Predicting the Unconfined Compressive Strength of Rubber Fiber Modified Cemented Paste Backfill Using Support Vector Machine

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Abstract. Machine learning based on the support vector machine algorithm was used for the prediction of the unconfined compressive strength of rubber fiber modified cemented paste backfill. Grid analysis was used to find the optimal hyper-parameters. The SVM model was well trained on the training set, and performed well on the testing set. Analysis results showed that the SVM model achieved a higher accuracy. The squared correlation coefficient values were 0.9914 and 0.9321 on the training set and testing set, respectively. It is recommended that laboratories around the world could share UCS tests results of CPB to expand the dataset for the training of prediction models.

1. Introduction
Cemented paste backfill (CPB) has been widely used as a safe and environmental friendly way to disposal mill tailings and prevent the ground subsidence in recent years [1, 2]. These CPB structures are usually under compression in their serving life, thus the compressive mechanical properties of CPB have been the focus and key point for researchers. Fall et al. [3] investigated the mechanical behaviors of CPB under the uniaxial and tri-axial compression. They reported that the confinement and curing ages affected the stress strain behavior of CPB, and the increasing of confining pressure could change the failure mode, stiffness, and peak strength value of CPB. Ercikdi et al. [4] conducted a series of unconfined compressive strength (UCS) tests to study the influence of binder type and dosage on the mechanical properties of CPB. It was reported that CPB using sulphate resistant-based cements maintained good long-term strengths and stability, and the increase of cement dosage increased the UCS values of CPB.

The ductility of CPB is one of the most important mechanical properties to keep the safety of mining work. In 2016, an accident occurred in the west No.2 mining area of Gansu Longshou Mine, China. Without any warning, the overlying CPB structure collapsed suddenly, concurrent with the failure of the surrounding rocks, which could no longer sustain its weight. Due to the brittle behavior of the ordinary CPB, it has poor capability to bear the large deformation, and eventually led to the dramatic large area collapse of CPB structure. This accident resulted in the complete shutdown of the mining operations. Recently, Wang et al. [5] added scrap tire rubber fiber into CPB to explore new approaches of scrap tire disposal. They found that the addition of properly amounts of rubber fiber could not only facilitate the scrap tire disposal pressure, but also could improve the ductility and overcome the adverse impact of the brittleness of CPB. However, the increase in the rubber fibers content was found to be harmful to the UCS of CPB. The UCS of rubber fiber modified CPB was affected by several aspects such as the cement content, rubber fiber content, and curing age. Therefore, it is important for a CPB engineer to determine
the properly cement content and rubber fiber content. Artificial intelligence algorithms have been used for the prediction of UCS by Qi et al. [6], which has been proved that the artificial intelligence has well prospects to this set of problems. In this paper, an approach was proposed to predict the unconfined compressive strength of rubber fiber modified CPB based on the support vector machine (SVM).

2. Material and methods

2.1. Specimen Preparation

Tailings was obtained from the south of Shandong Province, China. It was classified as sandy silt. Rubber fibers were obtained from the recycling of scrap tires. The average length and width of the fibers were 16 mm and 2 mm, respectively. P.O.42.5 cement was used as the binder of this study. The cement contents of the rubber fiber modified CPB were selected to be 5%, 7.5%, and 10% by the weight of the tailings.

For preparing the rubber fiber modified CPB specimens. First, the tailings, rubber fibers, and cement were weighed on an electric scale and then poured in to a bucket to be initially mixed. Then the water was slowly added when the solid content was achieved to be 75%. All materials in the bucket were mixing for 7 minutes and then poured into the plastic mold with a diameter of 5 cm and a height of 10 cm, as shown in Fig. 2. After 12 hours, the specimens should be demold and cured in a humid chamber for 7 days and 28 days. The curing temperature was kept at 20°C constantly.
2.2. Testing Machine and Methodology
Uniaxial compression strength (UCS) tests were conducted on the TAW-200 electronic multifunctional material mechanics testing machine (Fig. 3), which was developed by Qingdao University of Science and Technology and Changchun Chaoyang Testing Machine Factory. Displace loading mode was selected and the loading rate was determined as 0.2 mm/min.

Fig.3. TAW-200 electronic multifunctional material mechanics testing machine (Developed by Qingdao University of Science and Technology and Changchun Chaoyang Testing Machine Factory)

2.3. Machine learning
A machine learning algorithm was utilized for the prediction work. Support vector machine (SVM) was an efficient supervised learning method developed by Vapnik [7, 8]. The dataset was constructed according to the UCS tests results. The input variables were the cement content, rubber fiber content, and curing age. The output variable was the UCS. The dataset was split into the training set and the test set with a size ratio of 7:3. All the input data were scaled to the [-1,1] range.

3. Result and discussion
The UCS results of rubber fiber modified CPB were shown in Fig. 4. It can be seen that CPB with longer curing age has a higher UCS value. At a same curing age, the UCS value of CPB increased with the increase of cement content, which may be contributed by the hydration effect of cement. And the UCS value decreased with the increase of rubber fiber content. This was mainly because the stiffness of the rubber fiber is lower than that of CPB matrix, thus the contribution of rubber fiber to the resistance to externally applied loads is not significantly [9].

Fig.4. Unconfined compressive strength values of rubber fiber modified CPB at (a) 7 days curing age and (b) 28 days curing age.
Grid analysis was used to find the optimal hyper-parameters. The optimal hyper-parameters were found to be $c=32$ and $g=0.02$. After the machine learning based on the SVM, the prediction model was trained well. The comparison between the predicted values and the experimental values are shown in Fig.5. It can be seen that the predicted values were very close to the experimental values. The performance of the well trained SVM model for the UCS predicting of rubber fiber modified CPB was tested by the regression analysis. Results showed that the SVM model achieved a higher accuracy in the prediction of UCS. The mean squared error were 0.00376 and 0.01913 on the training set and testing set, respectively. The squared correlation coefficient values were 0.9914 and 0.9321 on the training set and testing set, respectively.

However, due to the time cost and economic cost of UCS tests of CPB, the size of the dataset in this study was relatively small. This study exhibited that machine learning can be an efficient and accurate way to predict the UCS values of CPB. We recommended that laboratories around the world could share UCS tests data of CPB to expand the dataset for the training of the prediction model. As the data set grows larger, the prediction model could be adapted to any kinds of CPB and achieve a better accuracy for prediction.

4. Conclusion
In this paper, the feasibility of SVM model to predict the unconfined compressive strength of rubber fiber modified cemented paste backfill was explored. Results from the study can be jotted out as follows:

1) UCS of Rubber fiber modified CPB increased with the increase of cement content, and decreased with the increase of rubber fiber content.

2) SVM model can be well trained for the prediction of UCS. The best parameter ‘$c$’ was 32, and the best parameter ‘$g$’ was 0.022 in this study.

3) The trained SVM model achieved a higher accuracy in the prediction of UCS, which exhibited a good capability.

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