Construction and Building Materials 169 (2018) 826–834

Contents lists available at ScienceDirect

Construction and Building Materials

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

Predicting the strength of polymer-modified thin-layer asphalt with fuzzy logic

Ali Zehtabchi [a], Seyed Amir Hossein Hashemi [a,*], Somayeh Asadi [b]

[a] Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran
[b] Department of Architectural Engineering, Pennsylvania State University, 104 Engineering Unit A, University Park, PA 16802, USA

HIGHLIGHTS

- Fuzzy logic can predict the Marshall resistance of polymer-modified asphalt mixes.
- The thin-layered asphalt has high rutting-resistance.
- Higher fatigue resistance of modified asphalt than asphalt with continuous granulation.

ARTICLE INFO

Article history:
Received 6 July 2017
Received in revised form 29 January 2018
Accepted 1 February 2018

Keywords:
Thin-layer asphalt
Open-graded
Compressive strength
Fuzzy logic
Additives

ABSTRACT

Soft computing methods can be used with acceptable accuracy in predicting the strength of asphalt mixture. Moreover, estimating the compressive strength of asphalt mixture with 5% mean error by fuzzy logic shows the potential of this approach to predict its strength. More specifically, when the asphalt mix contains additives such as different types of polymers, accurate prediction of its compressive strength becomes more difficult. In most of the developed countries, polymer-modified thin-layer asphalt has long been used to increase the strength, lifespan, and properties of asphalt mixture. In the present study, the fuzzy logic model was developed to predict the compressive strength of the asphalt specimens in different scenarios including changing optimum bitumen percentage, adding granular polymer-modified bitumen, and using different percentages of fractured particles. Then the results were compared with laboratory measurements to determine the accuracy of the fuzzy logic model.

1. Introduction

Contrary to hard computing methods which exclusively focus on precision and accurate modeling, soft computing methods are based on imprecision, approximate, partial truth, and uncertainty tolerance. A clear understanding of reasons, methods, and the philosophy behind these new computation methods opens the door to solve future complex problems. To use simplified scientific language, hard computing methods are based on nature and machine behavior. On the other hand, soft computing methods try to mimic human behavior and the decisions made by their mind to solve a problem. In the era of new and creative technologies, fuzzy logic is an applied mathematical approach which is different from the classical Boolean logic and it advances quickly. Fuzzy set theory is employed in different applications to show uncertainty and ambiguity based on mathematics and provides an analytic tool with some level of uncertainty for most problems.

Recently, several studies were conducted to predict the compressive strength of Portland cement concrete and Hot Mix Asphalt (HMA) mixtures using fuzzy logic [1–3]. In a study conducted by Ozgan [4], Marshall resistance of the asphalt mixtures at various temperatures and operation times was studied using fuzzy logic. By examining the Marshall resistance after 1.5, 3, 4.5 and 6 h at 30, 40, and 50 °C, it was concluded that fuzzy logic and statistical method can be utilized for modeling the strength of asphalt bitumen at various temperatures. Karasahin et al. [5] conducted a study to investigate the relationship between fatigue life and deformation as a fuzzy rule set. They also proposed a fuzzy logic algorithm for estimating fatigue life by measuring deformation. The main advantage of the fuzzy model is its ability to describe knowledge in a human-like manner in the form of simple rules using only linguistic variables.

Shafabakhsh and Tanakizadeh [6] examined the effects of loading characteristics on the resilience module of asphalt mixes using

* Corresponding author.
E-mail address: hashemi@qiau.ac.ir (S.A.H. Hashemi).

https://doi.org/10.1016/j.conbuildmat.2018.02.002
0950-0618/

the adaptive neuro-fuzzy inference system (ANFIS). The flexible module of the asphalt mix specimen was determined using indirect tensile test under haversine and square wave at 5, 15, 25, and 40 °C. Applied loading times of 50, 100, 300, 600, and 1000 ms were equal to the rest-period-to-loading-time (L/R) ratios of 4, 9, and 30. Two ANFIS models were developed for two loading waves in which temperature, loading time, and L/R ratio were input parameters, and the resilience module was its output. Using the developed model, the effect of loading parameters on the resilience module was investigated. Results showed that the resilience module increases by decreasing the temperature and loading time and slightly increases by decreasing the R/L ratio. Moreover, the potentials of the ANFIS model to predict the resilience module were satisfactory which could be a proper alternative for expensive and time-consuming laboratory tests. Baghaee et al. [7] used ANFIS to predict the rutting performance of Polyethylene Terephthalate (PET) modified asphalt mixture by simulating the mixture's deformation.

In another study carried out by Pourtahmasb et al. [8], the accuracy of a soft computing technique for resilient modulus prediction based on a series of measurements of Recycled Concrete Aggregates (RCA) content in HMA and Stone Mastic Asphalt (SMA) mixtures was investigated. Kara and karacasu [9] investigated the effects of waste ceramic tile additives on performance properties of asphalt mixtures. In a similar trend, Amador et al. [10] employed fuzzy logic to predict asphalt density during its operation. The developed model is able to predict the density of asphalt mixture during the operation of stone overlay on site which reduces the experimental time and effort. Tayfur et al. [11] evaluated the mechanical properties of a conventional and five modified asphalt mixtures including amorphous polyalphaolefin, cellulose fiber, polyolefin, bituminous cellulose fiber and styrene butadiene styrene. It was found that Styrene-Butadiene-Styrene (SBS) mixtures have the most rutting resistance.

Open-graded surface layers are permeable and thin layers of warm asphalt mixes which contain coarse aggregates and little fine aggregates. In these layers, traffic load is provided by the contact between coarse aggregates and bitumen which holds the structure together. This feature improves the rutting resistance of the mix and its porous nature results in the fast drainage of water from the pavement surface. It also provides numerous safety and environmental advantages for road users, including higher friction and skid resistance as well as less surface-water dispersion. The use and performance of open-graded, thin-layer asphalt mixes in the USA were examined by Kandel and Malik [12]. They reported that over 70% of the projects using thin-layer asphalt had the service life of more than 8 years and most of the projects employing polymer-modified bitumen had acceptable performance. In addition, the projects with long lifespan had coarser geomaterials than other projects. They concluded that the appropriate mixture design and operation of this type of asphalt pavement are important factors affecting its performance [12]. Malik et al. [13] conducted another study on the mixture design and performance of open-graded thin-layer asphalt mixes. Results showed that the coarser gradation in these mixtures improved the performance of the mix, and the gradations with 15% of materials passing through a # 4 sieve (4.75 mm) had much better performance than finer gradations. Furthermore, using modifiers such as polymers highly improved the performance of these mixes. According to these studies, an appropriate mixture design method must be introduced for these mixes [13].

Furthermore, as a bitumen-modifying polymer material, SBS is among the most widely used and effective additives for asphalt mixes and may be the only additive which improves all the mechanical-thermal properties of asphalt mixture without any negative effect. The main advantages of using this polymer in asphalt mixes are increasing rutting resistance, having few thermal cracks, low fatigue, better binding between bitumen and geomaterials, low thermal sensitivity, and decreasing raveling and stripping phenomena. Despite all the advantages of the SBS polymer, the use of this additive has received little attention in Iran due to its complex application. The difficult and complex usage of this additive stems from the fact that it must be first mixed with bitumen and the polymer bitumen must then be used in asphalt production, causing executive and operational problems. In the present study, we employed the SBS polymer in the form of processed granules as a modifying additive for asphalt mixes. Then the compressive strength of the laboratory specimens by changing optimum bitumen percentage, adding granular polymer-modified bitumen, and using different percentages of fractured particles were measured and the results were compared with the results of the fuzzy logic model.

2. Laboratory design

2.1. Materials

2.1.1. Bitumen

Tehran Refinery's pure bitumen with the permeability of 60/70 which has extensive applications in road-building projects in hot and mild climates was used in this study. Several tests were carried out to determine the physical properties of the mentioned bitumen according to the requirements of bitumen permeability gradation (i.e., ASTM D946/AASHTO M20) [14–15]. Table 1 shows the list of the conducted test, associated standards, and the obtained results.

2.1.2. Geomaterials

Mountain fractured limestone materials were excavated from Asbcheran Mine, eastern Tehran, and sampled in three sizes of coarse-grained, fine-grained, and filler from heated silos of the asphalt factory. Fine-grained materials were provided exclusively from mountain fractured geomaterials without natural sand. These

Table 1
Physical properties of pure bitumen.

Test	Standard Method	Result
Bitumen specific weight at 25 °C	ASTM D70	1.019
Bitumen permeability at 25 °C, 100 g, 5 s (0.1 mm)	ASTM D5	63
Bitumen flash point, Cleveland open-cup (°C)	ASTM D92	298
Bitumen elasticity at 25 °C, 5 cm/min (cm)	ASTM D113	<100
Bitumen softening point (°C)	ASTM D36	50.9
Bitumen solubility in trichloroethylene (%)	ASTM D2042	99.8
Bitumen kinematic viscosity at 135 °C (cSt)	ASTM D2170	377
Bitumen thin-layer asphalt oven process at 163 °C for 5 h, change in initial mass (%)	ASTM D1754	0.02
Thin-film oven process waste bitumen permeability at 100 °C, 25 g, 5 s (0.1 mm)	ASTM D5	43
Permeability of waste bitumen compared with initial bitumen (%)	ASTM D5	68
Thin-film oven waste bitumen elasticity at 5 °C, 25 cm/min (cm)	ASTM D113	>50