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RESEARCH ARTICLE

Evaluation of Application of Thin HMA Overlay on the Existing Flexible Pavement for High-Traffic-Volume Rural Highways

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Abstract

Thin hot mix asphalt (HMA) overlay of flexible pavement is a conventional method for preventive maintenance of the existing flexible pavements especially in high-traffic-volume rural roads. In this research, MEPDG software is used to investigate the effects of thin HMA overlay on the pavement performance improvement by considering various scenarios for applying overlay layer under different climatic conditions. These scenarios consist of applying dense graded asphalt concrete (DGAC) and gap graded asphalt rubber concrete (GGARC) as thin overlay layer with and without thin milling the existing asphalt concrete layer. The analyses are made for the climatic conditions of three cities in Iran. According to the obtained results, the effect of mean annual air temperature on thin HMA overlay performance is more than rainfall. The results also indicate that the performance of GGARC in retention of fatigue cracking is better than DGAC. Furthermore, the results suggest that thin HMA overlay remarkably increases the service life of existing flexible pavement for heavy traffic rural highways.

Keywords

Flexible pavement · thin HMA overlay · dense graded asphalt concrete · gap graded asphalt rubber concrete · high-traffic-volume rural highway

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1 Introduction

Maintenance and rehabilitation (M&R) of asphalt concrete pavements are necessary to maintain existing pavement performance conditions and to increase its service life. M&R are classified to three categories including localized M&R, global M&R and major M&R [1]. The first and second categories are pavement preventive maintenance which is a planned strategy for treatment of existing pavement to postpone future distresses and economically maintain system performance conditions [2]. The third category which raises the pavement condition index (PCI) to 100, includes reconstruction and structural overlays [1]. Various strategies can be considered for preservation and maintenance of flexible pavements in order to improve their performance. These strategies include crack seal, chip seal, slurry seal, thin hot mix asphalt (HMA) overlay, cold in-place recycling, stone matrix asphalt (SMA) or open graded friction course (OGFC) as thin overlay layer, and milling of the existing asphalt concrete layer and applying thin HMA overlay [3]. The use of treatments for preventive maintenance varies widely depending on various criteria such as present pavement condition and economical aspects. Microsurfacing and thin HMA overlay methods were compared in a research by considering pavement life and construction costs and it was found that thin HMA overlay is more suitable for heavy traffic rural roadways and harsh climatic conditions and microsurfacing is better for light traffic roadways [4]. In another research in Kansas, it was found that seal coat and slurry seal are not suitable for rural roads with light traffic [5]. Minnesota Department of Transportation (Mn/DOT) reported that the milling of the existing asphalt concrete layer to 37.5 mm and overlaying its surface with thin HMA layer is a very effective preventive maintenance treatment; although, it is the most expensive method [6]. Based on practical experiences in Hungary, Pallos [7] concluded that applying thin asphalt wearing courses produced with the modified bitumens could be economical for the preservation and renewal of pavement surfaces. Generally, it has been established that when applied early before pavement conditions get worse, thin surface treatments cost less than reconstruction and rehabilitation treatments that are applied after pavements already lost or on the verge of losing their functional/ structural capacity. SHRP SPS No 3, which involves flexible pavements preventive maintenance experiments, has evaluated various treatment methods involving thin HMA overlay and has indicated that these methods can be economical in a long term [8].

Irfan et al. [9] investigated the thin HMA overlay service life using different performance indicators for pavements that had been treated by thin HMA overlay in 2001 to 2006. These indicators included international roughness index (IRI), pavement condition rating (PCR) and rut depth. According to this research, differences in climatic severity (represented by freezing index) can have a significant impact on the service life of the treatment. Minhoto et al. [10] carried out a three dimensional finite element analysis and concluded that application of asphalt rubber HMA reduces reflective cracking in overlay layer better than conventional dense graded HMA.

By considering the above explanations, thin HMA overlay can be an appropriate method for pavement preventive maintenance, especially for high-traffic-volume roadways. These overlays are generally 37.5 mm or less in thickness, and are comprised of aggregate having a small nominal maximum aggregate size, conventionally 12.5 mm or less [11]. Overlay performance is influenced by many factors such as existing pavement conditions, traffic loading, and environmental conditions.

The major objective of this research is to investigate the effects of thin HMA overlay on the extension of the pavement service life and reduction in pavement distresses for rural roads with high-traffic-volume by considering various climatic conditions. Different scenarios for applying thin HMA overlay layer on the existing flexible pavement are considered in this regard.

2 Methodology

To evaluate thin HMA overlay for high-traffic-volume rural roadways, climatic conditions of three cities in Iran with various amount of mean annual temperature and rainfall are considered. These cities include Tehran, Rasht and Ahvaz. Considered scenarios include applying dense graded asphalt concrete (DGAC) and gap graded asphalt rubber concrete (GGARC) with and without thin milling. For this purpose, mechanistic empirical pavement design guide (MEPDG) software is used which can evaluate distresses created in the pavement during its design life according to climate and traffic conditions and its outputs can be used to determine appropriate time for applying overlay layer. MEPDG software employs a layered elastic model and integrates it with the AASHTO pavement design guide to predict distresses created in pavement [12]. In this study, version 1.1 of the software is used (Release date: August 2009). The main criteria for evaluation of application of thin HMA overlay on the existing flexible pavement are fatigue cracks, IRI and rutting all which can be calculated by MEPDG software. The results obtained from this software are compared with the results obtained by KENLAYER software developed by Huang [13]. The KENLAYER computer program is applied only to flexible pavement with no joints or rigid layers and the backbone of this software is the solution for an elastic multilayer system under a circular loaded area. In addition, KENLAYER can be applied to layered systems under single, dual, dual-tandem, or dual-tridem wheels with each layer behaving differently, either linear elastic, nonlinear elastic, or viscoelastic. Therefore, since both MEPDG and KENLAYER softwares are based on the multilayered elastic theory, they are applied in this study.

It should be mentioned that the effectiveness of the performance prediction models in MEPDG software has been the subject of previous investigations conducted by Rodezno and Kaloush [14]; and Pasquini et al. [15]. Also, this software has been used to evaluate the performance of flexible pavements; e.g., Amini et al. [16] used MEPDG and highway development and management 4 (HDM-4) to compute life cycle cost of conventional and perpetual pavement sections over a period of 40 years.

In the MEPDG software, first created distresses in the existing flexible pavement are obtained during its design life under passing traffic by modeling the pavement sections properties. In the next step, using these predicted distresses, appropriate time for application of thin HMA overlay layer is evaluated. Finally, pavement serviceability life after applying overlay layer on the existing pavement surface is determined for the considered scenarios and climatic conditions. Four scenarios considered for the application of the overlay layer on the existing flexible pavement surface include:

- Overlay with 37.5 mm thickness by dense graded asphalt concrete (Overlay with DGAC).
- Milling 25 mm thickness of the existing pavement surface and overlay with 37.5 mm thickness by dense graded asphalt concrete (Milling and overlay with DGAC).
- Overlay with 37.5 mm thickness by gap graded asphalt rubber concrete (Overlay with GGARC).
- Milling 25 mm thickness of the existing pavement surface and overlay with 37.5 mm thickness by gap graded asphalt rubber concrete (Milling and overlay with GGARC).

3 Pavement layers Characteristics

Asphalt concrete pavement sections which are involved in our analyses are shown in Table 1. These sections consist of asphalt concrete layer, base layer and subbase layer. Thicknesses considered for existing flexible pavement are obtained from MEPDG analyses by try and error such that they could endure high-traffic-volume in such a way that there is no need for overlay for 10 years after initial construction. It should be mentioned that in the cases that the amount of distresses in the existing pavement is too high, a structural overlay will be required instead of thin overlay. The structural ovelay can be designed using an appropriate method such as the mechanistic-empirical approach developed by Fi and Szentpéteri [17].

In this study, A - 2 - 4 soil type with CBR of 20 and A - 6 soil type with CBR of 5 are considered for the roadbed. Section No. 1 is applied for roadbed soil A - 2 - 4, and section No. 2 is used for roadbed soil A - 6. The characteristics of existing asphalt mixture is listed in Table 2, using the results presented by Rodezno and Kaloush [14]. As shown in this table, the binder grade used in the considered mixture is PG 58 - 22 and the penetration degree of this bitumen is 60. Also, the air void of the selected DGAC is 6%. The properties of this asphalt mixture are the same as the conventional asphalt mixture used in Iran; as such, this DGAC has been employed in this study. Gradation of base and subbase layers materials is shown in Table 3 according to the ASTM D1241 - 07 [18]. Values of CBR considered for base and subbase layers are equal to 80 and 30, respectively, which are minimum requirements [19].

An analysis of the ADT classification criteria on rural and urban high-traffic-volume roads, resulted in the following definition of rural high-traffic-volume routes: minimum amount of average annual daily traffic (AADT) is equal to 5000 vehicle per day for rural roadways with heavy traffic [20]. Because high-traffic-volume roadways are considered here, AADT is taken as 10000 and average annual daily truck traffic (AADTT) is taken as 1000 for the design lane by assuming that 10% of traffic consists of truck and traffic growth rate is assumed as 4%. In addition, truck traffic group of 1 presented in Table 4 is used. This table shows AADTT distribution by vehicle class for this group [21]. According to the Iranian highway asphalt paving code [18] as well as the research conducted by Ameri and Khavandi [22], the majority of heavy vehicles traveling on paved roads in Iran have axle loads equal to 8 ton, 18 ton and 24 ton; respectively for single, tandem and tridem axle types. As shown in Table 4, about 74 percentage of trucks are considered as 5-axle single-trailer truck (Class 9) in which the axle load ranges between 5 to 18 ton for tandem axle and about 8.5 percentage of heavy vehicles are single unit (class 5) in which axle load ranges between 1.5 ton to 8 ton. Therefore, truck traffic group of 1 can appropriately model the standard axles traveling on rural highways in Iran. In addition, the MEPDG manual suggests that truck traffic group of 1 is an appropriate selection for the high-traffic-volume routes such as interstate routes [21].

Climatic situation of the cities studied in this research (Rasht, Tehran and Ahvaz) is imported to MEPDG by integrated climatic model (ICM) files. Hourly climatic data of temperature, precipitation, wind speed, percentage of sunshine and relative humidity are essential for creating ICM files [23]. So, the meteorological data of twenty consecutive years (1982 - 2002) presented by the Iranian meteorological organization (IMO) are utilized [24, 25]. The characteristics of climatic conditions in the studied cities are presented in Table 5. As shown, Tehran and Ahvaz are approximately the same as each other in terms of the mean annual rainfall. Also, Tehran and Rasht have minor difference in terms of the mean annual temperature.

The characteristics of the gap graded asphalt rubber concrete used as thin overlay are shown in Table 6. Also, Fig. 1 compares dynamic modulus of DGAC and GGARC imported to MEPDG as input level 1. The dynamic modulus master curves for DGAC and GGARC at each test temperature and frequency are obtained using unconfined and confined compression tests [14, 15]; although, the results of other tests such as indirect tension test on cylindrical specimen (IT-CY) can be used to develop master curve [26]. In the case that dense graded asphalt concrete is used as overlay layer, its characteristics are considered the same as the properties of the existing asphalt concrete layer as shown in Table 2. It should be noted that in scenario that thin milling is considered, the thickness after milling is used for the thickness of the existing asphalt concrete layer.

It should be mentioned that according to a research by Rodezno and Kaloush [14], the developed coefficients of performance predictive models for dense graded asphalt concrete in MEPDG can be used for gap graded asphalt rubber concrete, as long as confined dynamic modulus values are inputted to the software. In the present study, since confined modulus values are imported to the MEPDG software for gap graded asphalt rubber concrete, the same coefficients developed for DGAC are considered for GGARC.

4 Results

4.1 Evaluation of existing flexible pavement performance

As mentioned previously, the thicknesses considered for the sections of the existing flexible pavement obtained from MEPDG analyses are such that they could endure high-traffic-volume and at least there is no need for structural overlay during 10 years after initial construction. Table 7 shows predicted distresses in the existing flexible pavement by MEPDG in section No. 1 (designation 20 - 25 - 35) after 10 and 20 years from initial construction. According to these results, considered section can endure more than 10 years without any structural damage; as such, applying overlay on the existing pavement after 10 years from its initial construction is appropriate. Von Quintus [27] stated that for high volume routes, pavement failure occurs when fatigue cracking reaches 20% of the road surface or when 12 mm of rutting is observed on the surface. As it can be seen in Table 7, after 20 years from initial construction, amount of fatigue cracking is more than 10% and total pavement rut depth is more than 10 mm for climatic conditions of Ahvaz. According to the obtained results by MEPDG, distresses reach a value that overlay layer should be applied to maintain pavement performance. In other words, the pavement being overlaid may be milled or unmilled, but it should not show signs of structural distresses requiring a more extensive rehabilitation or reconstruction. Consequently, applying overlay on the existing pavement after 10 years from its initial construction is appropriate for these weather conditions. According to a research by Chou et al. [28], the average cost of thin overlay is only around 60% of the average cost for a minor rehabilitation technique on the general system pavements.

Tab. 1. Sections considered for existing flexible pavement

Section No	Thickness of each layer (mm)			Abbreviated designation for each section	Initial two-way AADTT
	Asphalt concrete layer	Base layer	Subbase layer		
1	200	250	350	20 - 25 - 35	2000
2	200	300	400	20 - 30 - 40	2000

Tab. 2. Mix design properties of dense graded asphalt concrete (DGAC) [14]

Characteristic	Unit	Value
Level of input	-	Level 1
Type of asphalt binder	-	PG 58-22
Specific gravity of asphalt binder	-	1.04
Penetration degree of asphalt at 25°C	0.1 mm	60
Absolute viscosity	Poise	6000
Optimum asphalt binder content	%	5.1
Effective asphalt binder content	%	4.6
Asphalt mixture air voids content	%	6

Tab. 3. Gradations used for granular base and subbase layers [18]

Sieve size	Percentage passing	
mm	Base – Type I	Subbase – Type I
	(Gradation B)	(Gradation B)
50	100	100
37.5	—	—
25	85	85
19	—	—
9.5	57.5	57.5
4.75	45	45
2	32.5	32.5
0.425	22.5	22.5
0.075	5	8.5

Tab. 4. AADTT distribution by vehicle class for truck traffic group 1 [21]

Vehicle class		4	5	6	7	8	9	10	11	12	13
Vehicle name		Bus	2 axle SU[1]	3 axle SU	4 or more axle SU	4 or less axle ST[2]	5 axle ST	6 or more axle ST	5 or less axle MT[3]	6 axle MT	7 or more axle MT
AADTT distribution for each vehicle class (%)		1.3	8.5	2.8	0.3	7.6	74	1.2	3.4	0.6	0.3
Number of axles per vehicle	**Single axle**	1.62	2	1.02	1	2.38	1.13	1.19	4.29	3.52	2.15
	Tandem axle	0.39	0	0.99	0.26	0.67	1.93	1.09	0.26	1.14	2.13
	Tridem axle	0	0	0	0.83	0	0	0.89	0.06	0.06	0.35
Range of axle loads (ton)	**Single axle**	3 - 7	1.5 - 8	3 - 7	4 - 9	1.5 - 10	3 - 7	3.5 - 7	2.5 - 8	2.5 - 8	3 - 7.5
	Tandem axle	9 - 14	3 - 7	3 - 12	3 - 10	3 - 10	5 - 18	6 - 17	5 - 16	6 - 14	5 - 16
	Tridem axle	20 - 23	17 - 19	6 - 16	16 - 29	15 - 28	6 - 13	6 - 24	6 - 12	6 - 26	15 - 28

1. Single Unit 2. Single Trailer 3. Multi-Trailer

Tab. 5. Characteristics of climatic conditions in the studied cities

Climatic properties	Unit	Tehran	Rasht	Ahvaz
Scanned period	Year	1982-2002	1982-2002	1982-2002
Mean annual air temperature	°C	17.9	16.3	25.8
Mean annual rainfall	mm	246.4	1378.2	241.8
Freezing index	°C - day	10	0.5	0
Average annual number of freeze-thaw cycles	-	2	0	0

Tab. 6. Physical properties of asphalt rubber and gap graded asphalt rubber concrete (GGARC) [15]

Characteristic	Unit	Value
Level of input		Level 1
Viscosity at 60°C	Poise	21667
Penetration at 25°C	0.1 mm	48
Softening point	C	59
Viscosity at 135°C	mm^2/sec	3093
AR binder specific gravity		1.04
AR binder content	%	7.9
Effective asphalt binder content	%	7
Asphalt mixture air voids content	%	5.8

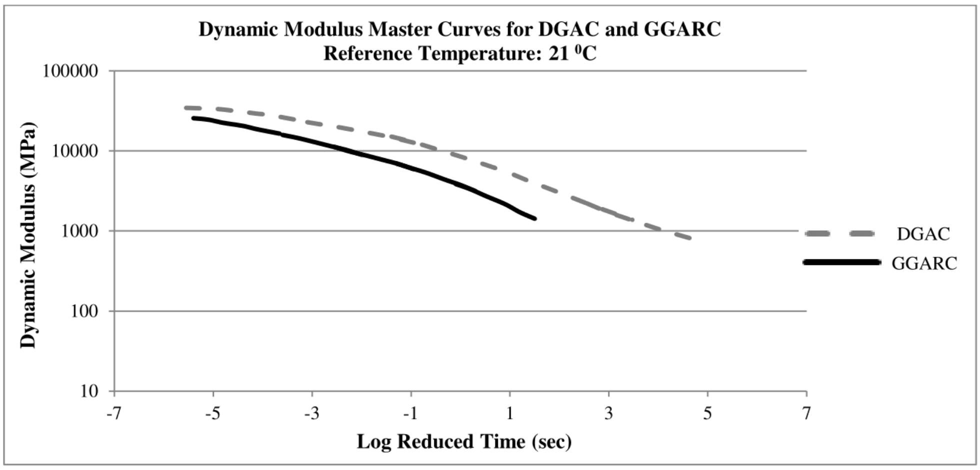

Fig. 1. Comparison of dynamic modulus master curves for DGAC and GGARC [14, 15]

Predicted damage in the existing flexible pavement obtained from KENLAYER software is shown in Table 8 in order to compare with the results of MEPDG presented in Table 7. According to Table 8, this pavement could be designed to last more than 10 years without any structural damage. In KENLAYER, damage analysis is based on two criteria, i.e., the fatigue cracking based on the tensile strain at the bottom of the asphalt concrete layer and the rutting based on the compressive strain on the surface of subgrade. Therefore, each year has been divided into 4 periods and modulus computed by MEPDG for each period and each flexible pavement layer has been considered as inputs to KENLAYER for various periods and layers. To model the effects of various loading conditions, 11 load groups have been considered in KENLAYER to evaluate the effects of single, tandem and tridem axles. It should be mentioned that performance of section No. 2 (designation 20 - 30 - 40) in Table 1 is the same as section 20 - 25 - 35 and the main difference between these sections is in considering 50 mm additional thicknesses for the base and subbase layers of section No. 2 because it is assumed that this section is located on a weaker subgrade; i.e., A - 6. It should be noted again that the thin asphalt overlays are only considered as a valid option for pavement rehabilitation when the bearing capacity of the underlying pavement is good and the pavement shows only surface distresses.

4.2 Evaluation of thin HMA overlay performance

4.2.1 Effect of thin HMA overlay on the pavement distresses

By the use of results obtained by MEPDG software, evaluation of performance of various scenarios for application of thin HMA overlay on the existing flexible pavement can be made.

Fig. 2 compares amount of IRI on the pavement surface 10 years after initial construction and 10 years after applying thin overlay layer. The IRI calculated by MEPDG contains all types of distresses as shown by Eq. (1) ; therefore, it is an appropriate parameter for evaluation of pavement performance.

$$IRI = IRI_0 + \alpha Age + \beta (FC_{Total}) + \eta (TC) + \gamma (RD) \qquad (1)$$

Where [29]:

- IRI_0 initial IRI measured within six months after pavement construction
- SF site factor related to pavement life, average annual rainfall and freezing index
- FC_{Total} total area of fatigue cracking, percent of wheel path area, %
- TC total length of transverse cracks, m/km
- RD average depth of rutting, mm
- α, β, η, γ constant coefficients

It can be observed that the IRI value 10 years after placement of overlay does not reach the IRI value before applying overlay; as such, applying thin overlay layer on the existing flexible pavement in an appropriate time can reduce created distresses in the pavement and increase pavement life remarkably. It should be mentioned that initial IRI is taken as 1.2 m/km, because high-traffic-volume roadways are considered in this research.

Amount of fatigue cracks created after 10 years from applying thin HMA overlay for climatic conditions of Rasht, Ahvaz and Tehran are compared in Table 9. Fatigue cracks are divided into longitudinal cracks and alligator cracks in the MEPDG software. Fatigue cracking is predicted in terms of damage index by the Eq. (2):

$$DI = \sum_{i=1}^{N} \frac{n_i}{N_{f,i}} = \sum_{i=1}^{T} \frac{n_i}{k_{f1} C\,(\varepsilon_t)^{-k_{f2}}\,(E_{HMA})^{-k_{f3}}} \qquad (2)$$

Where [30]:

- DI damage index
- T total number of analysis period
- n_i actual number of load repetitions for period i
- $N_{f,i}$ number of load repetitions allowed under conditions prevailing for period i
- ε_t tensile strain at the critical location
- E_{HMA} stiffness of the HMA material
- $C = 10^{4.84\left(\frac{V_{be}}{V_{be}+V_a}-0.69\right)}$ laboratory to field adjustment factor
- V_{be} effective binder content of asphalt concrete, %
- V_a air void of asphalt concrete, %

In Table 9, total fatigue cracks including longitudinal cracking and alligator cracking in the new asphalt concrete layer and reflective cracking in existing asphalt concrete layer are presented. As shown, milling 25 mm of the existing asphalt layer increases the percentage of fatigue cracking. In this study, it is considered to apply thin HMA overlay with and without thin milling before the level of distresses in the existing flexible pavement increases remarkably; however, in some cases milling might be needed to avoid developing of reflective cracks and to improve performance of thin overlay.

According to Table 9, percentage of fatigue cracking in Ahvaz is more than Tehran and Rasht because of higher mean annual air temperature in this city. In a previous study conducted by Pethõ [31], almost the same results were concluded mentioning that the cumulated fatigue damage rises remarkably due to high temperature values. Table 9 also shows that performance of GGARC is better than DGAC in retention of fatigue cracking because of its higher binder content. As indicted in Eq. (2), by increasing effective binder content in HMA, allowable number of load repetitions increase and so damage index and fatigue cracks decrease. For instance, by milling existing layer and applying GGARC thin overlay layer for climatic condition of Ahvaz, total amount of fatigue cracks is 0.29% which is remarkably less compared with the case that DGAC is used as overlay layer.

In general, Table 9 shows the effectiveness of thin HMA overlay in reducing fatigue cracks in the existing flexible pavement. The same results were reported by Baladi et al. [32].

Tab. 7. Predicted distresses in the existing flexible pavement by MEPDG software for section 20 - 25 - 35

Type of distress (damage)	Climatic condition		
	Tehran	**Ahvaz**	**Rasht**
	20 years after initial construction		
	Amount of predicted distress		
Total fatigue cracking (%)	5.9	12.9	3.8
Rut depth in total pavement (mm)	9.6	12.5	8.1
IRI (m/km)	1.79	1.80	1.76
	10 years after initial construction		
Total fatigue cracking (%)	1.7	3.6	1.2
Rut depth in total pavement (mm)	7.6	9.45	6.8
IRI (m/km)	1.5	1.53	1.49

Tab. 8. Predicted damage in the existing flexible pavement by KENLAYER software for section 20 - 25 - 35

Type of distress (damage)	Climatic conditions					
	Tehran		**Ahvaz**		**Rasht**	
	Damage ratio	**Design life**	**Damage ratio**	**Design life**	**Damage ratio**	**Design life**
Tensile strain at the bottom of the asphalt concrete layer	0.0593	16.8	0.0827	12.1	0.0554	18.1
Compressive strain at the top of the subgrade layer	0.0323		0.0435		0.0297	

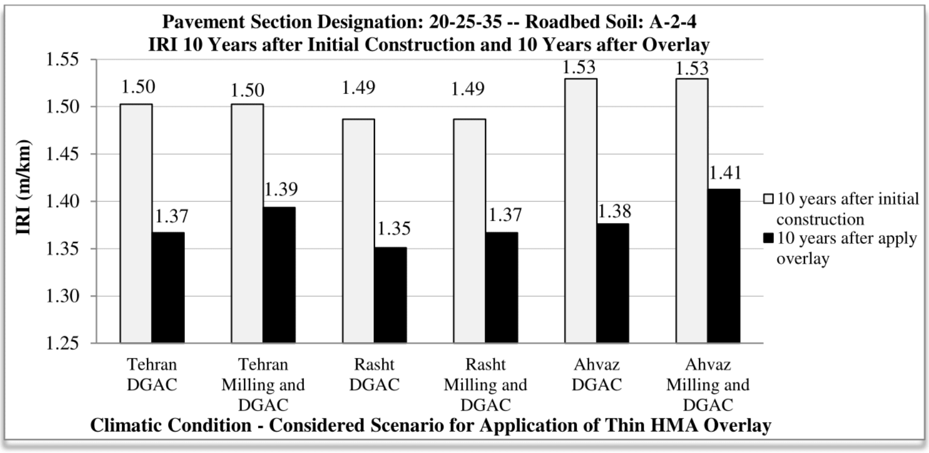

Fig. 2. Comparison of amount of IRI on the pavement surface before applying overlay and 10 years after applying thin overlay on the existing flexible pavement

Tab. 9. Amount of fatigue cracking (alligator, reflective and longitudinal) in asphalt concrete layers 10 years after applying overlay layer for section 20 - 25 - 35

Type of rehabilitation	Climatic condition		
	Tehran	**Ahvaz**	**Rasht**
	Total fatigue cracking (%) – Roadbed soil : A - 2 - 4		
	10 years after applying overlay		
Overlay with DGAC	0.1	0.39	0.03
Overlay with GGARC	0.02	0.12	0.01
Milling and Overlay with DGAC	1.05	2.52	0.58
Milling and Overlay with GGARC	0.1	0.29	0.06

In Fig. 3, the results of MEPDG with regard to the evaluation of thin HMA overlay performance against rutting for Roadbed A - 2 - 4 is shown. According to this figure, performance of DGAC and GGARC against rutting in pavement layers are the same; however, due to reduction in total thickness of the asphalt concrete layers, milling the existing asphalt concrete layer by 25 mm and applying overlay layer increases the rut depth.

Fig. 4 illustrates the results of MEPDG for Roadbed A - 6 by considering only DGAC as overlay layer because performance of DGAC and GGARC are almost the same as can be noted from Fig. 3. Fig. 4 shows that the amount of rut depth 10 years after applying the overlay is remarkably less than its amount before applying overlay. This is due to the fact that granular layers (base, subbase and roadbed soil) experience most of permanent deformation before applying the overlay. Fig. 4 also shows that the amount of rut depth in Ahvaz is more than Tehran and Rasht. Because of higher amount of rainfall in Rash, it might be expected to have higher permanent deformation in the granular layers; however it should be considered that due to higher thickness of the existing asphalt concrete layer (200 mm), effects of mean annual air temperature is more than rainfall. As demonstrated in Fig. 4, by milling and applying thin DGAC on the pavement surface for the climatic condition of Rasht, amount of rut depth 10 years after overlay is equal to 2.30 mm, approximately one-fourth of the value obtained before applying overlay layer. But, for climatic condition of Ahvaz, total pavement rut depth 10 years after overlay is nearly 50% of the value obtained before application of the overlay. According to the previous study carried out by Tarefder and Sumee [33], sensitivity analyses using MEPDG show that the asphalt concrete stiffness plays a significant role on rutting for thick asphalt concrete layers. So, high temperature values can enhance the formation of rutting in asphalt concrete layer by reducing the HMA stiffness.

4.2.2 Effects of thin HMA overlay on the pavement service life

Pavement service life is determined according to results obtained from MEPDG by considering various performance indicators and thresholds for them to evaluate the performance of thin HMA overlay. These performance indicators consist of IRI, rut depth, and fatigue cracking. Because high-traffic-volume roadways are considered in this study, amount of thresholds considered for these performance indicators are 2 m/km, 10 mm, and 20% respectively by assuming 95% reliability as reported by Amini et al. [16]. Table 10 shows the amount of thin HMA overlay service lives obtained for these climatic conditions. These service lives are a certain period of time that the pavement with a thin overlay layer will last before reaching the selected threshold of the performance indicator. Based on the results in this table, for section No. 1 (designation 20 - 25 - 35), application of GGARC as thin overlay layer on the extension of the pavement service life against fatigue cracking is remarkable and pavement can endure more than 20 years after milling and application of thin GGARC overlay by considering fatigue cracking as main performance indicator.

Table 10 also shows that for section No. 2 (designation 20 - 30 - 40), IRI on the pavement surface and rut depth in the pavement layers limit the pavement service life and the amount of fatigue cracks is not a determining factor in terms of pavement service life. The main reason for higher value of IRI and rut depth is that the assumed section is located on a weaker subgrade; i.e., A - 6.

4.2.3 Comparison of thin HMA overlay service life from MEPDG and KENLAYER

Predicted damage and pavement service life after applying thin HMA overlay by KENLAYER software are presented in Table 11 in order to compare with the results of MEPDG. In KENLAYER, damage caused by fatigue cracking and rutting in each period over all load groups is summed up to evaluate the design life. According to Table 11, after applying DGAC as overlay layer, the results obtained by KENLAYER are the same as the results obtained by MEPDG; i.e., the best performance of flexible pavement after applying overlay layer is for climatic condition of Rasht and the worst performance is for Ahvaz. However, using asphalt binder that is more consistent with warm climatic condition, can improve performance of pavement under this climatic condition. Also, milling 37.5 mm of the existing asphaltic layer and applying thin overlay, increases damage ratio and reduces pavement life; nevertheless, pavement can endure 7 to 12 years after milling and application of thin HMA overlay by reducing the pavement distresses.

4.3 Discussion of results

Overlay performance is influenced by many factors such as existing pavement conditions, traffic loading, and environmental conditions. This study evaluated thin HMA overlay performance by considering various scenarios and different climatic conditions. For better evaluation, the results of this research and other similar studies made in New York, Wisconsin and Indiana are interpreted and compared in Fig. 5. This figure shows that according to the present study, thin HMA overlay extends pavement service life between 8 to 11 years based on IRI criterion, between 13 to more than 20 years based on rut depth and between 5 to more than 20 years based on fatigue cracking. Fig. 5 also shows that application of thin HMA overlay has increased the road service life substantially in New York, Wisconsin and Indiana. It should be mentioned that the conditions related to the above-noted cases were not exactly the same as conditions assumed in the present study. For instance, in New York, the thin HMA overlay layer was constructed with thickness of 25 to 37.5 mm for highways with AADT between 12000 and 35000, and about 5 percent trucks [2].

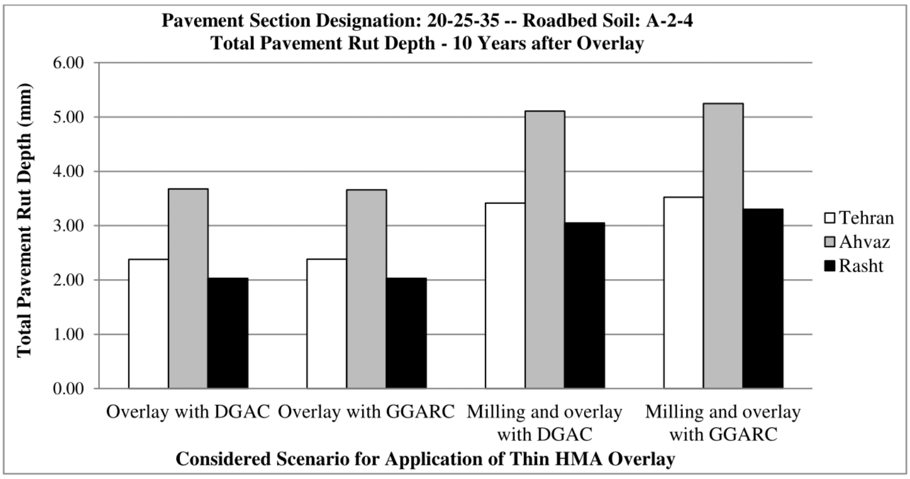

Fig. 3. Comparison of amount of rut depth in total pavement 10 years after applying overlay on the existing flexible pavement for various climatic conditions

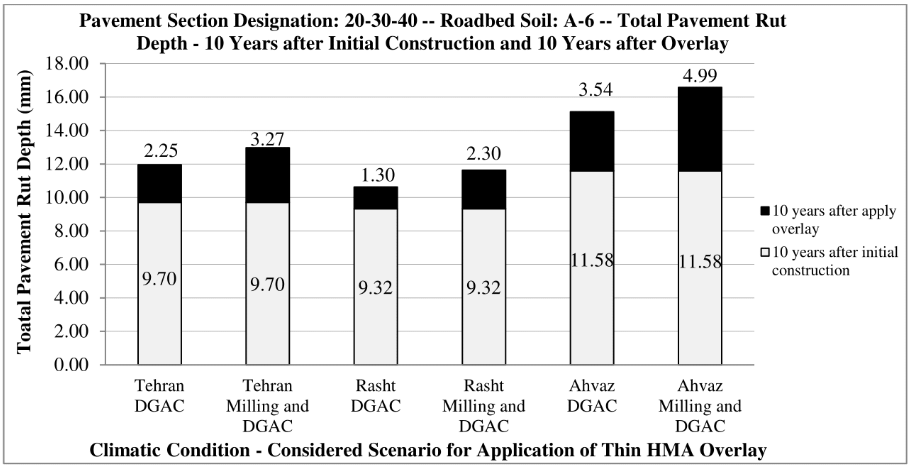

Fig. 4. Comparison of amount of rut depth in total pavement 10 years after applying overlay on the existing flexible pavement with 10 years after its initial construction

Tab. 10. Thin HMA overlay service lives predicted by MEPDG software

Type of distress (parameter)	Criteria (Threshold)	Climatic condition		
		Tehran	Ahvaz	Rasht
		Service life for each distress		
		Milling and apply DGAC as thin overlay layer Section 20 - 25 - 35 |Roadbed soil: A - 2 - 4		
Rut depth (mm)	10	>20	14.8	>20
Fatigue cracking (%)	20	9.9	5.7	13.7
IRI (m/km)	2	9.9	8.9	11
Type of distress (parameter)	**Criteria (Threshold)**	**Milling and apply GGARC as thin overlay layer Section 20 - 25 - 35 |Roadbed soil: A - 2 - 4**		
Rut depth (mm)	10	>20	13.8	>20
Fatigue cracking (%)	20	>20	>20	>20
IRI (m/km)	2	9.8	8.8	10.9
Type of distress (parameter)	**Criteria (Threshold)**	**Milling and apply DGAC as thin overlay layer Section 20 - 30 - 40 |Roadbed soil: A - 6**		
Rut depth (mm)	10	>20	14.8	>20
Fatigue cracking (%)	20	>20	>20	>20
IRI (m/km)	2	9.2	8.4	9.8
Type of distress (parameter)	**Criteria (Threshold)**	**Milling and apply GGARC as thin overlay layer Section 20 - 30 - 40 |Roadbed soil: A - 6**		
Rut depth (mm)	10	>20	13.9	>20
Fatigue cracking (%)	20	>20	>20	>20
IRI (m/km)	2	9	8	10.1

Tab. 11. Predicted damage in flexible pavement after applying thin HMA overlay layer by KENLAYER software for section 20-25-35 (Overlay with DGAC)

Type of distress (damage)	Climatic conditions					
	Tehran		Ahvaz		Rasht	
	Damage ratio	Design life	Damage ratio	Design life	Damage ratio	Design life
Apply DGAC as thin overlay layer						
Tensile strain at the bottom of the asphalt concrete layer	0.0597	16.7	0.0843	11.8	0.0524	19.1
Compressive strain at the top of the subgrade layer	0.0299		0.0419		0.0247	
Milling and apply DGAC as thin overlay layer						
Tensile strain at the bottom of the existing asphalt concrete layer	0.0914	10.9	0.129	7.8	0.0809	12.4
Compressive strain at the top of the subgrade layer	0.0462		0.0627		0.04	

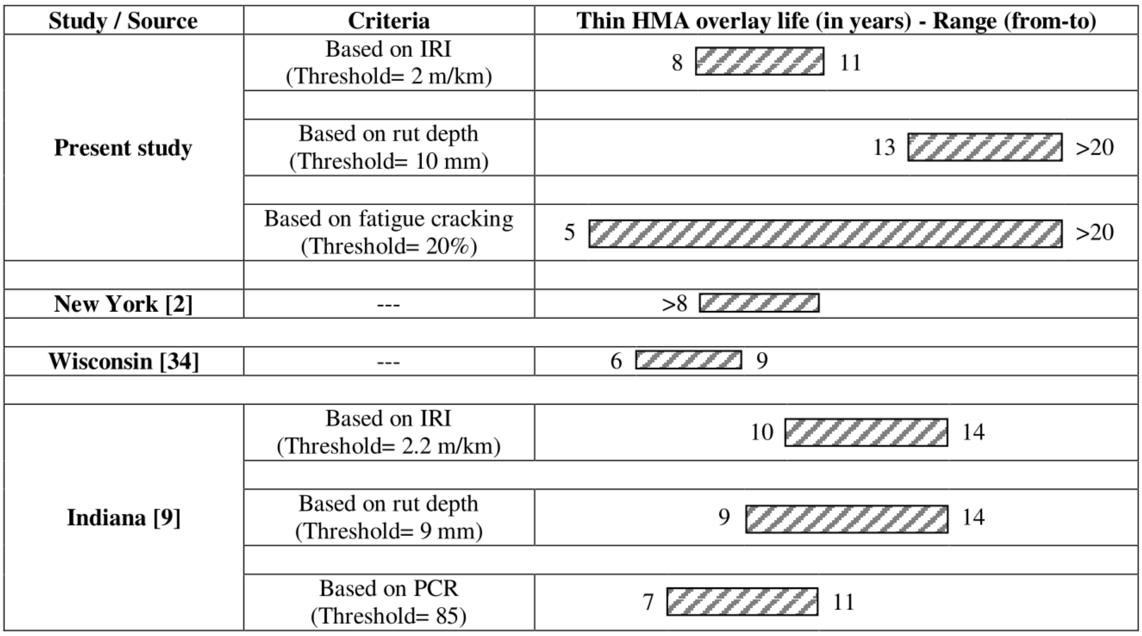

Fig. 5. Service life of thin HMA overlay – Comparison current results and past studies

5 Conclusions

In this research, different scenarios for application of thin HMA overlay layer were evaluated by considering various climatic conditions to assess their effects on the pavement life for high-traffic-volume rural roadways. For this purpose, MEPDG software was used. Also, the results obtained from this software were compared with the results obtained by KENLAYER for some cases. Based upon this study, the following conclusions can be drawn:

- Generally, there are not significant differences in pavement performance between using gap graded asphalt rubber concrete and dense graded asphalt concrete as thin overlay layer. However, performance of GGARC in retention of fatigue cracking is better than DGAC because of its higher binder content.
- Because of higher thickness of the existing asphalt concrete layer due to considering high-traffic-volume rural roadways in this study, mean annual air temperature affects thin HMA overlay performance more than mean annual rainfall for each climatic condition.
- Applying thin asphalt overlay with 37.5 mm thickness on high-traffic-volume rural roadways may considerably increase pavement service life by reducing the pavement distresses.
- Comparison of the results obtained from MEPDG and KENLAYER indicate that the predictions of this software with regard to the performance of thin HMA overlay comply well with each other.

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