Impact of Cyclic Micro Crack Healing on Tensile and Shear Behaviour of Asphalt Concrete Mixture

Saad Issa Sarsam[1]*

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

Email Address

saadisasarsam@coeng.uobaghdad.edu.iq (Saad Issa Sarsam)
*Correspondence: saadisasarsam@coeng.uobaghdad.edu.iq

Received: 11 December 2017**; Accepted:** 24 December 2017**; Published:** 12 January 2018

Abstract:

Healing of micro cracks in asphalt concrete may be considered as a sustainability measure of flexible pavement. An attempt has been made in this work to investigate the impact of cyclic crack healing process on tensile and shear behaviour. Asphalt concrete specimens of 100 mm diameter and 63 mm height have been prepared in the laboratory using Marshall Compaction procedure at optimum asphalt content and at 0.5% asphalt above and below the optimum. Specimens were divided into two groups. The first group was subjected to repeated indirect tensile stresses, while the second group was subjected to repeated double punch shear stresses, (both at 25 ℃) to initiate micro cracks within the specimen's structure using controlled stress mode of loading for 0.1 second followed by a rest period of 0.9 seconds for specified load cycles. Specimens were then subjected to external heating process in an oven at 60 °C and allowed to heal for two hours, conditioned at 25 °C for two hours, then subjected to another two successive courses of healing and repeated tensile or shear stresses. The indirect tensile strength and the double punching shear strength test procedures have been implemented to evaluate the resistance of the specimens to shear and tensile stresses after each repeated loading and each healing cycle. The impact of asphalt content, and healing cycles on the strength behaviour have been analysed as a sustainability measures. It was concluded that healing process have reasonably retained (21, 82, and 65) % of the (ITS) and (23, 24, and 44) % of the (PSS) after the crack healing cycle of load repetitions for mixes with (4.4, 4.9, 5.4) % asphalt content respectively. The impact of asphalt content was not significant among the various testing conditions implemented for tensile strength determination, while optimum asphalt content exhibit the best performance among other asphalt percentages at the various testing conditions implemented for shear strength determination.

Keywords:

Crack Healing, Shear Strength, Tensile Strength, asphalt Concrete, Repeated Loading

1. Introduction

Several degradation processes occurs during the service life of a roadway, the stiffness of asphalt concrete increases while its relaxation capacity decreases, the binder becomes more brittle causing the development of micro-cracks which will change to cracking on the interface between aggregates and binder, [1]. These typical asphalt pavement distresses occur due to the combination of oxidation of asphalt cement and traffic loads, [2]. Many researchers claimed that high tensile contact stresses generated on the road surface close to the tire edges, cause the appearance of small cracks. Before ageing, some of these small cracks may disappear by the kneading action of the tires and the healing effect of asphalt, [3]. At macro level, healing is thought to occur in two ways. One way is that some of the micro cracks can be healed during the rest periods between two axle passages. Another possibility is that micro crack healing happens during summer when the temperature is high. This implies that micro cracks developing during the winter can be healed during a hot summer, [4] and [5]. The concept of self-healing materials is related to their inherent ability to partially reverse damage such as small crack formation that might have occurred during its service life. It is known that asphalt is a self-healing material by itself, it is a slow process at ambient temperature and non-effective if the cracks are significant, [6]. Healing is considered to be cohesive when occurring in the asphalt or mastic and to be adhesive when occurring at the asphalt - aggregate interface. Adhesive healing at the asphalt – aggregate interface is due to the re bonding of the asphalt to the aggregate; and cohesive healing within the asphalt binder due to the cross-linking of asphalt materials at the micro crack surface, [7]. The crack healing phenomena has been investigated by many researchers [8; 9; 10; 11; 12; 13 and 14]. The self-healing capability of viscous materials including asphalt cement can retain the elastic property and flexibility of the pavement, [15]. Such healing issue could be developed when the crack size is very small, [16]. Repeated loading test and resilient modulus determination have been implemented by [17] to evaluate the healing behavior of asphalt mixtures. The healing phenomena could be utilized to overcome the negative impact of crack initiation. As reported by [18 and 19], it was believed that crack healing may retain the resilient properties of asphalt concrete. The aim of this investigation was to assess the cyclic crack healing of asphalt concrete in terms of its impact on the tensile and shear strength under repeated loading. Self-healing capabilities of asphalt mastic has been investigated by [20], Healing levels in the asphalt mastic samples with capsules were greater than samples without capsules.

2. Materials and Methods

2.1 Asphalt cement

The physical properties of asphalt cement are shown in Table 1. It was obtained from Dora refinery, Baghdad.

Table 1. *Physical Properties of Asphalt Cement*

SCRB Specification [21]	Result	Test as per ASTM, [20]
40-50	43	Penetration (25°C, 100g, 5sec) ASTM D 5
≥ 100	156 Cm	Ductility (25°C, 5cm/min). ASTM D 113
50-60	49 ℃	Softening point (ring & ball). ASTM D 36
< 55	31	Retained penetration of original, % ASTM D 946
> 25	147 Cm	Ductility at 25 °C, 5cm/min,(cm) ASTM D-113
-	0.175 %	Loss in weight (163°C, 50g,5h) % ASTM D-1754

2.2 Coarse and fine aggregates

Coarse and fine aggregates were obtained from Al-Nibaee quarry; their physical properties are presented in Table 2.

Table 2. *Physical Properties of Coarse and fine Aggregates*

Fine Aggregate	Course Aggregate	Property as per ASTM, [20]
2.631	2.610	Bulk Specific Gravity (ASTM C 127 and C 128)
0.542	0.423	Water Absorption % (ASTM C 127 and C 128)
-	20.10	Wear % (Los-Angeles Abrasion) (ASTM C 131)

2.3 Mineral filler

Ordinary Portland cement was implemented as mineral filler in the asphalt concrete mixture; the Physical properties are listed in Table 3.

Table 3. *Physical properties of Portland cement*

Physical Properties	
98	% Passing Sieve No.200 (0.075mm)
3.1	Specific Gravity
3.55	Specific Surface Area (m^2/kg)

2.4 Selection of asphalt concrete combined gradation

The selected gradation in this work follows the SCRB, [21] Specification for dense graded wearing course, with 12.5 (mm) nominal maximum size of aggregates. Table 4 presents the grain size distribution of the combined aggregate gradation.

Table 4. *Selected Asphalt concrete gradation as per SCRB, [21]*

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.75
Selected gradation	100	95	83	59	43	13	7
SCRB Specification limits	100	90-100	76-90	44-74	28-58	5-12	4-10

2.5 Preparation of hot mix Asphalt Concrete

The aggregate was dried, then sieved to different sizes, and stored in plastic containers. Coarse and fine aggregates were combined with mineral filler to meet the specified combined gradation. The combined aggregate mixture was then heated to a temperature of (150oC) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150oC), then, it was added to the heated aggregate to achieve the desired amount, and mixed thoroughly using mechanical mixer for two minutes until all aggregate particles were coated with thin film of asphalt cement. Marshall Size specimens have been prepared in accordance with ASTM, [20] using 75 blows of Marshall hammer on each face of the specimen. The optimum asphalt content was determined as per the procedure above to be 4.9% by weight of aggregates. Additional specimens have been prepared at 0.5% asphalt above and below the optimum. The prepared Marshall Size Specimens were divided into two sets, the first set was subjected to indirect tensile strength determination (ITS), while the second set was subjected to punching shear strength determination. Specimens of both sets have been tested in duplicate, and the average value was considered for analysis. Figure.1 shows part of the prepared specimens.

2.6 Testing of asphalt concrete specimens under repeated indirect tensile stresses

The test was conducted according to ASTM, [20]. The Pneumatic repeated load system (PRLS) was implemented; asphalt concrete specimens were subjected to repeated indirect tensile stress (ITS) for 20 minutes at 25 ˚C. Such timing and test conditions were suggested by [22]. Compressive repeated loading was applied on the specimen which was centered on the vertical diametrical plane through two parallel loading strips (12.7 mm) wide.

***Figure 1.** Part of the prepared specimens*

Such load assembly applies indirect tensile stress on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period is applied over test duration. Before the test, Specimens were conditioned in the test chamber at a temperature (25±1 ˚C), the pressure actuator was adjusted to the specific stress level equal to 69 kPa. The test was continued for 20 minutes to initiate micro cracking as suggested by [6]. The specimens were then tested for (ITS) resistance using versa testing machine. The average tensile strength of two specimens of each asphalt cement percentage was calculated and considered for analysis as recommended by [18 and 23]. Total of 36 specimens have been prepared and tested in duplicate. Figure.2 demonstrates the test setup in the (PRLS) System.

***Figure 2.** Repeated indirect tensile strength test*

2.7 Testing of asphalt concrete specimens under double punch shear stresses

Asphalt concrete specimens were subjected to repeated double punch shear stresses (PSS) for 20 minutes at 25 ˚C. Compressive repeated loading was applied on the specimen which was centered between the two plungers of 25.4mm diameter as per the procedure described by [2 and 6]. Such load assembly applies compressive load which was resisted by the specimen through double punching shear resistance. The stress on the specimen is in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period is applied over test duration. Before the test, Specimens were stored in the chamber of the testing machine at room temperature (25±1 ˚C), the pressure actuator was adjusted to the specific stress level equal to 69 kPa. The test was continued for 20 minutes to initiate micro cracking as suggested by [6 and 13]. The specimens were then tested for punching shear strength resistance (PSS) using versa testing machine. The average of two specimens of each asphalt cement percentage was calculated and considered for analysis. Total of 36 specimens have been prepared and tested in duplicate. Figure.3 demonstrates the test setup in the (PRLS) System. However, Figure 4 shows the PRLS testing devise.

Figure 3. *Repeated double punching shear test*

2.8 Crack healing technique

After subjecting asphalt concrete specimens to 20 minutes of repeated tensile or shear stresses, specimens were withdrawn from the PRLS chamber and stored inside an oven for two hours at 60 °C so that the initiation of micro crack healing could start. Afterwards, the healed specimens were returned to the PRLS chamber and stored for two hours at 25 °C, then the specimens were subjected to another round of tensile or shear stresses application. Specimens were subjected to a second healing cycle, then tested for (ITS) and (PSS). The determination of shear and tensile properties has been conducted after each repeated loading of 20 minutes and after each healing cycle. Similar procedure was followed by [6; 14; and 18]. Figure 5 shows the healing process.

Figure 4. *PRLS Testing devise*

Figure 5. *Healing process*

3. Results and Discussion

Figure.6 exhibit the variation of tensile strength of asphalt concrete at different asphalt percentages after it was subjected to repeated loading and crack healing cycles. It can be observed that tensile strength decreases by (2, 42, and 36) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively when it was tested after the first round of repeated loading as compared to the control specimens (tested before load repetitions). When the first micro crack healing cycle was implemented, the indirect tensile strength increases by (21, 82, and 65) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens before healing. This may be attributed to the extra stiffness gained by the specimen after healing. After the second run of load repetitions applied on the specimens, a reduction in the indirect tensile strength could be observed due to the possible micro damage occurred under the repeated load. The reduction in the tensile strength was (25, 37, and 35) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens after healing. When the specimens were subjected to the second cycle of healing, the tensile strength increases by (1, 3, and 2) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens before the second healing cycle. Such findings agree well with the work reported by [13 and 14]. After the third run of load repetitions, the specimens exhibit further reduction in the tensile strength by (22, 12, and 12) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens before the third run of repeated loading.

Such reduction in the tensile strength could be attributed to the deterioration of the mixture due to the cycles of loading and healing. It can also be observed that the impact of asphalt content was not significant among the various testing conditions implemented after healing process. On the other hand, the lower asphalt content of 4.4 % exhibit tensile strength of 1270 kPa for control mixture tested under static loading, while the tensile strength increases by (16 and 15) % when asphalt content rises to 4.9 and 5.5 % respectively. When the specimens were tested under repeated tensile stresses, the lower asphalt content of 4.4 % exhibit tensile strength of 1110 kPa, while the tensile strength decreasesby (26 and 18) % when asphalt content rises to 4.9 and 5.5 % respectively. This may be attributed to the stiffer mixture obtained at lower asphalt content which was capable to resist repeated loading due to the possible strain recovery during the rest period.

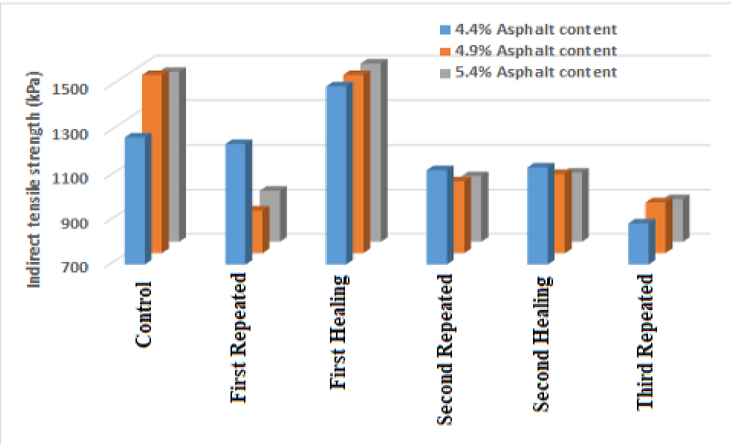

Figure 6. *Variation of tensile strength after various testing conditions*

Figure.7 exhibits the variation of shear strength of asphalt concrete at different asphalt percentages after it was subjected to repeated loading and crack healing cycles. It can be observed that shear strength decreases by (33, 32, and 35) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively when it was tested after the first round of repeated loading as compared to the control specimens (tested before load repetitions). When the first micro crack healing cycle was implemented, the shear strength increases by (23, 24, and 44) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens before healing. This may be attributed to the extra stiffness gained by the specimen after healing. Such behavior was in agreement with the work reported by [14 and 18]. After the second run of load repetitions applied on the specimens, a reduction in the shear strength could be observed due to the possible micro damage occurred under the repeated load. The reduction in the shear strength was (16, 16, and 31) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens after healing. When the specimens were subjected to the second cycle of healing, the shear strength increases by (28, 32, and 53) % for specimens with (4, 5, and 5) % asphalt content respectively as compared to the tested specimens before the second healing cycle. After the third run of load repetitions, the specimens exhibit further reduction in the shear strength by (27, zero, and 5) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively as compared to the tested specimens before the third run of repeated loading. It can also be observed that optimum asphalt content exhibit the best performance among other asphalt percentages at the various testing conditions implemented. It can be noted that repeated cycles of shear stresses application and crack healing exhibit mixtures with a stiffer nature which are capable to resist the double punching shear stresses. Such variation in the behavior between the two testing techniques (tensile and shear) may be attributed to un-confined nature of the indirect tensile test as compared to the confined nature of the double punch shear test in the direction of loading.

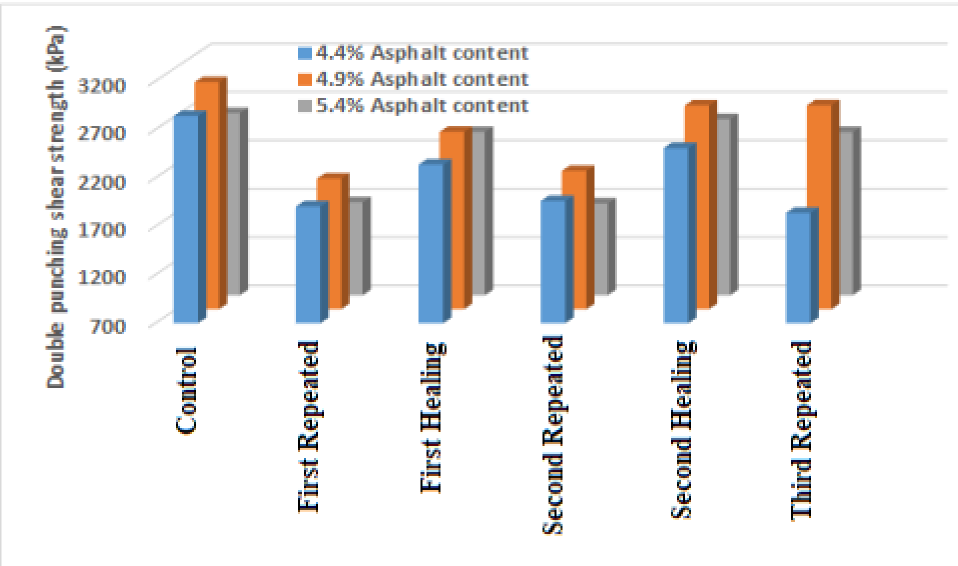

Figure 7. *Variation of shear strength after various testing conditions*

4. Conclusions

Based on the limited testing program, the following conclusions may be drawn:

1- The crack healing was able to retain (21, 82, and 65) % and (1, 3, and 2) % of the (ITS) after the first and second healing cycles under load repetitions for mixes with (4.4, 4.9, 5.4) % asphalt content respectively.

2- Tensile strength decreases by (2, 42, and 36) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively when it was tested after the first round of repeated loading as compared to the control specimens.

3- Asphalt content of 4.4 % exhibit tensile strength of 1270 kPa for control mixture tested under static loading, while the tensile strength increases by (16 and 15) % when asphalt content rises to 4.9 and 5.5 % respectively.

4- When the specimens were tested under repeated tensile stresses, the lower asphalt content of 4.4 % exhibit tensile strength of 1110 kPa, while the tensile strength decreases by (26 and 18) % when asphalt content rises to 4.9 and 5.5 % respectively.

5- The crack healing cycle was able to retain (23, 24, and 44) % and (4, 5, and 5) % of the (PSS) after the first and second healing cycles under load repetitions for mixes with (4.4, 4.9, 5.4) % asphalt content respectively.

6- Shear strength decreases by (33, 32, and 35) % for specimens with (4.4, 4.9, and 5.4) % asphalt content respectively when it was tested after the first round of repeated loading as compared to the control specimens.

7- Repeated cycles of shear stresses application and crack healing exhibit mixtures with a stiffer nature which are capable to resist the double punching shear stresses as compared to that of repeated tensile stresses.

8- The impact of asphalt content was not significant among the various testing conditions implemented for tensile strength determination, while optimum asphalt content exhibit the best performance among other asphalt percentages at the various testing conditions implemented for shear strength determination.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

References

[1] Barrasaa R., Lópeza V., Montoliua C. Addressing durability of asphalt concrete by self-healing mechanism. Proceedings, XVIII, 2014. Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística. PANAM.

[2] Sarsam S. I. Sustainability of flexible pavement in terms of the crack healing phenomena – a review, STM Journals, Trends in Transport Engineering and Applications TTEA. 2016, Vol.3, No. 2.

[3] Little D, Lytton R, Si Z. Crack Phenomenology: Formation and Healing - Task K Findings, Interim Report; Texas Transportation Institute, 2000. College Station, Texas.

[4] Jian Q, Self- Healing of Asphalt Mixtures- Towards a Better Understanding of the Mechanism, PhD. Dissertation, 2012, TU Delft.

[5] Bhasin A, Little DN, Bommavaram R, et al. Framework to Quantify the Effect of Healing in Bituminous Materials Using Material Properties, Int. J. Road Mater Pavement Des. 2008: EATA 08, 219-242.

[6] Sarsam S. I.. Crack Healing Potential of Asphalt Concrete Pavement, International Journal of Scientific Research in Knowledge, IJSRK 3(1), 2015, P. 001-012.

[7] Sutharsan T, Quantification of Cohesive Healing of Asphalt Binder based on Dissipated Energy Analysis, MSc. Thesis, 2010, Washington State University.

[8] Williams A, Little D, Lytton R, et al. Micro Damage Healing in Asphalt and Asphalt Concrete, Volume II: Laboratory and Field Testing to Assess and Evaluate Micro Damage and Micro Damage Healing. 2001, FHWA-RD-98-142, Texas Transportation Institution, College Station, TX.

[9] Kim B, Roque R. Evaluation of Healing Property of Asphalt Mixture. 85th Annual Meeting of the Transportation Research Board, 2006, Washington, DC.

[10] Little DN, Bhasin A, Exploring Mechanisms of Healing in Asphalt Mixtures and Quantifying its Impact. Self-Healing Materials- an Alternative Approach to 20 Centuries of Materials Science, Springer Series 2007, Mater Sci.; 100: P. 205–218.

[11] Si Z. Characterization of Micro Damage and Healing of Asphalt Concrete Mixtures, Ph.D. dissertation; Texas A&M University, 2001, College Station, Texas.

[12] Schlangen, E., Sangadji. S. Addressing Infrastructure Durability and Sustainability by Self-Healing Mechanisms. Recent Advances in Self-Healing Concrete and Asphalt. The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering. 2013, Procedia Engineering Volume 54, P. 39–57.

[13] Sarsam S. and Husain H. Monitoring the Impact of Micro Cracks Healing Cycles on the Deformation of Asphalt Concrete under Repeated Loading. Proceedings, International Congress and Exhibition, Sustainable Civil Infrastructures: Innovative Infrastructure Geo-technology, Advancement in the Design and Performance of Sustainable Asphalt Pavements 15-19 July, 2017, Sharm El-Sheikh, Egypt, pp 287-299. Springer Cham.

[14] Sarsam S. and Husain H. Monitoring the Deformation of Asphalt Concrete under Repeated Tensile and Shear Stresses through Micro Cracks Healing Cycles, Proceedings, International Conference on Highway Pavements and Airfield Technology 2017; ASCE T&D 08.

[15] Garcia A. Self-healing of Open Cracks in Asphalt Mastic, Fuel. 2012; P. 93: 264–272.

[16] Ajam H., Lastra-González P., García P., Self-healing of dense asphalt concrete by two different approaches: electromagnetic induction and infrared radiation, Proceedings, 8th RILEM International Conference on Mechanisms of Cracking and De-bonding in Pavements, Volume 13, 26 May 2016, Springer Netherlands, P. 241-246.

[17] Roque R., Simms R., Chen Y., Koh C., Lopp G. Development of a test method that will allow evaluation and quantification of the effects of healing on asphalt mixture. University of Florida, Project UF00084223, 2012, Final report.

[18] Sarsam S. I. and Husain H. K. Impact of Repeated Load on Crack Healing Cycles of Asphalt Concrete. American Journal of Traffic and Transportation Engineering 2016; 1(3): P. 26-33.

[19] Su J., Yang P., Wang Y., Han S., Han N., and Wei Li W., Investigation of the Self-Healing Behaviours of Microcapsules/Bitumen Composites by a Repetitive Direct Tension Test, Materials, 9, 600; 2016. P. 2-18.

[20] Al-Mansoori T., Norambuena-Contreras J., Micaelo R., and Garcia A. Self-healing of asphalt mastic by the action of polymeric capsules containing rejuvenators. Construction and Building Materials, 2018, Vol.161 P. 330–339.

[21] ASTM, Road and Paving Materials, Annual Book of ASTM Standards, Volume 04.03, 2009. American Society for Testing and Materials, West Conshohocken, USA.

[22] State Commission of Roads and Bridges (SCRB), Standard Specification for Roads & Bridges, 2003, Ministry of Housing & Construction, Iraq.

[23] Sarsam S. and AL-Shujairy A. Assessing Tensile and Shear Properties of Recycled Sustainable Asphalt Pavement. Journal of Engineering, 2015, Volume 21 Number 6, June.

[24] Sarsam S. and Husain H. Influence of Healing Cycles and Asphalt Content on Resilient Modulus of Asphalt Concrete. Trends in Transport Engineering and Applications, 2017. Volume 4, Issue 1, P. 23-30.