filling coal mine gob

The development of filling techniques in China has progressed along with barren-rock dry filing intended to dispose solid wastes, hydraulic filling using classified tailings and crushed rocks, tailing cemented filling, high-concentration filling and other stages [2]. Nowadays, in China, the traditional filling techniques for gob mainly contain hydraulic filling, coal-ash filling, wind-power filling, waste-rock filling by gravity, coal-wastes strip filling, pasty and pasty-like filling that are developing latterly. At present, many experts are probing into the new-type methods of filing by high-moisture and super high-moisture materials, driving the filling techniques of mine gob into a new development period.

On the other hand, lots of problems, for example, the paucity of filling materials that is a rather serious issue, are still puzzling the mining-gob filling. Waste rocks produced by mining have been far from meeting the requirements of mine gob filling while the filling techniques by new high-moisture materials are still inchoate. Hence, it is necessary to seek more proper materials for mine filling.

3.2. Research on the filling of urban construction wastes

3.2.1 Technical feasibility of the filling of urban construction wastes. With the development of mining science and the improvement of machine manufacturing skills, mine exploitation has proceeded into an era of large-scale mechanized mining, which also laid foundation for mine filling by construction wastes. In the aspect of theoretical research, many scholars have made remarkable accomplishments in ground pressure and strata control and been able to analyze the mechanical deformation after mine gob filling. In the aspect of mechanical haulage, long-distance ribbon conveyors and the application of filling pipelines made possible the gob filling by construction wastes from the ground surface. In the respect of auxiliary equipment, the widespread application of crushers, mixing machines and solid aggregate manufacturing equipment created favorable conditions for gob filling by construction wastes.

As technology is continuously progressing, we have been capable of technically solving all kinds of problems caused by construction waste filling. Meanwhile, there have been engineering practices of underground construction waste filling, which entails the upgrade of the new-generation filling and haulage equipment to achieve high intellectualization and informationization.

3.2.2 Economic feasibility of the filling of urban construction wastes. The underground filling by construction wastes can fulfill the improvement of underground excavation conditions, surrounding rock control and the curtailment of financial loss caused by surface subsidence. In addition, using construction wastes which occupy much urban land for gob filling can save more urban space. What’s
more, construction waste filling is of environmental-friendly significance that the costs for environmental governance can be reduced. Nowadays, what should be addressed is the cooperation between the places that produce construction wastes and mine companies, where the government can play a coordinating part to help assure best economic benefits at the lowest expense.

4. Establishment of the evaluation system of green-mine filling

With the development of the social economy, people are increasingly concerned about the environmental protection. How to fulfill the green mining of coal sources and the clean utilization of them has been puzzling coal mine researchers. The so-called green mine signifies that in the whole mining process of mineral sources, well-organized mining can be accomplished and great attention is paid to keeping the influence posed by excavation on surroundings in a controllable range. Through using the construction wastes for filling the gob, utilization efficiency can be improved, which is conducive to the green-mine construction. Directing at the filling outcomes of construction wastes in gob, evaluation system of green-mine filling was established.

4.1. Goals of green-mine filling

The usage of construction wastes for filling coal mine gob can realize the goals as follows: (1) acquiring the best filling outcomes at lower economic expenses; (2) recycling sources; (3) controlling the surface subsidence posed by underground mining; (4) harmonious development of both mining and urbanization.

4.2. Evaluation index system of green-mine filling

In accordance with the technical and economic feasibility analysis of the filling using construction wastes and the goals of green-mine filling, the evaluation index system of green-mine filling, which consists of three grades, was established. As is shown in Figure 1, the final evaluation index is the environmental-friendly level, which is a comprehensive evaluation index of green-mine filling [3].

![Evaluation System of Green-mine Filling Diagram](image)

**Figure 1. Evaluation system of green-mine filling**
H, which stands for the environmental-friendly level in the system, has a range from 1 to 3. And higher value H has, more environmental-friendly the coal mine filling will be, which means more emphasis that has been laid on the environmental protection. We chose three first-grade indexes to measure the main factors impacting environmental-friendly level.

The constitution of the subsystem:

(1) Economic factors: they refer to the cost and benefit factors containing investment costs, filling costs and recycling benefits, which should be taken into consideration when making green-mine filling.

(2) Technical factors: they refer to the necessary technical support containing conveying ability, filling ability and collecting ability when implementing green-mine filling.

(3) Filling outcomes: they refer to three aspects in evaluation of green-mine filling, which are comprised of degrees of surface damages, support effectiveness and system stability.

4.3. Weighted calculation of evaluation index system

Weight is the relative importance of each index in the system. According to the three-grade structure that was established, analytic hierarchy process (AHP) was employed to calculate the weight of each index.

**Figure 2.** Calculation flow of index weight

\[
C_{ij} = \frac{1}{n} \sum_{k=1}^{n} (b_{ik} - b_{jk}) 
\]

\[
a_{ij} = 10^{c_{ij}}
\]

Based on the calculation flow shown in Figure 2, the weight of the first-grade indexes was obtained. With the second-grade indexes obeying the laws in the upper grade, AHP method was utilized to construct the judgment matrix. Meanwhile, the weight results were modified according to the actual situations in the green-mine filling, obtaining the weight calculation results of each factor, which are shown in Table 1.


| Evaluation Indexes                  | Weight |
|------------------------------------|--------|
| Economic Factors 0.37              |        |
| Investment Costs                   | 0.28   |
| Filling Costs                      | 0.34   |
| Benefit Recovery                   | 0.38   |
| Technical Factors 0.28             |        |
| Conveying Ability                 | 0.27   |
| Collection Ability                 | 0.38   |
| Filling Ability                    | 0.35   |
| Filling Outcomes 0.35              |        |
| Surface Destruction Degree         | 0.37   |
| Support Effectiveness              | 0.34   |
| System Stability                   | 0.29   |

4.4. Establishment of membership function of evaluation indexes

During the green-mine filling, choosing the index parameters is a nonlinear, variable and fuzzy process. In combination with field situation, this paper adopted construction methods of fuzzy set membership functions that are simple and standard [4, 5]. Based on the field experience, on-site statistics, economic and technical indexes and related data, a hierarchical membership function of the second-grade indexes was constructed with reference to the construction methods of standard fuzzy sets. The economic factor sharing the maximum weight was set as an example to construct its reliability indexes.

4.4.1 Investment costs. Investment costs can exert influence on the percentage of the investment from fixed assets to the overall investment in the whole system of green-mine filling. Thus a higher value of this index means more investment from fixed assets. On the basis of the practical experience and related data, its membership degree is shown in Table 2.

Table 2. Membership degree of investment costs

| Index k | k≤20% | 20% < k≤50% | k>50% |
|---------|-------|-------------|-------|
| Membership Degree | 0 | \( f = \frac{k-50}{50-20} \) | 1 |

4.4.2 Filling costs. Filling costs refer to the percentage of the filling costs to the overall costs in the whole green-mine filling process. The greater this index is, the more filling costs will be. With reference to related field experience and data, its membership degree is shown in Table 3.

Table 3. Membership degree of filling costs

| Index k | k≤80% | 80% < k≤90% | k>90% |
|---------|-------|-------------|-------|
| Membership Degree | 0 | \( f = \frac{k-80}{90-80} \) | 1 |

4.4.3 Benefit recovery. Benefit recovery, which refers to the percentage of the economic benefits from green-mine filling to the overall investment costs, is proportional to the generated economic benefits. And its membership degree is shown in Table 4.

Table 4. Membership degree of benefit recovery

| Index k | k≤10% | 10% < k≤70% | k>70% |
|---------|-------|-------------|-------|
| Membership Degree | 0 | \( f = \frac{k-70}{70-10} \) | 1 |
4.5. Disposal of comprehensive evaluation results

The membership degree of all of the second-grade indexes should be calculated when the green-mine filling was being evaluated. Then the comprehensive evaluation was implemented according to the scores of each index. And finally the formula below was applied for calculation:

\[
H = \sum_{i=1}^{4} N_i \times \sum_{j=1}^{f} N_{ij} \times f_{ij}
\]  

(3)

Where, H is environmental-friendly degree which refers to the comprehensive evaluation result of the green-mine filling; \(N_i\) is the weight of first-grade (criterion grade) indexes; \(N_{ij}\) is the weight of second-grade (factor grade) indexes; \(f_{ij}\) is the membership degree of second-grade indexes.

During the real evaluation, the membership degree of each factor belonging to the second grade was obtained in accordance with the specific parameters of the tunneling face. And the comprehensive scores were classified and made statistics, which is shown in Table 5.

Table 5. Evaluation classification of green-mine filling

| H              | H≥0.80 | 0.60≤H<0.80 | 0.40≤H<0.60 | H<0.40 |
|----------------|--------|-------------|-------------|--------|
| Classification | A      | B           | C           | D      |

Level A stands for the best outcomes of the green-mine filling; level B demonstrates that most of the requirements can be satisfied; level C means the requirements cannot be satisfied with poor outcomes; level D indicates that the whole system should be rectified and reformed in all respects.

5. Conclusion

Stemming from the disposal problem of construction wastes produced by urbanization, this paper took the current situations of coal mine gob filling into consideration, proffered the methods of using construction wastes for gob filling and meanwhile made technical and economic feasibility analysis of this strategy.

In view of the environmental protection concept, this paper established the evaluation system of green-mining filling whose goals were analyzed as well. Simultaneously, a new concept called environmental protection degree, which functioned as an ultimate evaluation index of green-mine filling, was proposed.

Since determining the membership degree of each factor and establishing the judgment matrix can exert great influence on the results, the evaluation of green-mine filling mentioned by this paper is a relatively fuzzy concept which can be improved through adjusting parameters in accordance with the actual situations.

References

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