Available online at www.sciencedirect.com
ScienceDirect
J China Univ Mining & Technol 18 (2008) 0551–0555
JOURNAL OF CHINA UNIVERSITY OF MINING & TECHNOLOGY
www.elsevier.com/locate/jcumt

Using particle swarm optimization algorithm in an artificial neural network to forecast the strength of paste filling material

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Abstract: In order to forecast the strength of filling material exactly, the main factors affecting the strength of filling material are analyzed. The model of predicting the strength of filling material was established by applying the theory of artificial neural networks. Based on cases related to our test data of filling material, the predicted results of the model and measured values are compared and analyzed. The results show that the model is feasible and scientifically justified to predict the strength of filling material, which provides a new method for forecasting the strength of filling material for paste filling in coal mines.

Key words: mining engineering; paste filling material; neural network; particle swarm; optimized algorithm; prediction

1 Introduction

Paste backfilling in coal mines is an effective technology for coal mining under buildings, railways and water-bodies. This technology is an important part of the green mining proposed by academician Qian Ming-gao[1]. By using this technology, we can effectively control surface subsidence within a permitted range so that villages do not need to relocate, the coal under buildings can be safely mined and the environment as well as the groundwater resources in mining areas can be protected[2]. Therefore, green mining is an important technology in coal mining for us to study in the 21th century. The application of paste backfilling mining technology will provide new power for a healthy development of the coal industry in China. Paste backfilling material is the key to backfilling technology and the result of controlling surface subsidence depends mainly on the strength of the filling material[3–4]. Therefore, accurate strength prediction of the backfilling material is of great importance to control surface subsidence.

Practice indicates that the strength of the backfilling material is affected by many factors[5], some of which are definitive and quantitative, others are random, fuzzy and qualitative. In addition, there are complex nonlinear relationships among the factors, which are tough to illustrate in a definite mathematical or mechanical model. So far, there are many methods, both at home and abroad, to predict the strength of filling material, such as experience of analogy, empirical formulas, physical simulation, elasticity analysis, etc. There are many methods, but they lack a certain amount of scientific rigor, so that their prediction results are not sufficiently precise. Compared with the methods mentioned, an artificial neural network optimum is a preferred option[6].

The particle swarm training optimization algorithm and artificial neural network technology, developed in recent years, have provided powerful means for solving this problem. With its self-organized, self-learning and strong error-tolerance, this technology can be applied to build complex nonlinear mapping relationships[7]. Consequently, it has been increasingly applied in areas such as mining and geotechnical engineering, etc. Given a comprehensive analysis of the factors affecting backfilling material, combined with site engineering cases, we established a prediction model for backfilling strength and conducted an industrial experiment about paste backfilling for the first time in China. In doing this, we accumulated large amounts of experimental data and laid a foundation for further studying the technology of backfilling.

Received 29 January 2008; accepted 21 June 2008
Projects 50490270, 50774077, 50574089, 504902730 supported by the National Natural Science Foundation of China, NCET-06-0475 by the New Century Excellent Personnel Training Program of the Ministry of Education of China and 200760 by the Special Funds of University Outstanding Doctoral Dissertation
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2 Factors affecting the strength of backfilling material

The main factors affecting the strength of paste backfilling material are the concentration of the filling slurry, the variety and dosage of the cementing material, temperature, fly ash content and size of the aggregate. Targets for strength control are early strength and late strength of the backfilling body, ease of movement and bleeding of the backfill material and its cost. The relationship among the six factors and the five targets is complex; a change in any of the factors may have a certain effect on the targets. Sometimes, in practice, some factors remain unchanged, such as the main material, the variety of slurry, the temperature, the strength and the costs which can be calculated according to the proportions. For this reason, research on paste backfilling strength is actually an investigation of the relationships between the concentration of the fill slurry, the fly ash, the cementing material and the strength of the backfilling material.

2.1 Concentration of backfilling material

As illustrated in Fig. 1, ceteris paribus, the strength of the backfilled body improves with an increase in the concentration of the backfilling material, which is particularly true when the concentration is high[8]. Increasing the slurry content not only cuts costs, but also reduces the amount of cementing material carried by water bleeding and decreases the compression ratio of the filled body, which will greatly improve the packed percentage. Therefore, in practice, we can change the slurry concentration to regulate the strength of the backfilling material and, with the transmission ability of the pipe permitting, we should increase the fill slurry concentration as high as possible.

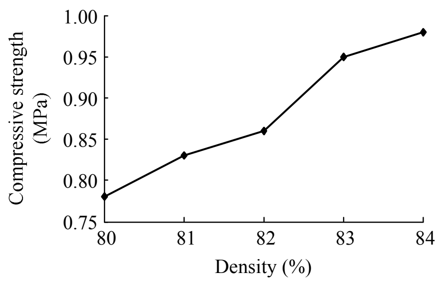

Fig. 1 Relationship between concentration of slurry and strength of backfilling material

2.2 Dosage of cementing material

Fig. 2 indicates that the higher the consumption of the cementing material, the stronger the backfilled body and the higher the backfilling cost[9]. Under the same conditions, as the dosage of the cementing material increases, the strength of the backfilled body clearly increases, largely because the gelatification of the material itself enhances the strength of the backfilling body. In backfilling mining technology, different strengths of filling bodies is required, due to the variation in stability of the stope surrounding the rock and that of the mining depth.

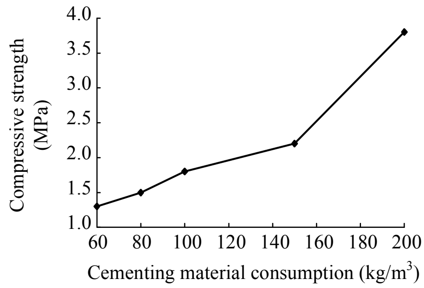

Fig. 2 Relationship between cementing material and strength of backfilling body

2.3 Dosage of fly ash.

Fig. 3 indicates that, when the fill slurry concentration and the dosage of cementing material remain unchanged, the strength of the filling body increases with an increase in the amount of fly ash, because of the activity of both the glassiness and alumina in the fly ash. The higher their content in the fly ash, the better the gelling property and the stronger the filling material. In addition, the ease of flow of the slurry can also be improved by fly ash.

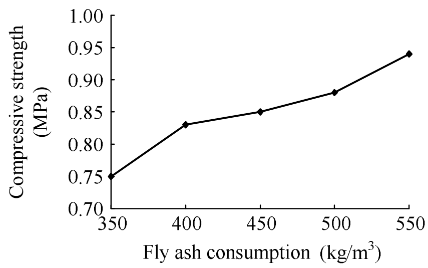

Fig. 3 Relationship between backfilling material strength and fly ash

3 Prediction model

3.1 Modification of learning algorithm

In neural network training, Back Propagation (BP) is the most commonly adopted method. This technology, equipped with self-organized, self-learning and good error-tolerance, can be used to build complex nonlinear mapping relationships. But this algorithm is a gradient-based learning algorithm, showing problems of slow convergence and easily obtaining local minima. In addition, there is also a conflict between the rate of network convergence and learning precision. Targeting this problem, a particle swarm optimization algorithm was used to reach a high rate of convergence and high reliability[10].

Particle swarm optimization, an algorithm based on swarm intelligence, is a new evolutionary calculation method proposed by Kennedy and Eberhart in