Genetic Algorithm for Optimizing Components of Mine Tailings Curing Agent

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Abstract. Mine tailings harmless disposal is priority research in mining industry. Although a number of tailings disposal methods have been developed in the past, surface stacking still remains a major challenge in engineering. A key to realizing mine tailings surface stacking is developing high efficient curing agent to enhance the strength of consolidated tailings. In this study, an optimal approach based on genetic algorithm is developed for determining the best ratio of components. The proposed optimal approach succeeds in improving the compressive strength of consolidated tailings compared with orthogonal test. In addition, the developed optimal approach takes less test time than orthogonal test, which saves materials and shortens experimental time. The results indicate that a better compressive strength of consolidated tailings is achieved by the optimal curing agent based on genetic algorithm.

1. Introduction

The safety and environmental problem attributed to improper disposal of mine tailings have been increased in many regions all over the world due to the development of mining industry. Tailings dam is a traditional way to store tailings, but its safety problem always threatens lives and properties who lives downstream of dam. On Jan. 25, 2019, a tailings dam break accident occurred in Brazil's Minas Gerais state [1], causing 179 deaths and 131 missing. Therefore, the harmless and safety disposal of mine tailing are priority research area. In order to improve the safety problems causing by tailings dam, developing the harmless disposal ways of tailings is the key.

Previously, underground filling was a main method to solve the problem of excessive tailings production, which can consume over 70 percent of tailings. In parallel, other researchers attempted to make tailings into building materials [2]. Despite the previous researches, there are still major challenges in reducing cost and solving heavy metal pollution in tailings [3]. These drawbacks highlight the need for developing a new method to disposal mine tailings.

In the past decade, some researchers proposed that mine tailings are still available mineral resources. The metal left in tailings could be extracted with the development of beneficiation technology. Therefore, storing mine tailings in a safety way can establish foundation to recycle.

Surface harmless stacking is a safety method to deal with mine tailings. The key factor to realize the surface stacking is to develop an efficient curing agent to keep the consolidated tailings steady. Generally, gluing material, such as cement or slag powder, and activating agent are selected as components and mixed at a proper ratio to be curing agent. But the best ratio of component is complex and changes with physical and chemical properties of mine tailings. A traditional method to optimal
curing agent is single factor test or orthogonal test. The premise of single factor test is that there is no mutual influence among factors, but in most cases, it will not happen. As for orthogonal test, the experiment should repeat many times to obtain the best result [4].

In order to overcome the drawbacks of the orthogonal test, the genetic algorithm is introduced and implemented in this paper. The slag powder, quicklime, industrial gypsum and bentonite are selected as component of curing agent. A genetic algorithm optimal approach is designed to find the best ratio of components. In order to demonstrate its applicability, the developed method is applied to a case study in Sanshandao gold mine tailings samples.

2. Basic principle
The Genetic Algorithm, proposed by Holland [5], is a random search and optimized solution that mimics the process of natural evolution and genetics. A simple genetic algorithm is based on three processes:

1. Reproduction
2. Crossover
3. Mutation

The genetic algorithm starts with solutions of a random generation. Every solution can be a candidate result of the problem, called chromosome. Its performance can be evaluated by a fitness function. The better performed chromosomes have a higher probability to reproduce and contribute to next generation. The chromosomes of next generation come from the crossover of two matched chromosomes of the current generation. The crossover positions are random. When new chromosomes generated, genes have a specific probability to mutation, which positions are random too. The process of new generation continues iteratively until the algorithm reaches a termination criterion, and the best performed chromosome will be selected as the optimal solution.

3. Case study

3.1. Material
The mine tailings come from Sanshandao gold mine. The curing agent has 4 components, which are slag powder, quicklime, industrial gypsum and bentonite. Slag powder is main material to glue tailings. Quicklime, industrial gypsum and bentonite are used to activating agents. Therefore, to develop an efficient curing agent is to determine the best ratio of components. Besides components of curing agent, the mine tailing mortar concentration is another factor to influence the strength of deposit body. The lower and upper limit concentration and the step of each component is in Table 1. In curing agent, the ratio of slag powder is determined by the ratio of quicklime, industrial gypsum and bentonite, which can be defined as:

\[ s = 1 - (q + i + b) \]  \hspace{1cm} (1)

Where \( s \) is the ratio of slag power; \( q \) is the ratio of quicklime; \( i \) is the ratio of industrial gypsum; \( b \) is the ratio of bentonite.

| Component          | Lower limit(%) | Upper limit(%) | Step |
|--------------------|----------------|----------------|------|
| Tailing mortar concentration | 68.25          | 72             | 0.25 |
| Quicklime          | 5              | 20             | 1    |
| Industrial gypsum  | 0.75           | 12             | 0.75 |
| Bentonite          | 0.5            | 5              | 0.5  |

3.2. Test method
The ratio of curing agent and tailing is 1:20 in this paper. Tailing mortar and curing agent are well mixed by mixer and poured into a square groove. After consolidation, the consolidated tailings are
maintained in constant temperature room for 3 days. Then, use pressure tester and pressure sensor to test the compressive strength of consolidated tailings.

3.3. Genetic algorithm optimal design
1. Code. The binary coding method is adopted in this paper. According to Table 1, the factors are divided into 16 parts. Therefore, each length of factor can be defined 4 due to \(2^4=16\). The length of one chromosome, formed from the combination of 4 factors, is 16.

2. Initial generation. 10 chromosomes randomly generated as the initial generation. The purpose of test is to find the best ratio of components to keep consolidated body in maximum intensity. Therefore, the compressive strength is the criterion of fitness.

3. Match and crossover. Roulette wheel selection is adopted to select chromosomes as parents. The better performed chromosome has higher probability to be chosen. Then, two parents’ chromosomes crossover at random position to obtain children. The crossover also has a certain probability. In this paper, the probability of crossover is 0.7.

4. Mutation. The genes on the chromosome may mutate. But the probability of mutation should not be high in case of divergent. In this paper, the probability of mutation is 0.05.

5. New generation. After selection, match, crossover and mutation, the new generation comes out. In new generation, the best performed chromosome in parents should be included to maintain better evolution.

4. Result and discussion
The test carries out 8 generations. The compressive strength of each generation is shown in Figure 1. It can be seen that compressive strength of consolidated body increase rapidly in the former 4 generations. When from 5th to 8th generation, its increasing speed decreases. The value has basically no change between the 7th generation and the 8th generation. This shows that the genetic algorithm rapidly found out a well ratio of components. According to this method, the best ratio of components is determined to slag powder, quicklime, industrial gypsum and bentonite is 80.75%, 12%, 5.25% and 2%, the compressive strength reaches 0.072MPa.

![Figure 1. Compressive strength of each generation.](attachment:image1)

In order to demonstrate its applicability, an orthogonal test is carried out to compared with genetic algorithm. A 4 level test is designed as Table 2. Orthogonal test carries out 16 times and determines the best ratio of components are determined to slag powder, quicklime, industrial gypsum and bentonite is 78.8%, 13%, 7% and 1.2%, the compressive strength reaches 0.066MPa. It can be seen that the effect
of curing agent determined by genetic algorithm improves 9% compared with orthogonal test, and the genetic algorithm takes less test time.

Table 2. Factor value of 4 level orthogonal test

| Level | Tailing mortar concentration(%) | Quicklime(%) | Industrial gypsum(%) | Bentonite(%) |
|-------|---------------------------------|-------------|---------------------|-------------|
| 1     | 66                              | 4           | 1                   | 0           |
| 2     | 68                              | 7           | 3                   | 0.4         |
| 3     | 70                              | 13          | 7                   | 1.2         |
| 4     | 72                              | 19          | 11                  | 2           |

5. Conclusion
In this study, a genetic algorithm optimal method is applied to improve effect of mine tailings consolidated curing agent. The result demonstrated that the best ratio of components is determined to slag powder, quicklime, industrial gypsum and bentonite is 80.75%, 12%, 5.25% and 2%, the compressive strength reaches 0.072MPa. Compared with orthogonal test, the developed method provides an effective way to improve effect of curing agent, and takes less test time.

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