Construction and Building Materials 159 (2018) 635–641

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Modeling of creep compliance behavior in asphalt mixes using multiple regression and artificial neural networks

Esra'a I. Alrashydah *, Saad A. Abo-Qudais

Department of Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan

HIGHLIGHTS

- A multilayer feed-forward ANN HMA creep compliance behavior model was developed.
- HMA creep compliance behavior can be predicted using multiple regression analysis.
- The ANN model can predict HMA creep behavior in a short time with a low error rates.

ARTICLE INFO

Article history:
Received 12 June 2017
Received in revised form 28 September 2017
Accepted 31 October 2017

Keywords:
Neural networks
Regression analysis
Creep compliance
Asphalt mixture

ABSTRACT

This research aims to provide an appropriate approach to enhance asphalt mixtures creep compliance performance predictions and presents two predictive models, one with multiple regression analysis and the other with feed-forward artificial neural networks (ANN). The two models were evaluated in terms of loading time, testing temperature, asphalt modification, air voids level, and aging condition. The results showed that the two proposed models can be used to predict the HMA creep compliance behavior. However, The prediction accuracy of the feed-forward ANN model is much better as compared with the multiple regression model. The developed feed-forward ANN model has the capability to explain more than 99% of the measured data. Such feasible prediction model provides an attractive alternative for making a better primary decision about selecting asphalt mixtures variables in a quite short time with a very low error rate.

1. Introduction

Creep behavior as a mechanical property has a significant impact on pavement design, distress and service life. In order to predict HMA mechanical response, HMA creep behaviors have to be modeled. For linear viscoelastic materials such as HMA mixes, the ratio of the instantaneous strain to the applied stress subjected to continuously applied sinusoidal loading in the temperature domain is defined by its creep compliance.

Recent studies showed that the effect of changes to the HMA characteristics (air voids level, asphalt modification, and aging condition) on creep compliance values can be accounted by multivariable regression models [8].

In order to analyze the HMA mechanical response, many researchers have investigated the use of ANN approach to model the performance of asphalt mixture and to compare their results with regression analysis approach. The results indicated that both approaches fit the data accurately, although ANN provides a slightly better fit predictions [19,17,18].

Although there are several studies conducted to improve asphalt mix properties and to explain its physical and mechanical behavior, it still too complicated to determine it mathematically. In recent years, researchers have investigated modern pattern recognition methods such as neural networks, genetic algorithms, and fuzzy logic to accurately predict the performance of asphalt mixtures considering different effective parameters. Among those modern patterns, a great interest was observed for ANN especially in asphalt pavement performance models to analyze complex relationships involving multiple variables [15,11,10]. This was due to its capability to learn, adapt, and to find an appropriate relation between input and output variables. Also, it has the ability to tolerate relatively imprecise tasks, approximate findings, and even has less sensitivity to outliers [7]. In addition, ANN approach is a very attractive system due to its ability to draw parallelism and to handle fuzzy information. However, it has some restrictions such as the difficulty in choosing suitable input variables, the long training time period, and the large amount of data trained [5].

* Corresponding author.
E-mail addresses: aiesraa13@eng.just.edu.jo (E.I. Alrashydah), aboqdais@just.edu.jo (S.A. Abo-Qudais).

https://doi.org/10.1016/j.conbuildmat.2017.10.132
0950-0618/

The ANN is a layered system of neurons with weighted connections [12] and it consists of a large number of simple processing units which are called nodes (artificial neurons), those nodes are linked together in a way similar to the structure of the human brain creating the ANN [14,6,16]. The network consists of three layers, the input layer which presents the independent variable of the model, one or more hidden layers and the output layer which presents the solution. Each node receives and process information entering from other nodes and then relay the signals to other nodes.

Recently applications of ANN have been developed rapidly. Most researchers focus on predicting models that use ANN. There were many attempts to predict different asphalt mixture performance using ANN approach such as permanent deformation [13], fatigue performance [4], indirect tensile strength and the tensile strength ratio [9], and creep compliance [20,21].

1.1. Objectives

The main objective of this study was to evaluate the using of ANN approach and multiple linear regression approach to predict the HMA creep compliance behavior. To achieve this object, feed-forward ANN model with ten neurons was developed using MATLAB software. Also, multiple regression model was developed using Software Package for Statistical Analysis (SPSS). The performance of ANN model was compared to the performance of the regression model.

2. Research approach

2.1. Experimental program

2.1.1. Materials

The asphalt binder used in preparing the HMA specimens was obtained from Jordan petroleum refinery. Two types of asphalt binders were used, unmodified asphalt binder and asphalt binder modified with 2% Elvaloy by weight of the binder. The binders have a performance grade (PG) of 64–22 and 76–22, respectively. Crushed limestone obtained from Al-Huson quarries at the northern part of Jordan was used to prepare the HMA specimens. Mid limits of Superpave aggregate gradation for 12.5 mm nominal maximum size was used for preparing the HMA specimens, as presented in Fig. 1.

2.1.2. Specimens preparation and testing methods

One hundred and twenty (120) HMA specimens were prepared and tested. For each specimen, the aggregate and the asphalt binder were heated to 150 °C and mixed together to achieve full coating of aggregate particles. In order to simulate HMA short-term aging, the asphalt mixture was then placed in an oven at a temperature of 135 °C for four hours, in accordance with AASHTO PP2 [2]. Half of the compacted HMA specimens were exposed to long-term aging according to AASHTO R30 [1] by placing the HMA compacted specimen in the oven at 85 °C for four days. This simulates about 7.5 years aging in the field. The mixtures were compacted at three different air voids levels in accordance with the AASHTO TP4 [3]. All the prepared HMA specimens were exposed to a dynamic creep test using a pulse load of 107 kPa at five different testing temperatures (5, 15, 25, 45 and 60 °C). The strains induced by the applied load were obtained and the creep compliance was calculated for each HMA specimen. The description of the creep compliance model's variables is presented in Table 1.

2.2. Models development

In this study, attempts have been made to employ multiple regression analysis approach and ANN approach to provide an appropriate model for prediction of creep behavior in asphalt mixtures prepared with different combinations.

SPSS software was used to develop the creep compliance multiple regression model. The best fit relation between the creep compliance values and the evaluated parameters was explored using "curve expert professional version 2.4" software. The relation between the dependent variable and the independent variables was examined using multiple linear stepwise regression analysis. The resultant regression model was tested to evaluate its adequacy through the Analysis of Variance (ANOVA).

The same data used to develop the multiple regression model were used to develop a multilayer feed-forward back-propagation ANN model using MATLAB software. Two main stages of processing are involved in ANN analysis, the training process, and the testing process. For training process, the supervised method was used. This method employed the back-propagation algorithm and starts by adjusting initial random numbers for weights and biases. After submitting the input vector, the output vector produced by forward-propagation of the intermediate results. The error which represents the difference between the target output and the network output is calculated. In order to minimize the error in the subsequent cycle of prediction, the weights and biases would be modified by back-propagation of the error in the network. During the testing process, the network replies to an input without any change in the network architecture.

Two parameters were used to determine the model's performance, R^2 and the mean standard error (MSE). The highest value

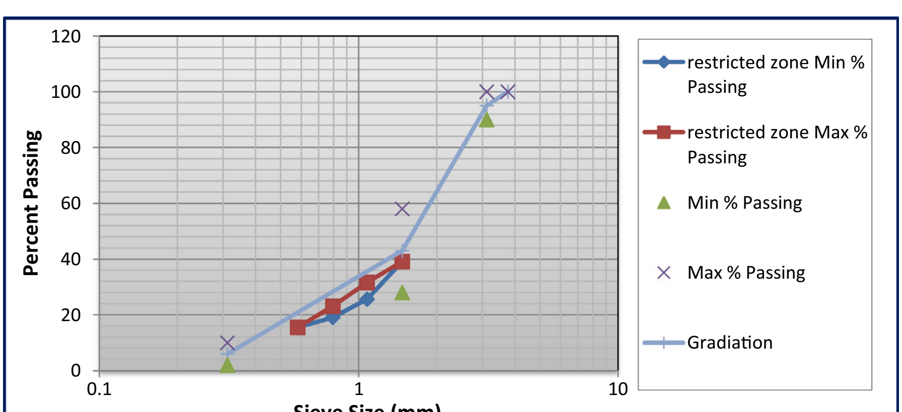

Fig. 1. Gradation of used aggregate.