Available online at www.sciencedirect.com

ScienceDirect

International Journal of Pavement Research and Technology xxx (2018) xxx–xxx

www.elsevier.com/locate/IJPRT

Asphalt foaming quality control model using neural network and parameters optimization

An-Lin Wang, Zhen-Sheng Fu *, Fu-Min Liu

[a] School of Mechanical Engineering, Tongji University, Shanghai 201804, China

Received 15 May 2017; received in revised form 26 September 2017; accepted 18 December 2017

Abstract

Industrial asphalt foaming is a process of mixing, transferring heat and phase transition of multi-phase multi-component flow in the expansion chamber, including a series of complex problems such as difficult analysis and observation. In the context of this research, asphalt foaming quality control model using neural network was constructed to map the pertinent parameters (asphalt temperature, water content and air pressure) into the foaming properties (maximum expansion ratio and half-life time). In addition, Particle swarm optimization was adopted to avoid the local infinitesimal defect and slow constringency in the traditional BP algorithm. The prediction error of Shell 60/70 quality control model indicates that the asphalt foaming quality control model using PSO-BP neural network is effective, and this provides a novel idea for studying of the foam asphalt, which has practical significance for the design of asphalt foam equipment. Finally, a parameter optimization model with the maximization of the foaming index was proposed based on the quality control model to improve the foaming performance of the asphalt foaming equipment. With the analysis of a parameter optimization model of Shell 60/70 asphalt, the better foaming properties are the maximum expansion ratio of 12.28 times and half-life time of 11.02 s at the foaming condition of asphalt temperature of about 168 °C, the water content of about 1.5 wt% and the air pressure of about 1 bar. The method proposed in this paper is of important reference significance for the engineering with difficult analysis and observation.

Keywords: Road engineering; Asphalt foaming; Neural network; Particle swarm optimization (PSO); Parameter optimization model

1. Introduction

Cold recycling technology using foam asphalt is a new type of renewable construction methods of pavement, and is used widely in many countries and regions as its remarkable advantages, such as energy saving, environmentally friendly and economic [1,2]. Foam Asphalt is the product of asphalt foaming which is a critical part of the cold regeneration technique with foam asphalt. During foaming, asphalt, water, and air constitute a multi-phase turbulent flow in the expansion chamber and low-temperature water in contact with high-temperature asphalt brings about heat transfer and phase transition instantaneously. Formation and decay of foam bitumen are a highly nonlinear dynamic temperature dependent process which makes the study of foaming mechanism difficult [3,4]. The foaming quality of bitumen has a highly significant impact on the performance of foamed asphalt mixture. At present, the two observation values in the asphalt foaming experiment, called maximum expansion ratio (ER_m) and half-life ($\tau_{1/2}$), are mainly used to evaluate the foaming quality of foam asphalt. It is generally believed that the better foaming performance has the greater maximum expansion ratio and the longer half-life time. In engineering applications, the minimum recommended

* Corresponding author.
E-mail address: zhensheng_fu@163.com (Z.-S. Fu).
Peer review under responsibility of Chinese Society of Pavement Engineering.

https://doi.org/10.1016/j.ijprt.2017.12.005
1996-6814/

Please cite this article in press as: A.-L. Wang et al., Asphalt foaming quality control model using neural network and parameters optimization, Int. J. Pavement Res. Technol. (2018), https://doi.org/10.1016/j.ijprt.2017.12.005

values of ER_m and $\tau_{1/2}$ are 8 times and 8 s, respectively [5]. There are many factors to affect the performance of asphalt foaming, which can be attributed to structural parameters and process parameters, and the three key factors, including the temperature of asphalt (T), the water content (WC) and the air pressure (AP), are usually taken into consideration in the study and test.

For the foam asphalt technology, the development trend is to realize a quick design of high-quality foam asphalt cold regeneration equipment [6]. Therefore, it is necessary to establish the foam asphalt quality control model with the pertinent parameters to determine the structure and process parameters and to improve the foaming efficiency of the equipment. At present, there are few studies on the asphalt foam quality model at home and abroad. The main reason for the missing research on this topic can be explained by the difficult characterization of foam bitumen. He GP [7] has established the decay curve of foam asphalt based upon the experimental data, but it gives only the volumetric property of the foam asphalt and does not answer the relationship between foaming performance and the pertinent parameters. Wang [8] has established the parametric model of foam asphalt quality control by polynomial fitting based upon the experimental data. The highest order of the polynomial is related to the number of considered parameters and the calculation of the model is large and complicated, which makes it difficult to be applied in the engineering.

Neural network model is a data-driven model which usually relates to the input and output data without requiring the internal mechanism of the process, so neural network model has been used extensively to solve complicated modeling problems in many fields [9,10]. In this paper, neural network model was used to characterize the relationship between the performance of foaming and pertinent parameters of asphalt foaming. Besides, particle swarm optimization (PSO) was introduced to optimize the initial weight (connection weight and threshold) of neural network in order to improve the prediction accuracy. Moreover, a parameter optimization model with the maximization of foaming index on the basis of the neural network model of asphalt foaming was proposed for improving the performance of asphalt foaming equipment.

2. Experiment of asphalt foaming

In this research, the foaming experiment of Shell 60/70 asphalt, physical properties presented in Table 1, was carried out by the laboratory-scale foamed bitumen plant WLB 10 of Wirtgen. Asphalt temperature, water content and air pressure were selected for studying in terms of their effects on the foaming performance. The experimental conditions are the combination of different factors and levels which are asphalt temperature of 160, 170, 180 and 190 °C, water content of 1, 2, 3, 4 and 5 wt% by mass of bitumen, and air pressure of 1, 3, 5 and 7 bar. For each experimental condition, three duplicate tests were conducted and took the mean value of maximum expansion ratio and half-life as the final experimental value for reducing the error created by subjective factors of man. The experimental result was shown in Table 2. In order to create the model and to validate the algorithm performance, 10 sample data were randomly selected as the forecast samples which were presented in Table 3, and the remaining ones were used as the training dataset to build the neural network model of asphalt foaming.

Table 1
Physical properties of shell 60/70 asphalt.

Properties	Properties value
Penetration (25 °C,100 g, 5 s)/0.1 mm	66.6
Softening temperature (ring and ball method)/°C	49.45
Viscosity (135 °C)/Pa·s	464

3. Asphalt foaming quality control model

3.1. BP neural network for asphalt foaming quality control model

BP neural network is one of the most popular techniques in network models. It is a massively parallel distributed processor that has a propensity for storing experimental knowledge and making it available for use [11,12]. A three-layer BP network with infinite hidden layer neurons can realize any nonlinear mapping. In this paper, a three-layer BP neural network was used to construct the asphalt foaming quality control model. The establishment of asphalt foam neural network model is equivalent to that of mapping a relation between the pertinent parameters and the foaming properties, as expressed in Eq. (1).

$$(ER_m, \tau_{1/2}) = f(T, WC, AP) \tag{1}$$

In this study, the input variables of neural network model of asphalt foaming are asphalt temperature, water content and air pressure, so the number of input neurons is 3; the output parameters are expansion ratio (ER^P) and half-life (τ^P), so the number of output neurons in the output layer is 2. The corresponding target values are the measured values of the asphalt foaming experiment, namely expansion ratio (ER^T) and half-life (τ^T). Therefore, the neural network architecture of one hidden layer with three inputs and two outputs has been used to model the process, as depicted in Fig. 1.

The number of neurons in the hidden layer affects the prediction precision and generalization ability of the neural network. At present, the determination of the number of neurons in the hidden layer is still a lack of theoretical basis and is usually required to rely on previous design experience and repeated tests. According to the Kolmogorov theorem and empirical formula, it can be determined that the number of nodes in the hidden layer is 3–20, and the golden divisional method was conducted to reduce the test number