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Investigation of the effect of nano-silica on thermal sensitivity of HMA using artificial neural network

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HIGHLIGHTS

- SM of modified asphalt is higher than conventional asphalt.
- Asphalt at initial ages has a lower stiffness modulus compared to aged asphalt.
- Result shows that MLP method gives a more accurate model than RBF method.
- Performance of HMA modified with silica is improved.
- Nano-silica can improve temperature sensitivity of asphalt Mixtures.

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ABSTRACT

Due to changes in weather conditions, engineers try to improve performance characteristics and properties of asphalt mixtures using additives. In this regard, modifiers are used because bitumen cannot have a good performance in all environmental and loading conditions. This paper examined the impact of one of the most efficient and widely used nanomaterials in various industries called nano-silica (Nano SiO_2) on the thermal properties of bitumen and asphalt mixture. Using a solution that can reduce the cost and time of assessment is very important. Using artificial neural networks in many cases facilitates operations on data engineering sciences. It is necessary to ensure that a comprehensive study is performed through considering all or most of the parameters affecting the behavior. The aim of this study was to evaluate temperature sensitivity of asphalt mixture modified with nano-silica. To achieve this goal, 5 types of mixtures with different percentage of nano-silica (0, 0.2, 0.4, 0.7 & 0.9%) were prepared and the temperature sensitivity of modified mixtures was evaluated. Results showed that nano-silica can improve the temperature sensitivity of asphalt mixtures. Moreover, the thermal sensitivity of asphalt mixtures modified with nano-silica using artificial neural network and methods of multilayer perceptron (MLP) and radial basis function (RBF) was simulated and analyzed.

1. Introduction

Bitumen, as an adhesive and preservative material of rocks in asphalt coating, despite its low weight percent (4–6%), has contributed significantly to the strength and consolidation of coverings against a variety of corrosive factors of surface. Unfortunately, along with the growing urban traffic volume and coming and going of heavy vehicles as well as increasing global temperatures, problems such as low thermal resistance have overshadowed the use of bitumen. Thus, many efforts have been made to improve the properties of bitumen in recent decades [1]. Thermal sensitivity of asphalt mixtures is a major problem since asphalt contains bitumen that is very sensitive and susceptible to heat. Nanomaterials are among the families of additives, which improve the properties of hot asphalt in terms of thermal sensitivity [2]. According to previous studies on nanomaterials such as concrete, nano-silica is a material that improves the properties of bitumen and hot asphalt mixture [3].

2. Literature review

In a study conducted in 2007, the effect of adding nanoclay on long-term performance of asphalt pavements was studied. The results showed that adding nanoclay to bitumen led to increased fatigue life of asphalt pavements [4]. In a study conducted in 2009, the issue of asphalt pavement was studied using both

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conventional and well-known nano-clays of nano fill and Cloiste. In this study, the process of mixing nanoclays with bitumen was assessed. The examination of the fatigue resistance of bitumen clearly showed that bitumen modified with nanoclay increased adhesion and shear strength of bitumen. However, the addition of nanoclay, due to reduced flexibility of bitumen, reduced bitumen performance against fatigue, especially at low temperatures [5]. The performance of low temperature thermal cracks in hot asphalt mixtures with failure mechanisms was assessed and analyzed in another study carried out in 2013. Failure models of asphalt mixture include threshold failure energy and nonlinear thermal coefficient. The generalized model is able to predict the induced thermal stresses and failure temperature that corresponds to experimental results obtained for three types of asphalt. The result showed that the generalized model takes a closer step to understand the thermal cracks performance at low temperature by introducing the three parameters. The result also demonstrated that a more accurate image of the linear assumption can be achieved assuming the nonlinear heat transfer coefficient [6]. In one study in 2014, the effect of nano-Titanium dioxide (TiO2) on HMA properties was investigated. To this end, mixtures with different content of bitumen and nano-Titanium dioxide were made and effects of these parameters were investigated on the modified mixtures in comparison to conventional asphalt mixtures. With the experimental results and the numerical analysis, experimental models were proposed for prediction of the creep behavior and fatigue performance of both the conventional and modified asphalt mixtures. To this purpose, nano-TiO2 was used for different conditions depending on temperature and stress. The results showed that adding nano-TiO2 resulted in great improvements on permanent deformation and fatigue life of HMA [7]. In another study, the thermal properties of asphalt concrete were determined with the help of field data and laboratory results. New methods of pavement design based on the methods of experimental mechanistic and use of parameters such as the coefficient of thermal shrinkage, thermal conductivity (parameter k), specific heat capacity (parameter c) as parameter predicting thermal cracks and aging issues have been proposed. This study was conducted based on data collected on the ground and thermal strains in pavement sections on interstate roads [8]. In one study, the effect of graphite on thermal parameters of hot asphalt mixture in the binder layer was studied. Using laboratory studies, the effect of graphite on thermal sensitivity of the binder layer was investigated. Experimental results showed that the thermal conductivity linearly increased by increasing the effect of graphite and the specific heat reduced with downward trend. However, the capacity of energy storage of asphalt mixed with graphite was more than a simple mixture [9]. Yet in another study, a quantity model was provided for the relationship between temperature and microstructure of asphalt modified with styrene-butadienestyrene. This study provided a new way to describe changes in the microstructure of asphalt mixture modified by styrene-butadienestyrene during the temperature change [10]. In a study, seasonal changes of thermal strains in flexible pavement was investigated by laboratory and field methods. Response of flexible pavement is susceptible to fluctuations in temperature of pavement. Results indicated that the thermal strain in winter was 1.4–2 times the amount of thermal strain in summer [11]. The response and performance of thermal modified asphalt pavement was evaluated in a study. Many three-dimensional finite element models have been defined to determine the thermal field and crisis response performance of pavement under the weight of wheels. Long-term pavement performance, including fatigue cracks and grooves shrinkage, was evaluated using an experimental-mechanistic approach. The use of asphalt with low thermal conductivity at level and the use of asphalt with higher thermal conductivity in depth of pavement can also reduce fatigue cracking at low temperatures. As a result, thermal modification pavement improves the fatigue cracking and shrinkage grooves and its use is recommended [12]. The binder of asphalt modified with carbon nanotube for Egypt's climate was evaluated in a research laboratory. This study sought to investigate the effect of multilayer carbon nanotubes on the rheological properties of asphalt mixture. The effect of the new multilayer carbon nanotubes at 0.5%, 1.0%, 2.0% and 3.0% wt% of asphalt at 120 °C was combined with the mixture. Moreover, rheological and experimental properties of asphalt mixtures in different aging conditions were examined using Superpave mix design. At constant temperature of experiment, resistance to fatigue cracking and low temperature cracking resistance was reduced by increasing the percentage of the new multilayer carbon nanotubes [13]. In one study, the effect of nano-silica and dolomite on mechanical, physical and chemical properties of unaged asphalt binder under oxidation was studied. To further examine the role of nano-silica and dolomite additives in the binder, an asphalt mixture was added and performance of the unaged binder under oxidation was assessed and analyzed. The results indicated that the mechanical, physical and chemical behavior of the binder with chemical interactions within the material and in the aging process can be explained and presented [14]. The asphalt binder modified with nano-silica and nano-clay was evaluated in another study. Accordingly, the study investigated the characteristics of two different nano additives. The results showed that the nano-silica synthesized from micro-silica decreased the penetration rate but increased the hardening point temperature. However, nanoclay as another additive increased the penetration rate but reduced the hardening point temperature [2]. In recent years, artificial neural networks (ANNs) have been used to model the properties and behavior of materials. They have also received much interest in order to find complex relations between different properties in many fields of civil engineering applications because of their ability to learn and adapt. In this regard, one study in 2015 discussed the application of ANNs in predicting permanent deformation of asphalt concrete mixtures modified by nano-additives. A total number of 270 asphalt mixtures were constructed from two different aggregate sources (natural and steel slag) and modified by micro silica and nano TiO_2/SiO_2. An ANN model was developed using five input parameters including aggregate source, additive type, additive content, temperature, and stress. The result indicated that the proposed model can be applied to predict the final strain of asphalt mixtures. The model was further applied to evaluate the effect of different percentages of nano-additive on permanent asphalt deformation. Results showed that an increase in percentage of nano-additives is very effective in reducing the final strain of asphalt mixtures. However, an increase in percentage of additives over 8.5% does not help to reduce permanent deformation under dynamic loading in asphalt mixtures [15].

3. Methodology

3.1. Materials

The aggregates used in this study were graded using the continuous type IV scale of the ASHTOO standard [16] presented in Table 1. Specifications of stone materials and their specific gravity

Table 1
Gradation values of the HMA aggregates.

Sieve number	#200	#50	#8	#4	3/8″	1/2″	3/4″	1″
Sieve size (mm)	0.075	0.3	2.38	4.75	9.5	12.5	19	25.4
Aggregation Type	Percentage Passing (%)							
Topka	6	13	43	59	–	95	100	–