Mitigation of Reflection Cracking in Asphalt Concrete Overlay on Rigid Pavements

Yasmin S. Ajool[1,a*], Abbas A. Allawi[1,b] and Amjad H. Kalil[1,c]

[1]Civil Engineering Department, University of Baghdad, Baghdad, Iraq

[a]yasmeen.dawood2001m@coeng.uobaghdad.edu.iq, [b]A.allawi@uobaghdad.edu.iq and

[c]a.khalil@uobaghdad.edu.iq

*Corresponding author

Abstract. Reflective cracking is one of the primary forms of deterioration in pavements. It is widespread when Asphalt concrete (AC) overlays are built over a rigid pavement with discontinuities on its surface. Thus, this research work aims to reduce reflection cracks in asphalt concrete overlay on the rigid pavement. Asphalt Concrete (AC) slab specimens were prepared in three thicknesses (4, 5, and 6 cm). All these specimens were by testing machine designed and manufactured at the Engineering Consulting Office of the University of Baghdad to examine for the number of cycles and loads needed to propagate the reflection cracking in the asphalt concert mixture at three temperatures (20, 30, and 30°C). It was noticed that the higher thickness AC mixtures increased the reflection cracking performance life of the AC overlay. Also, it was found that the number of crack initiation and failure cycles increased as the temperature increased. In contrast, the increased temperature decreased the required load to crack initiation and failure load in the sample.

Keywords: Asphalt concrete overlays; cracks treatment; overlay testing machine; reflection cracking.

1. INTRODUCTION

The construction of new roads is essential for the economic development of a country. The road has several negative meteorological and natural-climatic influences throughout its useful life, including functional temperature variations, regular wetting by surface and ground waters, seasonal freezing, and unequal thawing of road structural layers. As a result, the water-thermal state of the subgrade changes, and the ultimate strength of the road pavement's structural layers weakens, leading to an instability of the "road pavement - subgrade" [1, 2, 3]. As maintenance, riding quality, skid resistance, noise, and repair methods, overlays are constructed on the existing pavement. An overlay's cracking occurs in sites with joints in the underlying pavement due to stress concentration when an overlay is put on top of the existing pavement and subjected to heat, shrinkage, or traffic-induced loadings. "Reflection cracking" describes this kind of damage. Water may seep into the pavement structure through reflective cracks in the overlay, contributing to several other kinds of pavement degradation, such as raised roughness, spalling, and a shortened fatigue life [4].

Under a passing wheel load, three load pulses at the crack tip can be observed. The first is due to shearing forces when the load approaches the crack, the second is due to bending forces when the load is directly on the crack, and the last is expected to be shearing forces again when the load leaves the crack [5]. Figure 1 presents these pulses of the different locations of the wheel load.

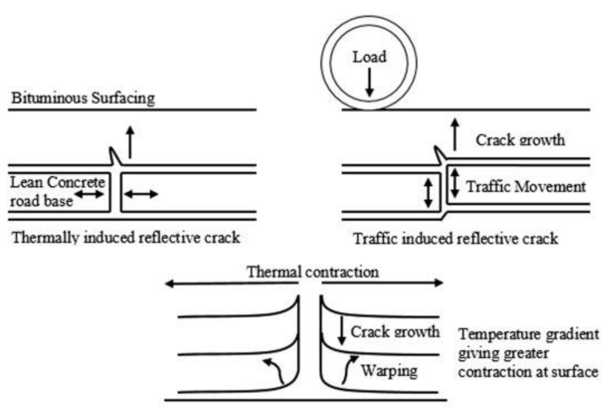

Figure 1: Mechanisms of reflection cracking [13].

Reflection cracking is the process by which preexisting pavement cracks spread to newly installed overlays or the cracking of a resurfacing or overlay over underlying cracks or joints, with the likely cause being the movement of some kind in the underlying pavement. Also, it is a special kind of pavement cracking in which a fracture that begins in the subgrade or base course eventually reaches the pavement's surface [6]. Reflection cracking is seen in Figure 2 here in a simplified schematic.

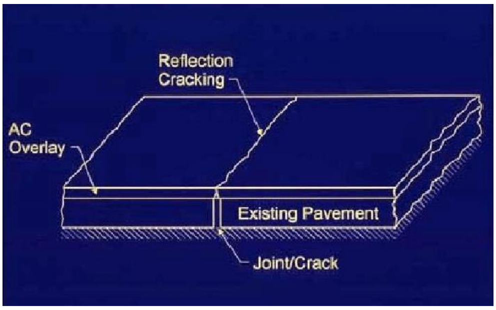

Figure 2: Propagation of reflective crack from the existing concrete pavement into the new asphalt overlay [7].

To reduce or postpone reflective cracking, several experiments have been done. Many approaches have been tried and assessed, from raising the HMA overlay thickness to using crack-arresting interlayers to utilizing a three-ply composite applied only over the joint/crack location. Although some of these methods have effectively reduced reflective cracking in specific contexts, many still need to be studied, especially in colder climates.

Different methods are concentrated to gain a better solution. One or more of the following procedures are categorized by [8] as below:

- Treatment technologies of the surface layer HMA overlays.
- Different rigid pavement rehabilitation techniques.
- Saw and Seal.
- Treatment technologies by the interlayer system.

2. AVAILABLE LABORATORY TEST SETUP TO SIMULATE REFLECTION CRACKING

Different types of reflective cracking devices are used in the lab, and these categories are based on the effects simulated by the test setups. Some of it includes tools that attempt to simulate the impact of seasonal or daily temperature changes. These apparatuses are uniaxial tension test devices, with the principal components being a fixed portion and a moveable section over which the beam or slab specimens are attached. The fractures open and close because of the horizontal cyclic tensile tension produced by the mobile portion. Overlay testers from the Texas Transportation Institute (TTI) and the Iraqi Overlay Testing Equipment (OTE) [6, 9, and 10]. Other devices are used just for traffic load simulation. Devices that apply a wheel load moving back over the specimen, like the Hamburg wheel tracking tester [11], and devices that apply only a vertical point load in pre-determined locations, static and cyclic, on the specimens, like the one used to test geogrid systems at Florida Atlantic University [12].

2.1 Texas Transportation Institute (TTI) Overlay Tester

Lytton and his colleagues developed The TTI overlay tester in the late 1970s [13] to simulate the opening and closing of joints or cracks, the primary driving factors for reflection crack initiation and propagation. As shown in Figure 3, the composition of the equipment consists of two steel plates, one of which is permanent and the other of which is moveable horizontally to simulate the opening and closing of joints or cracks in the old pavements under an overlay.

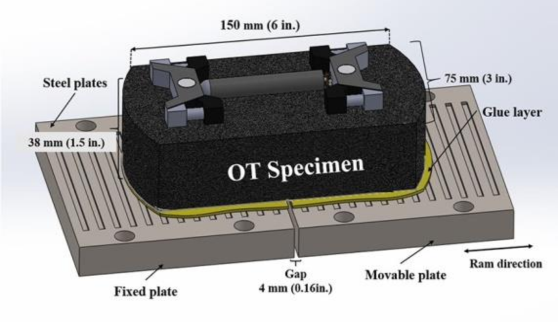

Figure 3: Overlay tester [14].

2.2 The Designed Overlay Testing Machine

The overlay testing machine aims to create a useful tool that engineers can use to measure the resistance of the asphalt mixture to reflective cracks. The overlay testing machine manufactured at the consulting engineering bureau/ University of Baghdad is shown as a schematic diagram in Figures 4 and 5.

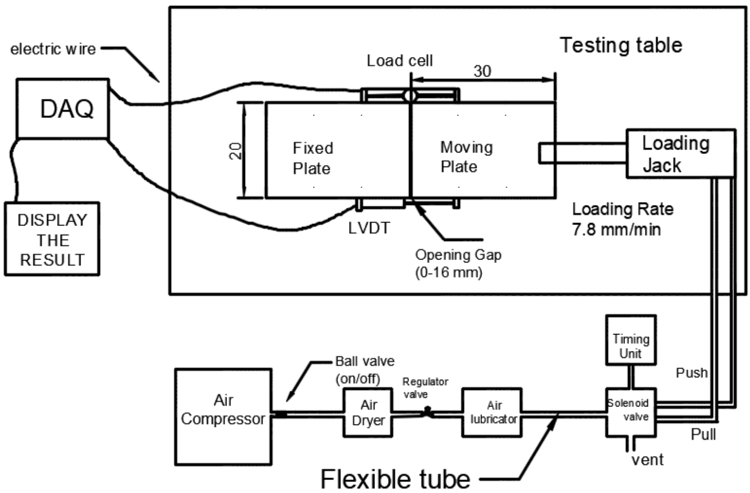

Figure 4: Schematic diagram of the design test machine.

The components of the overlay testing machine:

- Air compressor: A pneumatic device, an air compressor transforms mechanical energy into the potential energy of compressed air. When the air in the tank is let out, the pressure drops and the kinetic energy it contains may be used in several ways, including using a pneumatic tool.
- Air dryer: Compressed air systems often have issues with moisture condensation. It shows itself throughout the distribution network, blocking filters and machinery and causing failures. Damage to air-based machinery from water vapor condensation is possible. A pneumatic system may benefit from an air drier, eliminating the need for moisture to collect in the air. The air dryer's primary objective is to remove the surrounding atmosphere.
- Air lubricator: In order to keep pneumatic tools and other equipment running smoothly, a pneumatic lubricator injects an aerosolized stream of oil into an airline.
- Regulator valve: A pipeline medium of any kind requires precise pressure control. Sustaining, lowering, and relieving pressure valves are all part of a system of pressure-regulating valves that ensures a stable working environment and automatically adjusts to any changes in pressure. Pressure-sensing valves monitor pressure and adjust the flow of air to either indicate or control a process pneumatically.
- An LVDT (Linear Variable Differential Transformer) may be considered an electromechanical passive inductive transducer. An LVDT is a composite electronic device that stores electrical radiation and converts it into a readable signal to represent linear displacement or the movement of an object along a single axis. An external source powers it and has both electrical and mechanical operations. One of the best and most accurate ways to measure linear distances is using an LVDT Sensor.
- A load cell is a device that measures and transmits pressure. It measures and standardizes mechanical forces by transforming them into electrical signals. The load cell's electrical signal varies directly with the applied force. A load cell has a metal body to which strain gauges have been secured. The voltage read by the strain gauges represents the tension or compression force. When the load delivered to the cell causes a voltage change, the load cell's output may be used to determine the pressure applied.
- Data acquisition (DAQ): It is the technique of determining the value of a physical or electrical quantity. Sensors, DAQ measuring hardware, and a computer with programmable software are the three main components of a data acquisition system.

The lab's device to simulate reflect crack consists of an air compressor that pumps air that passes through an air dryer and air lubricator. After that, the air passes through a flexible tube to the regulator valve and the seined valve with a vent attached to the timing unit. Then, two tubes pass from the valve to the loading jack, providing a loading rate of 7.8 mm/min. The loading jack is placed over the testing table with two plats; one is fixed, and the other is movable. The testing table also includes a load cell and LVDT (Linear Variable Differential Transformer) attached to the two plates, each on a side. LVDT and load cell are then connected with electrode wire to Data acquisition (DAQ) and then to the computer to display the result, including time, displacement, and force, and saved as an Excel file.

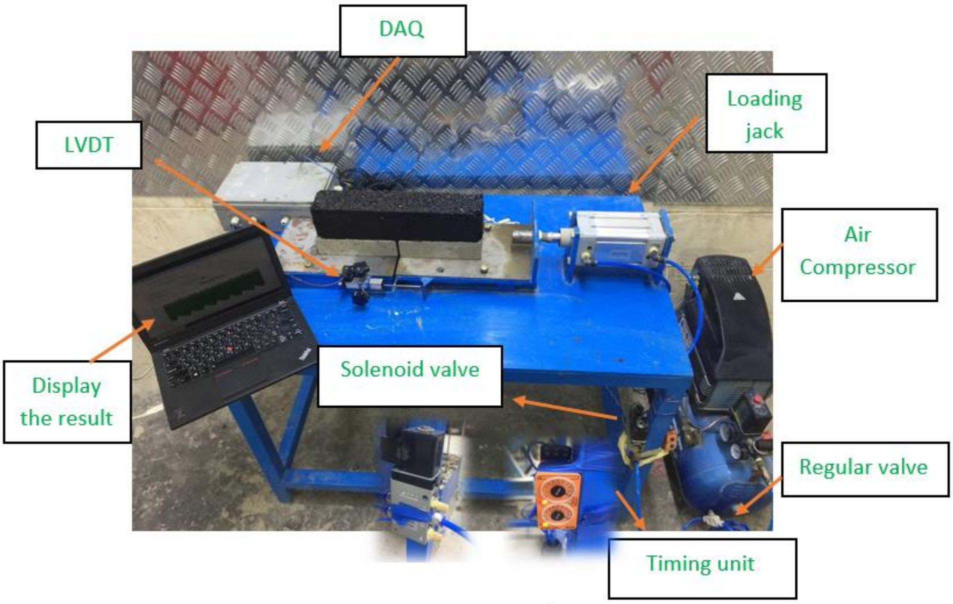

Figure 5: Device setup.

3. MATERIALS PROPERTIES

Aggregates and common local asphalt binders have been selected for making laboratory specimens to reach the most truthful simulation of HMA mixtures in Iraq. The Asphalt Concert (AC) used in this study to represent the overlay layer is made of coarse aggregate, fine aggregate, filler, and asphalt cement.

3.1 Aggregate

This study employed one kind of virgin aggregate, one Nominated Maximal Aggregate Size (NMAS), and a dense graded mixture because of limited resources and time. Al-Nibaee quarry provided crushed aggregates and natural sand. According to the criteria of the Iraqi State Corporation for Roads and Bridges (SCRB)R9/2003 for wearing course type IIIA, the aggregate was sieved, separated, and graded in the laboratory to match the specified gradation for surface course type III A (12.5NMAS). In addition, a single filler was chosen from the local market. The physical properties of aggregates are shown in Table 1.

Table 1: Physical properties of used aggregates.

Property	ASTM Specification	Coarse aggregate	Fine aggregate
Bulk specific gravity	C-128	2.646	2.63
Apparent specific gravity	C-127 and C-128	2.656	2.667
Percent of water absorption %	C-127 and C-128	0.14	0.523
Percent of wear loss angels abrasion %	C-131	20.860	-----

3.2 Mineral Filler

One type of mineral filler is Portland cement from Kubaissa plant; this filler's gradation and physical properties are shown in Table 2.

Table 2: Basic properties of Portland cement.

Type of filler	Apparent Density (g/cm^3)	Apparent Density (g/cm^3)	% Passing Ratio		
			0.3 mm	0.15 mm	0.075 mm
Portland Cement	2.985	3689	100	98.5	97.6

3.3 Asphalt Cement

According to previous investigations, the asphalt employed in this research comes from the Dourah refinery and has a penetration grade of 40-50. Table 3 displays the asphalt cement's physical characteristics. All analyses were conducted in the labs of Baghdad University under SCRB guidelines.

 https://doi.org/10.1051/e3sconf/202342703004

Table 3: Physical properties of Asphalt cement.

Test	ASTM Specification	Units	Results	SCRB Specification
Penetration (25ºC, 100 gm, 5 sec)	D5	1/10 mm	44	40-50
Absolute viscosity at 60 ºC	D2171	Poises	2288	----
Kinematic viscosity at 135 ºC	D-4402	Cst	611	>400
Ductility (25ºC,5cm/min.)min.	D113	Cm	135	>100
Flash point	D92	ºC	290	>232
Softening point (Ring and Ball)	D36	ºC	55	54-60
Specific gravity at 25/25ºC	D70	---	1.04	-----
Solubility in Trichloroethylene	D2042	%	99.5	>99

4. OVERLAY TESTING EQUIPMENT RESULTS

Test results are displayed using a laptop, as shown in Figure 6. Analog input channel 1 in Figure 7a shows the relationship between the number of cycles and load in triangular waves that gradually decrease. Firstly, the highest load with the number of cycles was recorded. The point at which the crack begins to spread was recorded, at which the load is low, where 93% of the highest load was previously recorded with the number of cycles at that point. Finally, the load the sample failed was recorded, representing 7% of the highest load with the number of courses. In Figure 7b, analog input channel 2 shows the relationship between the number of cycles and displacements, which are also in the form of triangular waves but are at the same level.

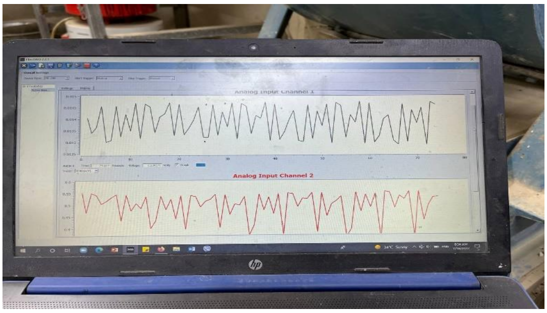

Figure 6: Test results shown on the computer.

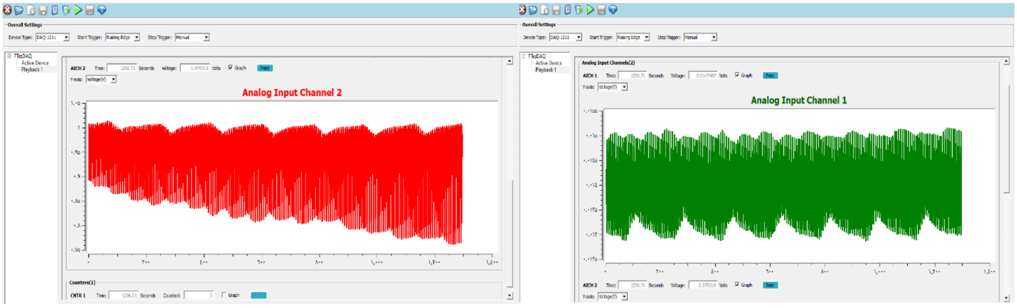

Figure 7: (a) The relationship between load and number of cycles, (b) the relationship between displacement and number of cycles.

4.1 Effect of Thickness of Asphalt Concrete Beams

Based on local observations, an empirical relationship was discovered between the thickness of HMA and the reduction of reflected cracking. Asphalt Concrete (AC) slab specimens were prepared, which have dimensions (37.5*7.61 cm) in three thicknesses (4, 5, and 6 cm). These samples were tested under three different temperatures (20, 30, and 40°C). From the typical data obtained from the OT test, the load acquired for each cycle is plotted. The first cycle provides the maximum load where the initial damage occurs. The remaining processes represent the crack propagation phase until the failure limit of 93% of the maximum load is reached. It can be seen in Figure 8 for the sample thickness of 4cm that the number of crack initiation and failure cycles increased as the temperature increased. In contrast, the increased temperature decreased crack initiation and failure load. This sample can be considered the reference.

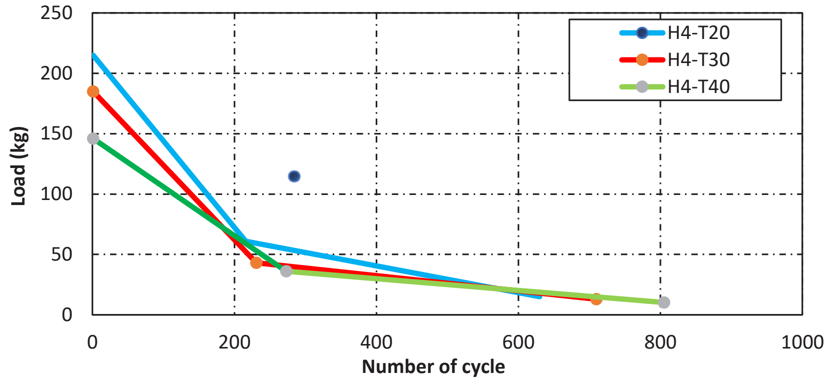

Figure 8: Results of the specimen height of 4cm at three temperatures (20, 30, and 40°C) produced by (40-50) asphalt grade, tested by overlay testing.

The number of crack initiation and failure cycles increased as the temperature increased. In contrast, the maximum load needed for crack initiation decreased with the increased temperature for the sample has a thickness of 5 cm. This result is similar to the specimen with 4 cm thickness, but the initial load needed for crack initiation and failure and the number of cycles are higher values shown in Figure 9.

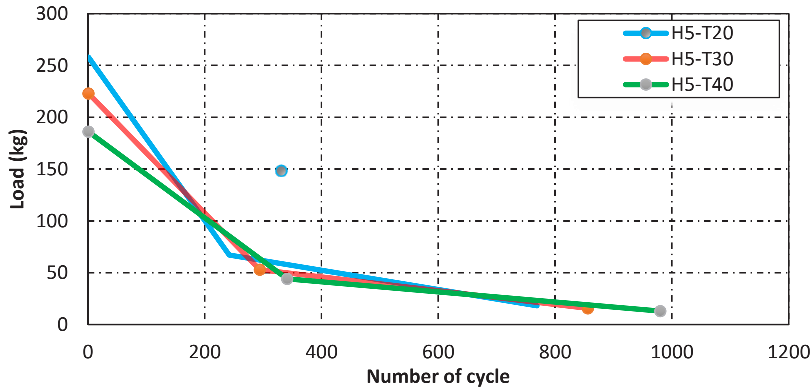

Figure 9: Results of specimen height 5cm at different temperatures produced by (40-50) asphalt grade, tested by overlay testing machine.

The effect of temperature in the sample has a thickness of 6 cm, similar to the previous two examples. However, from the results shown in Figure 10, the effectiveness of the thickness is clear; when the overlay thickness increased, the load and number of cycles up to failure increased.

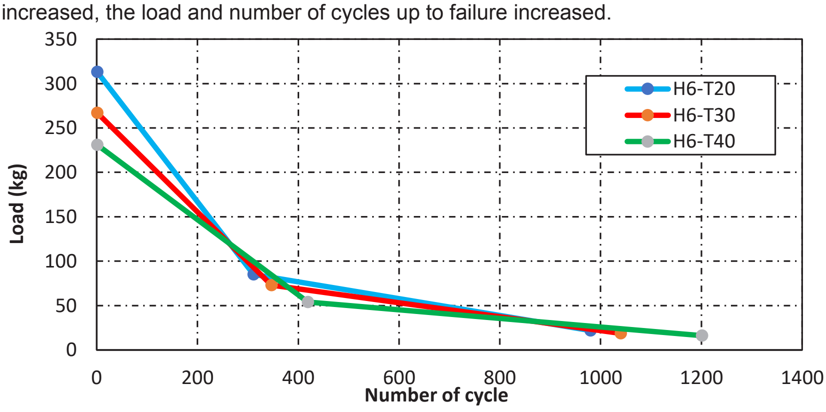

Figure 10: Results of specimen height 6cm at different temperatures Produced by (40-50) asphalt grade, tested by overlay testing machine.

Table 4: The characteristics (stability, flow, % Va, % VMA, and %V.F.A) of the conventional mixture at the optimum asphalt binder content.

Asphalt binder %	4	4.5	5	5.5	6
Stability (kN)	8	9.14	10.3	9.42	7
Flow (mm)	2.13	2.37	2.5	2.66	2.87
Unit weight (gm/cm^3)	2.274	2.299	2.302	2.289	2.281
Gmm	2.434	2.417	2.389	2.382	2.366
Va (%)	6.5	4.89	4	3.98	3.6
VMA (%)	16.706	16.302	16.64	17.54	18.21
VFA (%)	61	70	75.94	77.3	80.24

5. CONCLUSIONS

When applying an overlay on the damaged pavement, reflection cracking is a serious issue. Reflection cracking is caused by daily temperature cycles of opening and reopening joints and fractures. This process is being recreated in the lab at the University of Baghdad using a modified overlay tester. Following extensive overlay testing and application investigations, the following conclusions and recommendations are made:

The number of crack initiation and failure cycles increased as the temperature increased, while the maximum load of crack initiation decreased with the increased temperature. This means that the effect of stiffness on ACO performance is critical in determining how soon the reflection cracks will develop.

REFERENCES

[1] Goryachev MG. Clarification of the design parameters of road pavement loading. Science and Engineering for Highways. 2013; 3(1).
[2] Goryachev MG. The estimation of the reduction degree of cohesive soils elastic modulus as a result of their spring decompression for the forecast of pavement condition. Bulletin of the Moscow Automobile and Road Construction State Technical University (MADI). 2013; 4(1):35.
[3] Wise B. Rising from the rubble: Los Angeles repairs its roads. American City and County. 1994; 109(13):36-43.
[4] Dhakal N, Elseifi MA, Zhang Z. Mitigation strategies for reflection cracking in rehabilitated pavements–A synthesis. International Journal of Pavement Research and Technology. 2016 May 1;9(3):228-239.
[5] GURP C, Molenaar AA. Simplified method to predict reflective cracking in asphalt overlays. REFLECTIVE CRACKING IN PAVEMENTS. 1989.
[6] Alneami AH, Almudadi TH. A Laboratory Tool Used to Evaluate the Reflective Cracking in Overlay Asphalt Pavement. Al-Rafadain Engineering Journal. 2011 Jun 1;19(3).
[7] Bayomy FM, Al-Kandari FA, Smith RM. Mechanistically based flexible overlay design system for Idaho. Transportation Research Record. 1996 Jan;1543(1).
[8] Cleveland GS, Button JW, Lytton RL. Geosynthetics in flexible and rigid pavement overlay systems to reduce reflection cracking. Texas Transportation Institute, Texas A and M University System. 2003.
[9] Stanzl-Tschegg SE, Mayer HR, Tschegg EK. High frequency method for torsion fatigue testing. Ultrasonics. 1993 Jul 1; 31(4):275-280.
[10] Zhou F, Scullion T. Overlay tester: A rapid performance related crack resistance test. Texas Transportation Institute, Texas A and M University System. 2005.
[11] Yu B, Lu Q, Yang J. Evaluation of anti-reflective cracking measures by laboratory test. International Journal of Pavement Engineering. 2013 Aug 1;14(6):553-560.
[12] Sobhan K, Crooks T, Tandon V, Mattingly S. Laboratory simulation of the growth and propagation of reflection cracks in geogrid reinforced asphalt overlays. In 5th International RILEM Conference on Cracking in Pavements-Mitigation, Risk Assesment and Prevention. Edited by Petit C., Al-Qadi IL et Millien A. 2004.
[13] Lytton RL. Use of geotextiles for reinforcement and strain relief in asphalt concrete. Geotextiles and Geomembranes. 1989 Jan 1; 8(3):217-237.
[14] Miramontes A, Garibay JL, Abdallah I, Nazarian S, Garcia V. Improved overlay tester for fatigue cracking resistance of asphalt mixtures. University of Texas at El Paso. Center for Transportation Infrastructure Systems.2017 Jan 1.