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Assessment of the Effect of Aging on Asphalt Mixtures in Egypt: A Case Study

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Abstract

Aging significantly affects the rheological properties of asphalt mixtures and hence the performance of the asphalt pavements. This study presented a case study on the effects of field aging on the performance of asphalt mixtures over time in Egypt. Four samples were extracted from the selected field test section with different service times. Raw materials used in this study were also collected for fabricating laboratory specimens in accordance with selected long-term aging (LTA) protocols. The Marshall and Wheel Tracking tests were carried out to assess the evolution of mixture stiffness and rutting resistance with field and laboratory aging. Test results indicated that the laboratory LTA protocol of one day at 85°C, three days at 85°C and five days at 85°C were representative of in-service field aging equivalent to 6, 11, and 14 months, respectively for mixture stiffness and rut depth values. Therefore, the LTA protocol specified in AASHTO R30 did not sufficiently simulate field aging for 5–10 years after placement and compaction as expected.

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Keywords: Aging, performance, asphalt mixtures, mixture stiffness, rutting resistance.

1. INTRODUCTION AND BACK GROUND

Pavements are a key component of transportation systems and contribute significantly to the global economy. Pavements in Egypt have witnessed heavy traffic loads due to a significant increase in traffic volumes, especially after the expansion of the highway network recently. This results in an increase in pavement distresses (e.g., cracks, rutting, shoving, and stripping), which may negatively impact the service life and performance of the pavement [1,2]. Despite increasing maintenance and rehabilitation activities, there is a growing need to keep the pavement in good condition [3]. Several research has focused on improving the performance of asphalt mixtures by using various additives to reduce maintenance cost. There is limited research on the aging phenomenon found in asphalt mixtures. Asphalt pavement aging is an inevitable phenomenon that results in changes in the physical, chemical, and rheological characteristics of asphalt binders with time [4-6].

The performance of the pavements is affected by climatic and environmental conditions like temperature, moisture, and heavy rains during their service life [1]. Asphalt pavement is subjected to severe weather conditions at high temperatures in Egypt, which frequently reach or exceed 40°C through the summer months. These high temperatures lead to aging due to oxidation [7], which may result in fatigue cracking and, finally, pavement failure under heavy and repeated traffic loads. Oxidation referred to the chemical reaction that occurs at the aggregate-binder interfaces between the asphalt binder and separated oxygen. Oxidative aging of asphalt pavement is primarily caused by accessible oxygen in the atmosphere, temperature, and ultraviolet rays. This process begins with asphalt mixing [6,8]. It was reported that oxidation increased the stiffness and decreased the ductility of the asphalt mixtures, reducing their resistance to fatigue cracking [6,9]. The aging process takes place in two stages: short term aging (STA) and long-term aging (LTA). STA refers to aging that occurs during production, storing, transportation, and placement operations, whereas that which occurs during the service life of the pavement is defined as LTA [4,10]. To investigate the long-term aging of asphalt pavement, researchers utilized various conditioning methods (e.g., oxidation, extended heating, and UV/infrared treatment). Additionally, conditioning can be performed on the compacted specimen or the loose mixture [6]. The most common method to simulate the long-term aging of asphalt mixtures is oven aging on compacted specimens. Elwardany et al. [11] and Rahmani et al. [12] found that aging can cause embrittlement in asphalt mixtures. Islam et al. [13] observed that at all aging types, brittleness increases throughout in-field service conditions. Consequently, asphalt mixture durability and fatigue cracking resistance are affected, which becomes more noticeable as the temperature increases [14].

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Several studies [11,15-16] found that the long-term aging protocol differs based on the type of asphalt, method of laboratory aging, climatic conditions and laboratory aging temperature. Additionally, the majority of these studies evaluate the effect of long-term aging on the asphalt mixtures without appropriate validation with field findings. According to AASHTO R30 [17], the compacted specimen is conditioned for 5 days at 85°C to simulate field aging. This protocol depends on a constant temperature and does not take into consideration the mixture properties or environmental circumstances. Sirin et al. [6] reported that the application of this protocol for different climates, such as the Middle East remains questionable without field validation. Baek et al. [18] recommended development of an aging protocol that considers changes (e.g., traffic volume, climate conditions and mixture properties) in the design stage to improve the performance analysis of asphalt pavements. Studies have assessed the effect of both field and laboratory long-term aging on the properties of asphalt mixtures. The major studies focused on the long-term aging simulation are shown in Table (1). Bell et al. [19] evaluated the protocol of long-term aging for asphalt mixtures by including several climate zones. Based on experimental findings, the compacted specimen was conditioned for two days at 85°C or for one day at 100°C to simulate the long-term aging of new pavements (1-3 years). The mixture must be conditioned for a longer time (4-8 days at 85°C or 2-4 days at 100°C) to predict the aging of (9-10 years) of field aging. However, the authors suggested avoiding conditioning the mixtures at a higher temperature of 100°C since it could damage the specimens. Additionally, the researchers recommended further research to develop a model to simulate field aging, taking into consideration traffic volume, climate zones and age of laboratory mixtures. Recent studies attempt to improve the simulation of bitumen and asphalt mixture aging more effectively. Yin et al. [20] suggested long-term aging protocols of two weeks at 60°C and five days at 85°C, which resulted in mixtures with equivalent in-service field ageing of (7-12 months) and (12–23 months), respectively, depending on climate. The researchers found that WMA technology, recycled materials, and aggregate absorption significantly affect the long-term ageing properties of asphalt mixtures. However, production temperature and plant type had no impact. Sirin et al. [21] reported a severe aging of asphalt pavements as a result of harsh environmental conditions in the Middle East region. The compacted specimen would require being exposed to 85°C for 45 and 75 days, respectively, to simulate five years of field aging for wearing and base course. The researchers recommended conditioning the loose mixture as an alternative to avoid such a long conditioning period. It was observed that it would take 1-2 days and 2-3 days at 135°C to simulate the same degree of aging for wearing and base course, respectively. Additionally, Suchismita and Singh [22] investigate the effect of different protocols for long-term aging on the rheological and chemical properties of polymer-modified bitumen. Two oven aging protocols were selected for asphalt mixtures: 5 days at 85°C for compacted mixtures and 8 days at 85°C for loose mixtures. These studies raise questions about the effectiveness of using these aging protocols and indicate the importance of investigating the degree of aging achieved through these protocols [23]. Based on the above-mentioned studies, it can be noticed that there were very limited studies that evaluated the effect of field aging on the performance of asphalt mixtures. This subject still needs more investigation in some aspects of asphalt mixture performance.

TABLE 1. STUDIES ON THE LONG-TERM AGING SIMULATION OF ASPHALT MIXTURE

References	Aging	Findings
Bell et al. (1994)	0, 2, 4, and 8 days at 85°C 1, 2, and 4 days at 100°C	2 days at 85°C or 1 day at 100°C = 1–3 years field aging 8 days at 85°C or 4 days at 100°C = 9 years of field aging
Brown and Scholz (2000)	4 and 5 days at 85°C	4 days at 85°C simulates 15 years old pavement in the US
Rolt (2000)	Field ageing	Exposure time and ambient temperature significant effects while binder content, mixture AV, and filler content no effect
Houston et al. (2005)	5 days at 80, 85, and 90°C	5 days at 85°C = 7–10 years of field aging
Harrigan (2007)	5 days at 80°C, 85°C, and 90°C	5 days at 85°C = 7–10 years of field ageing
Rondon et al. (2012)	Field ageing	• Increased mixture stiffness, rutting resistance, and fatigue resistance for first 29 months of environmental exposure • Opposite trend observed between 30 and 42 months
Farrar et al. (2013)	Field ageing	Field aging not limited to the top 25mm of the pavement
Martin (2014)	1 to 16 weeks at 60°C	4–8 weeks at 60°C = first summer of field aging
West et al. (2014)	Field ageing	WMA less aging than HMA during production
Islam et al. (2015)	1, 5, 10, 15, 20, and 25 days of oven aging at 85°C	1-day laboratory aging is close to 1-year of field aging
Yin et al. (2017)	2 weeks at 60°C, 3 days at	2 weeks at 60°C = 7–12 months field aging 5 days at 60°C = 12–23 months field aging
Sirin et al. (2020)	0, 1, 2, and 3 days at 135°C on loose mixtures	2-3 days at 135°C = 5 years field aging in Middle East condition for wearing and base course, respectively

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2. EXPERIMENTAL INVESTIGATION

2.1. Project Information

- Location of field section and materials used

The project that was constructed in Menoufia Governorate in December 2022 was investigated. The test section of HMA pavement that was selected for this study is located in Menouf City, Menoufia Governorate, Egypt. Raw materials used in this study were also collected for fabricating laboratory specimens in accordance with selected LTA protocols. The aggregate gradation curve for the field mixture is shown in Fig. 1.

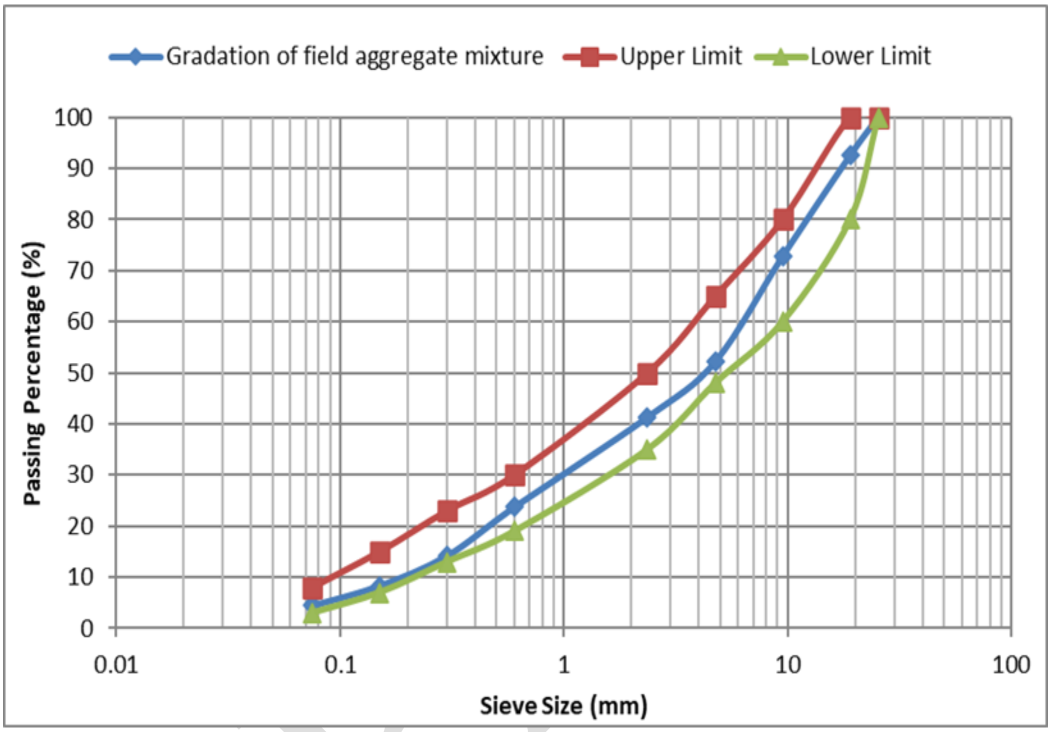

Fig. 1. Gradation of Field Aggregate Mixture.

- Field samples information

Four samples were extracted from the selected field test section with different service times between December 2022 and March 2024. Also, these samples were taken from the non-wheel path to study purely the effect of aging without taking into consideration the effects of traffic loads and to limit the potential of preexisting damage in the material. Several tests were performed, such as extraction test, rutting test and Marshall test to evaluate the field aging based on material property changes in pavement with time. The mixture properties of field samples were analyzed and then compared with the laboratory samples.

2.2. Specimen Fabrication

To fabricate laboratory specimens in accordance with selected LTA protocols, the aggregate (coarse, fine, and mineral filler) and asphalt cement were heated in the oven at the mixing temperature (175°C) for two hours. After that, the components were mixed until the aggregate was completely coated, and the blend was conditioned in the oven. Loose mixtures were placed in a pan to achieve a thickness between 25 and 50 mm, and they were cured in the oven at 135°C for 4 hours in accordance with AASHTO R30 [17]. Afterwards, the specimens were placed in the oven after compaction and aged at 85°C for 1, 3, and 5 days to simulate LTA in the field. Following the aging process, the specimens were left to cool at room temperature before being tested for mechanical properties.

2.3. Laboratory Tests

- Extraction Test

This test is used to determine the amount of bitumen in hot-mixed paving mixtures and pavement samples. The bitumen content is calculated by difference from the mass of the extracted aggregate, moisture content, and mineral matter in the extract. The bitumen content is expressed as mass percent of moisture-free mixtures. The test was performed according to ASTM D2172 [24]. The extracted asphalt mixture solution including the solvent was subjected to the centrifuge method to collect the mineral matters present in the solution. After the centrifuge process, the mineral matters were filtered by the filter paper inside the container and were excluded from the solution. The recovered aggregates were washed with a solvent, dried in an oven and the asphalt content was calculated from the weight difference before and after extraction. The recovered aggregates were then used for gradation analysis.

- Aggregate Gradation Test

Aggregate gradation was checked for the four rounds surveys. The particle size distribution of the recovered aggregates was determined following AASHTO T30 [25]. After extraction and drying, the aggregates were sieved through a standard set of sieves using a mechanical shaker. The retained weight on the sieves was determined, and the passing percent was calculated.

- Marshall Test

Marshall test was performed in accordance with ASTM D 6927 [26]. Specimens were submerged in a water bath of 60°C for 30 to 45 minutes after left them for at least 24 hours after compaction. The specimens were then put into a Marshall testing apparatus, which allowed for the measurement of their flow and stability. Then, Marshall Quotient (MQ) can be determined.

- Wheel Tracking Test

Marshall test was performed in accordance with AASHTO T324 [27]. The specimens were tested at 60°C and the deformation of rutting depth was recorded by cam and dial gauge. Measurements were taken until the wheel reaches 10,000 passes.

3. RESULTS AND DISCUSSIONS

3.1. Aggregate Gradation and Asphalt Content

Aggregate gradation helps determining important asphalt pavement properties such as stiffness and rutting resistance. Higher asphalt content generates thicker film thickness and reduces aging effect, whereas lower asphalt content in general increase mixture stiffness and result in better rutting resistance [7]. Table (2) summarizes aggregate gradation determined based on field samples. As observed, there is no significant gradation difference between the four rounds for the selected project. Asphalt content was also determined based on field samples. The asphalt content difference between the four rounds is smaller than 0.1%; such a small difference should not significantly affect the rutting resistance of asphalt pavement.

TABLE 2. AGGREGATE GRADATION PERCENT PASSING COMPARISON BETWEEN THE FOUR ROUNDS SURVEY

Sieve No.	Sieve Size (mm)	1st Round	2nd Round	3rd Round	4th Round
		December 2022	September 2023	December 2023	March 2024
1"	25.40	100	100	100	100
3/4"	19.00	94	93	92	92
3/8"	9.50	74	73	72.5	72.8
No. (4)	4.75	53	52	52.2	52
No. (8)	2.36	41	41	41	41.3
No. (30)	0.60	25	24	23.7	23.7
No. (50)	0.30	14	14	14.2	14.2
No. (100)	0.15	9	9	8.3	8
No. (200)	0.075	5	5	4.4	4.4

3.2. Effect of Field Aging on Mixture Performance

- Effect of Field Aging on Marshall Stiffness

Fig. 2 shows the results of the field samples. The results indicated that with the aging time, the stiffness tends to increase as expected due to the viscoelastic nature of asphalt mixtures. The stiffness after 15 months from

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construction recorded the highest value as it increased by 43.56%. This shows the significant effect of the duration of long-term conditioning on the measured properties of asphalt mixtures.

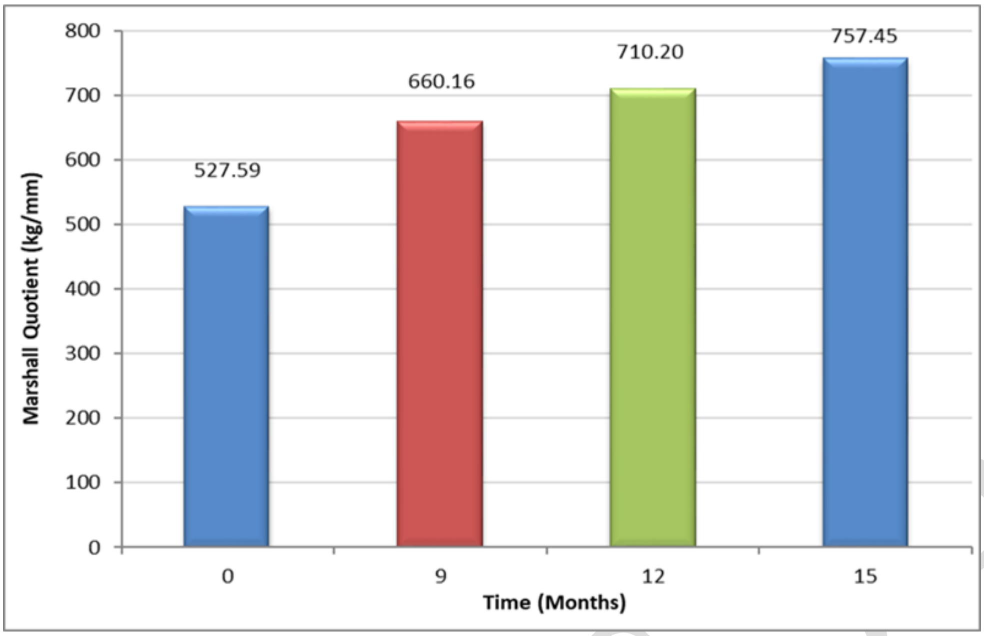

Fig. 2. Marshall Quotient values of field samples versus service time.

- Effect of Field Aging on Rutting

Wheel tracking test is a commonly used test method to determine the rutting resistance. The maximum rut depth for mixtures at different service time was determined as shown in Fig. 3. It is observed that with increasing the aging time, the rutting resistance increased as rut depth decreased. The large increase in rutting resistance after 15 months from construction. The rut depth values were reduced by 6.28%, 17.54% and 39.79% after 9, 12, and 15 months respectively. Since the aggregate gradation and asphalt content between the four rounds did not change greatly, the improved rutting resistance should have been contributed to a major extent by asphalt aging [7].

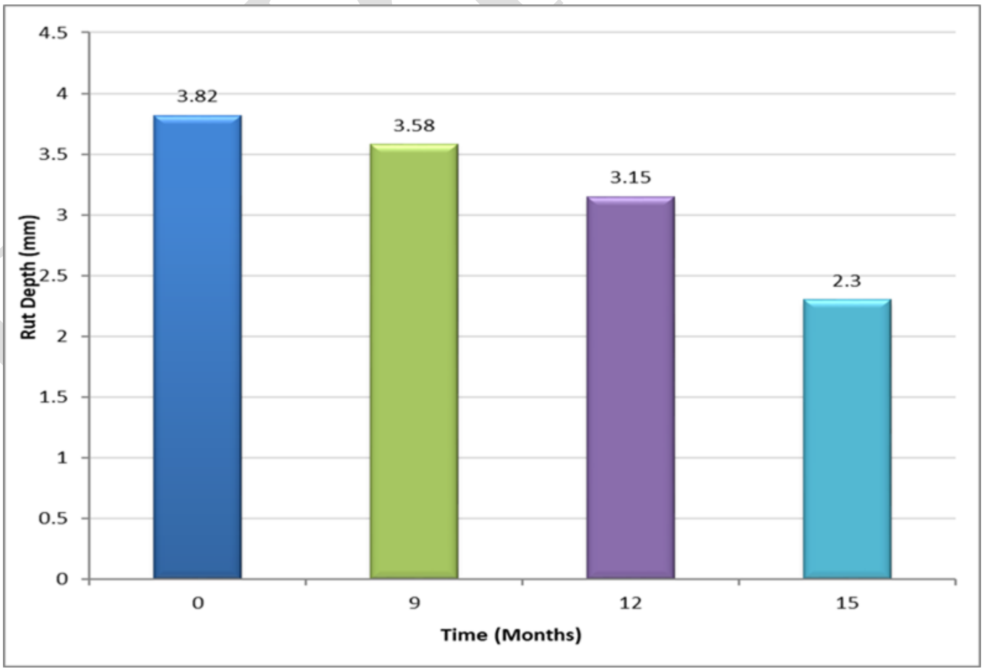

Fig. 3. Maximum rut depth of field samples versus service time.

3.3. Correlation of field aging with laboratory LTA protocols

To assess the effect of field aging on the asphalt mixture, the stiffness and rutting resistance of field samples was compared with the in laboratory prepared samples [20,28]. Fig. 4 and Fig. 5 illustrate the correlation of field aging and laboratory LTA protocols on the stiffness and rut depth, respectively. The mixture property values for laboratory long-term-aged specimens (LTA1D, LTA3D, and LTA5D) were plotted as markers by crossing the curves. The stiffness values for LTA protocols of one day at 85°C, three days at 85°C and five days at 85°C were approximately 621.48, 693.4, and 740.13 kg/mm respectively. The rut depth values for LTA protocols of one day at 85°C, three days at 85°C and five days at 85°C were approximately 3.65, 3.5, and 2.8 mm respectively.

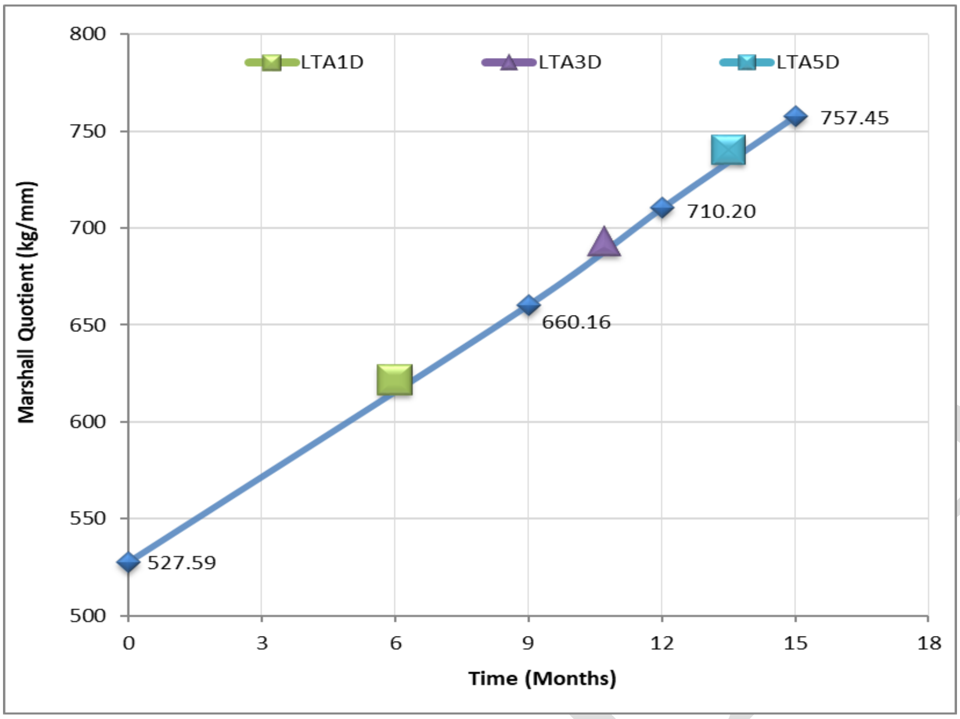

Fig. 4. Stiffness Correlation Between Field Aging and Laboratory LTA Protocols.

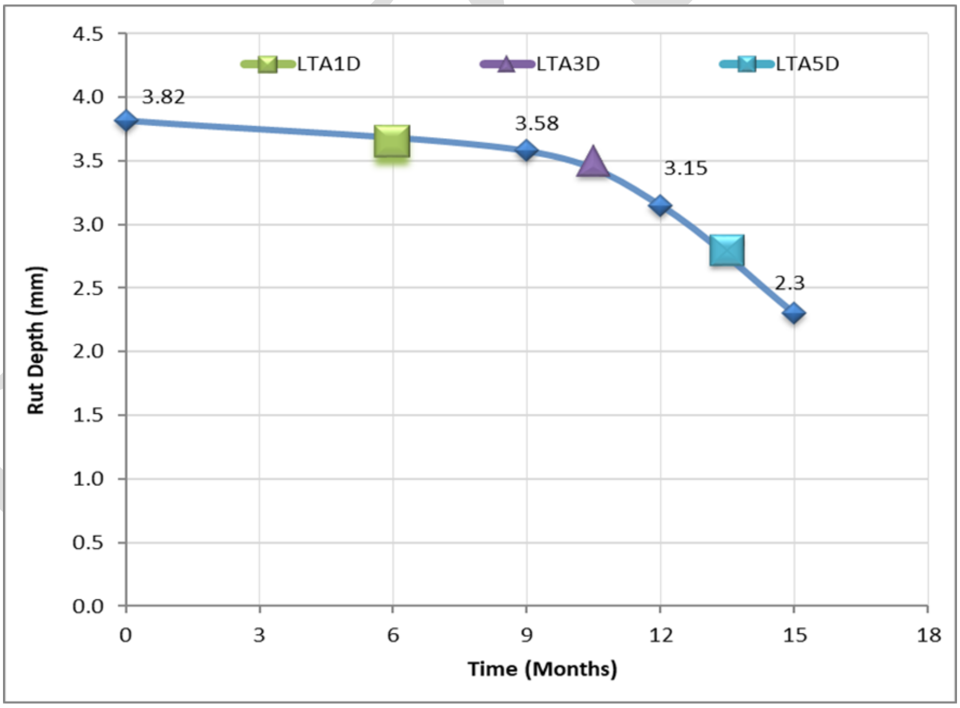

Fig. 5. Rut Depth Correlation Between Field Aging and Laboratory LTA Protocols.

Note: LTA refers to Long Term Aging

Based on the mixture stiffness and rutting resistance results discussed previously, the laboratory LTA protocol of one day at 85°C, three days at 85°C and five days at 85°C were representative of in-service field aging equivalent to 6, 11, and 14 months, respectively for mixture stiffness and rut depth values. Therefore, the LTA protocol specified in AASHTO R30 did not sufficiently simulate field aging for 5–10 years after placement and compaction as expected. This confirms the results found in previous studies by [20,21].

4. SUMMARY AND CONCLUSIONS

Asphalt aging is an inevitable phenomenon that results in changes in the physical, chemical, and rheological characteristics of asphalt binders with time. This paper assessed the effect of field pavement aging on properties of asphalt mixtures at four different rounds in Egypt, where asphalt pavement is subjected to severe weather conditions at high temperatures. Four field samples were collected from selected pavement section in Menouf City with different service times to represent field aging. In addition, raw materials were obtained for fabricating laboratory specimens in accordance with LTA protocols of 1, 3, and 5 days at 85°C. Several tests were performed, such as extraction test, rutting test and Marshall test to evaluate the field aging in pavement with time. Test results were analyzed to establish a relationship between field aging (1-2 years after construction) and laboratory LTA protocols for performance prediction. The conclusion obtained from this study can be summarized as follows:

1. Marshall stiffness increased gradually by 25.13%, 34.61%, and 43.56% after 9, 12, and 15 months from construction, respectively. This shows the significant effect of the duration of long-term conditioning on the measured properties of asphalt mixtures.

2. The results indicated that rutting resistance increases as aging time increases. The rut depth values were decreased by 6.28%, 17.54%, and 39.79% after 9, 12, and 15 months respectively.

3. The results reveal that the laboratory LTA protocol of one day at 85°C, three days at 85°C and five days at 85°C were representative of in-service field aging equivalent to 6, 11, and 14 months, respectively for mixture stiffness and rut depth values.

4. Laboratory aging on compacted specimens demonstrated that the LTA protocol specified in AASHTO R30 did not sufficiently simulate field aging for 5–10 years after placement and compaction in hot climatic regions like in Egypt.

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Conflicts of interest

The authors state that do not have any conflicts of interest.

Authors' contributions

We confirm that the manuscript has been read and approved by all named authors.

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