Construction and Building Materials 148 (2017) 666–674

Contents lists available at ScienceDirect

Construction and Building Materials

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

Rutting depth prediction of hot mix asphalts modified with forta fiber using artificial neural networks and genetic programming technique

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HIGHLIGHTS

- Adding fiber shows a higher rutting resistance due to lower thermal sensitivity.
- Increasing the amount of forta fiber lead to reduce permanent deformation.
- Better interlock between aggregates and forta fiber reduces the deformations.
- Neural network model has shown good agreement with experimental results.
- Genetic programming model has less error than the Burgers model.

ARTICLE INFO

Article history:
Received 23 October 2016
Received in revised form 3 May 2017
Accepted 8 May 2017

Keywords:
HMA
Rutting depth
Forta fiber
Artificial neural networks
Genetic programming

ABSTRACT

The most significant problems in the maintenance of highway networks are low strength against dynamic loads and short service life of pavements. In recent years using additive materials to improve the performance of asphalt mix under dynamic loading has been remarkably developed. Previous research show that adding appropriate polymer materials to hot mix asphalt improves the dynamic properties of these mixtures. A series of dynamic creep test were conducted under different temperatures and stress levels to evaluate rutting performance of asphalt samples. The proposed artificial neural networks (ANN) model for rutting depth has shown good agreement with experimental results. Beside, in this study a comparison is made between the Burgers model and genetic programming (GP) model in estimating the rutting depth of asphalt mix. Performance of the genetic programming model is quite satisfactory. The obtained results can be used to provide an appropriate approach to enhance the performance of asphalt pavements under dynamic loads.

1. Introduction

In the early twentieth century, the technology of building asphalt and concrete roads was transferred to out of the cities and to building the roads too [1]. Asphalt concrete is one of the materials widely used for pavements of the roads and airports. The researchers and engineers are constantly trying to improve the performance of asphalt pavements. Road pavement, as the surfaces frequently loaded by heavy axes, must have sufficient resistance to fatigue, cracking, creeping and sliding [2]. Life span of road pavement is an important topic in national economy. A good pavement must provide a smooth surface for driving, tolerate the high volume of traffic and transfer the tension to lower surface with the minimum loss [3]. The destructions occurred during useful life of the pavements primarily include permanent deformation in wheel track of the vehicles, rutting and thermal cracking. Since high costs must be spent for rehabilitation and reconstruction of these defects and errors, therefore early prevention is usually more affordable. To avoid these deconstructions, the pavement materials must be selected in a way to have sufficient strength and stability [4]. One of the problems of asphalt pavements is their considerable creep. Creep phenomenon is the gradual emergence of subsidence and sustainable displacements without cracks in pavements under the applied positive loads. Sustainable deformations that appear objectively as rutting of wheel tracks are considered as the primary criteria for an asphalt pavement project [5]. Excessive rutting usually referred to as the main cause of premature destruction and maintenance operations of road network, will lead to reduction in service life of the pavement [6,7]. Excessive use of bitumen, increase of fine aggregates, and high content of river stone materials and rounded particles of stone materials are the usual reasons

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http://dx.doi.org/10.1016/j.conbuildmat.2017.05.088
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Table 1
Gradation of aggregates used in the study.

Sieve size	3/4″	1/2″	# 4	# 8	# 50	# 200
Percent passing	100	95	59	43	13	6

Table 2
Particulars and specific gravity of stone materials.

Size of the Sieve	Specific Gravity	
	True	Apparent
The stone materials remained on the sieve # 8	2.435	2.628
The stone materials passed the sieve # 8 and remained on sieve # 200	2.412	2.688
The stone materials passed the sieve # 200	2.630	
The true specific gravity of stone material mixture	2.437	

Table 3
Physical characteristics of bitumen 60/70.

Characteristic	Standard Method	Result
Penetration rate in 25 centigrade degrees (0.1 mm)	ASTM D5	66
Softening point of bitumen (°C)	ASTM D36	49
Solubility in trichloroethylene (%)	ASTM D2042	99.5
Kinematic viscosity (c.s) in 125 °C	ASTM D2170	446
Bitumen thin-film oven procedure, primary mass change (%)	ASTM D1754	0.01
Waste penetration degree of thin-film oven procedure (0.1 mm)	ASTM D5	50

Table 4
Physical characteristics of forta fiber.

Materials	Polyolefin	Aramid
Form	Twisted and single-stranded strings	Single-stranded
Specific gravity	0.91	1.44
Tensile strength (PSI)	70,000	400,000
Length (mm)	19	19
Colour	Black	Yellow
Acidic/basic strength	Ineffective	Ineffective

depending on material properties that influence the lasting transformation of the work [8]. Cracking is the most important destruction state of asphalt pavement. Constructing a pavement that does not crack within a certain period of time after exploitation is impossible. Cracking is an inevitable problem raised in over two million miles of paved roads of United States [9]. Since cracking is the major form of pavement destruction, it is usually considered as a decisive factor in determining the appropriate time and method for rehabilitation [3]. The horizontal shear force created under the wheels of vehicle is the cause of great stresses and strains on the pavement surface and it moves in a direction perpendicular to the path. These strains occur near edges of the tire and create longitudinal cracks. Considering the fact that width of the loading area is limited to vehicle's track, these transverse cracks only develop in a limited length. These cracks are spread by flexural performance and shear performance of traffic load. Creation and spread of asphalt pavement cracks have various reasons, but the mechanisms involved in it can be classified in three forms: traffic, thermal and surface [10]. To enhance flexibility of pavements and also to increase their resistance to destructive factors such as fatigue, cracks caused by severe temperature changes and stable deformations, additives with the potential to improve the mechanical properties of asphalt pavements are applied in production of hot mix asphalt in recent years [11]. Anti-stripping additives and polymer modifiers are two common modifying methods for improving the fundamental properties of bitumen binders. Cohesion and adhesion are two important related factors of bitumen binders that can influence the performance of asphalt mixture. Results of the researches showed that the mixtures modified by polymer have a better performance compared to unmodified mixtures and the mixtures modified with anti-stripping additives. The studies have shown that the polymers improve the performance of adhesive bitumen against rutting and its adhesion and cohesion [12]. Yousofi and Ramzani (2005) studied the effect of modifying bitumen 60/70 of Isfahan refinery with two light polyethylene polymers (LDPE 200) and Styrene-Butadiene random co-polymer (SBR 1712), both of which are domestic products, on properties of the resulted asphalt mixes. It was observed that Marshal strength and fluidity of asphalt mixes was respectively increased and decreased in presence of polymer [13]. Zoorob et al. stated that plastic wastes can replace a part of stone materials or be used as bitumen modifiers. Dense Bitumen Macadam (DBM) along with plastic junks the major part of which is formed by light polyethylene (LDPE), decrease density of the mixture up to 16%. Also, they result in a 250% increase in Marshall Stability and an improvement in indirect tensile strength in plastic asphalt mixtures. Very detailed information about the applications of artificial neural networks in transportation engineering can be found in the relevant literature [14]. Shafabakhsh et al. evaluated the application of ANN 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 were modified by micro silica and Nano TiO2/SiO2. All samples were tested at three different testing temperatures of 40, 50, and 60 °C and five stresses of 100–500 kPa. An ANN model developed using five input parameters including: aggregate source, additive type, additive content, temperature, and stress. The result indicates that the proposed model can be applied in predicting final strain of asphalt mixtures. The model is further applied to evaluate the effect of different percentages of Nano-additive on permanent asphalt deformation. Results show that an increase in percentage of Nano-additives is very effective in reducing the final strain of asphalt

Table 5
Marshal test results for determination of optimized bitumen range.

Type of bitumen	Bitumen percent (% wt)	Stability (kg f)	Flow (mm)	Unit Weight (g/cm^3)	Void (%)
60–70	5.8	705	4.2	2.192	7.3
60–70	5.8	721	4.0	2.187	7.5
60–70	6.1	792	3.7	2.207	7.5
60–70	6.1	803	3.6	2.204	7.7
60–70	6.4	863	3.2	2.215	8.5
60–70	6.4	857	3.0	2.219	8.4
60–70	6.7	839	3.4	2.206	8.2
60–70	6.7	827	3.5	2.210	8.0