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Impact of Moisture Damage on Micro Crack Healing Process of Asphalt Concrete

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Abstract

Micro cracks healing of asphalt concrete is considered as one of the sustainability measures of asphalt concrete pavement. However, the impact of moisture damage on micro crack healing have not been investigated thoroughly. In this work, Marshall Asphalt concrete specimens of 100 mm diameter and 63 mm height have been prepared in the laboratory. Specimens were divided into three 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°C) to initiate micro cracks within the specimens using controlled stress mode of loading for 0.1 second followed by rest period of 0.9 seconds for specified load cycles. Specimens of the third group have practiced moisture damage as per the procedure recommended by super pave system. Specimens of the three groups were then subjected to external heating in an oven at 60°C and allowed to heal for two hours, conditioned at 25°C for two hours, then subjected to another course of repeated tensile or shear stresses. The deformation of the specimens was monitored through continuous video capture. The influence of moisture damage and the impact of asphalt content on the permanent deformation have been analysed as a sustainability measures. It was concluded that the higher deformation could be detected after moisture damage under both of tensile and shear stresses as compared to control mixes after 1000 load repetitions. After micro cracks healing, the permanent deformation decreases by a range of (55-16)% as compared to that after moisture damage under repeated tensile stress as was even lower than that of control mixes. On the other hand it decreases by a range of (18-16) % as compared to that after moisture damage under repeated shear stress.

Keywords

Moisture Damage, Micro Crack Healing, Shear and Tensile Stresses, Asphalt Concrete, Repeated Loading

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1. Introduction

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, [1]. Moisture damage is a durability problem in asphalt concrete pavement, it accelerates the deterioration in terms of disintegration and pot holes. [2] Have evaluated the moisture susceptibility of an asphalt mixture using the indirect tensile strength (ITS) and tensile strength ratio (TSR) test. [3] Studied the impact of coal fly ash additive on moisture damage of asphalt concrete, it was concluded that the 3% of coal fly ash in the asphalt concrete mix exhibit a significant increase in the resistance to moisture damage of 26% as compared to reference mix. It was stated by [4] in their work that, in general, the mixes subjected to moisture damage give lower resistance to indirect tensile strength at 40°C, by 19% as compared with reference mixture. 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

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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, [5] and [6]. [7] Concluded that the impact of moisture damage on asphalt concrete is lowering the indirect tensile strength and punching shear by (19% and 33%) respectively as compared with reference mix. The increment in asphalt content from the optimum by 0.5% had decreased the tensile and shear strength after the impact of moisture damage by 23% and 38% respectively. 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, [8].

A study by [9] concluded that the stiffness is susceptible to moisture damage when the test results are compared with those of control mix. Implementation of 400 and 750 Micro strain levels for the moisture damaged specimen's exhibits sharp reduction in the stiffness at initial load repetitions. The aim of this investigation was to assess the moisture susceptibility of asphalt concrete in terms of its impact on the permanent deformation. The moisture susceptibility parameters such as tensile strength ratio and shear strength ratio will be considered as a sustainability measures. The deformation will be determined under indirect tensile strength (ITS) and double punching shear strength PSS testing techniques. Write a suitable introduction, provide background, explain the context, summarize what has been done before; and explain the objective and significance of your work in relation to the work of others.

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.

Table 1. Physical Properties of Asphalt Cement.

Test as per ASTM, [10]	Result	SCRB Specification [11]
Penetration (25°C, 100g, 5sec) ASTM D 5	43	40-50
Ductility (25°C, 5cm/min). ASTM D 113	156 Cm	≥ 100
Softening point (ring & ball). ASTM D 36	49°C	50-60
Retained penetration of original, % ASTM D 946	31	< 55
Ductility at 25°C, 5cm/min,(cm) ASTM D-113	147 Cm	> 25
Loss in weight (163°C, 50g,5h)% ASTM D-1754	0.175 %	-

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.

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

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

2.4. Selection of Asphalt Concrete Combined Gradation

The selected gradation in this work follows the SCRB, [11] 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.

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 (150°C) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150ºC), then, asphalt cement 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 [10] 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. The prepared Marshall Size Specimens were divided into two sets, the first set was subjected to moisture damage process as per AASHTO, [12] before testing for deformation, while the second set was directly subjected to testing for deformation. Specimens have been tested for deformation in duplicate, and the average value was considered for analysis. Figure 1 shows part of the prepared specimens.

Fig. 1. Part of the prepared specimens.

2.6. Testing for Water Damage

Asphalt concrete specimens were subjected saturation under vacuum pressure of 3.74kPa in the water chamber for ten minutes, then the specimens were removed from the water chamber and stored in a deep freezer for 16 hours at (-18)°C as per the procedure of AASHTO, [12].

Specimens were withdrawn from the deep freezer and allowed for thawing for 120 minutes in the laboratory at room temperature of 24±2°C, then specimens were transferred into a water bath and stored for 120 minutes at 60°C. Specimens were then transferred to the PRLS chamber and stored at 25°C before testing for repeated ITS and PSS.

2.7. Testing of Asphalt Concrete Specimens Under Repeated Indirect Tensile Stresses

The test was conducted according to ASTM, [10]. 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 was suggested by [7], and [13]. 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. 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), dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level equal to 69 kPa. The test was continued for 20 minutes. The deformation of the specimens under repeated indirect tensile stress and the number of load repetitions were captured using digital video camera fixed on the roof of PRLS system. The average of two sample of each asphalt cement percentage was calculated and considered for analysis as recommended by [4] and [14]. Total of 18 specimens were prepared and tested. Figure 2 demonstrates the test setup in the (PRLS) System.

Fig. 2. Repeated indirect tensile strength test.

2.8. 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 [9].

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), dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level equal to 69 kPa. A digital video camera was fixed on the top surface of the (PRLS) to capture the dial gage reading of deformation of the specimens and the number of load repetitions under repeated punching shear stress. The test was continued for 20 minutes. Similar procedure was followed by [15]. The average of two sample of each asphalt cement percentage was calculated and considered for analysis. Total of 18 specimens were prepared and tested. Figure 3 demonstrates the test setup in the (PRLS) System.

Fig. 3. Repeated double punching shear test.

2.9. Crack Healing Technique

After subjection asphalt concrete specimens to 20 minutes of repeated tensile or shear stresses, specimens were stored inside an oven for two hours at 60°C so that the initiation of crack healing could start. Afterword, 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, and the deformation was captured.

3. Discussion

Figure 4 shows the impact of moisture damage and healing on asphalt concrete with 4.4% asphalt binder, it can be observed that at 1200 load repetitions dramatic increment of deformation could be detected for moisture damaged specimens, the deformation increases by 42% and the variation of deformation was not significant up to 100 load repetition of indirect tensile stresses. When crack healing was allowed, the deformation decreases by 18% as compared to the cased before moisture damage. This may be attributed to the micro crack healing process, which closes micro cracks and blocks voids inside the structure of the mixture. The figure also exhibits that the intercept of the deformation-load repetitions relationship decreases after crack healing by 78% as compared to that before moisture damage process.

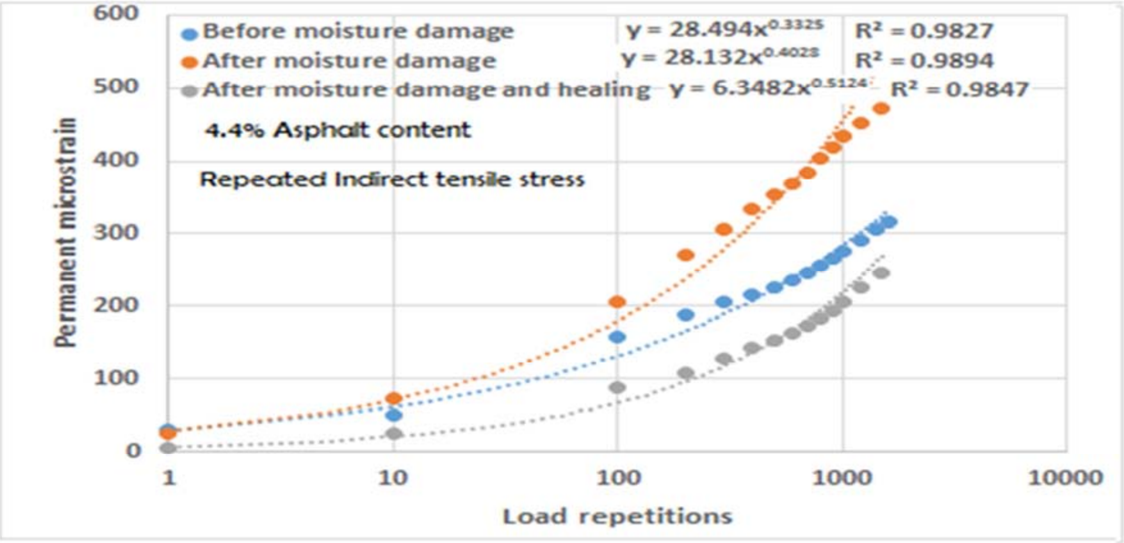

Fig. 4. Deformation of asphalt concrete under (ITS) at 4.4% asphalt content.

Figure 5 exhibits the behaviour of asphalt concrete under repeated tensile stresses when the asphalt content was at optimum value of 4.9%. It can be observed that at 1200 load repetitions, the deformation increases by 9% after moisture damage, while it decreases by 15% after healing as compared to the condition before moisture damage. On the other hand, the intercept of the deformation-load repetitions relationship of moisture damaged and healed mixtures decreases after crack healing by 58% as compared to that before moisture damage process. Between 100 to 1000 repetitions, the moisture damaged mixture exhibits higher deformation as compared to the case before moisture damage. This may be attributed to the wide exposure of asphalt concrete after the initiation of micro cracks to the moisture damage.

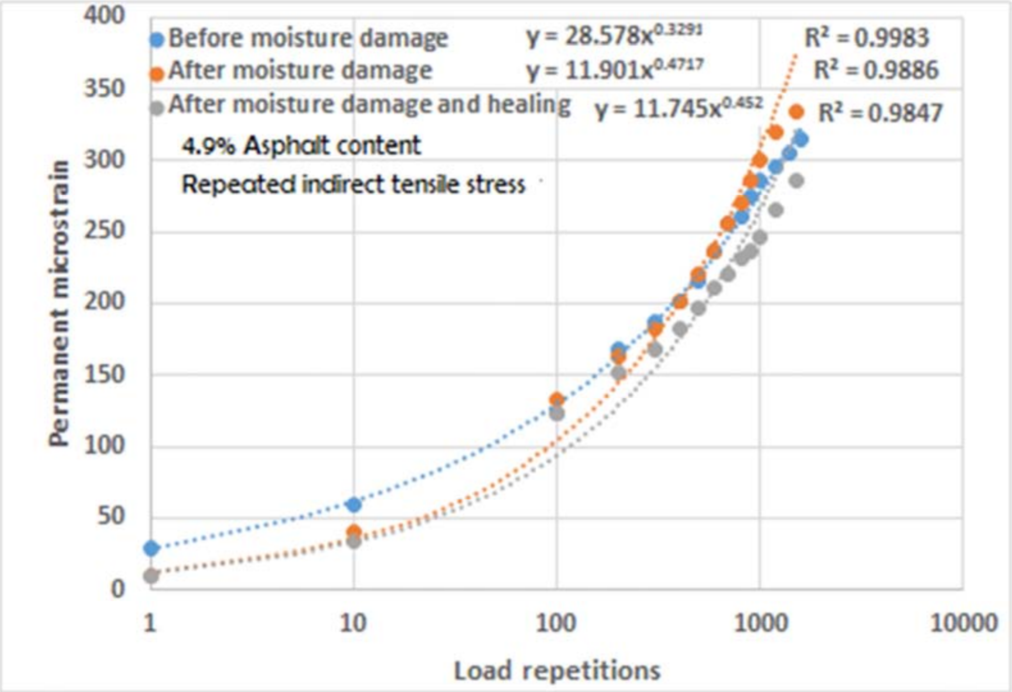

Fig. 5. Deformation of asphalt concrete under (ITS) at 4.9 % asphalt content.

Figure 6 presents the behaviour of asphalt concrete under repeated tensile stresses when the asphalt concrete exceeds the optimum requirements to 5.4%, it can be observed that after micro cracks healing process, the mixture was able to almost retain its original deformation before moisture damage. On the other hand, at 1200 stresses application, the deformation increases by 17% after moisture damage.

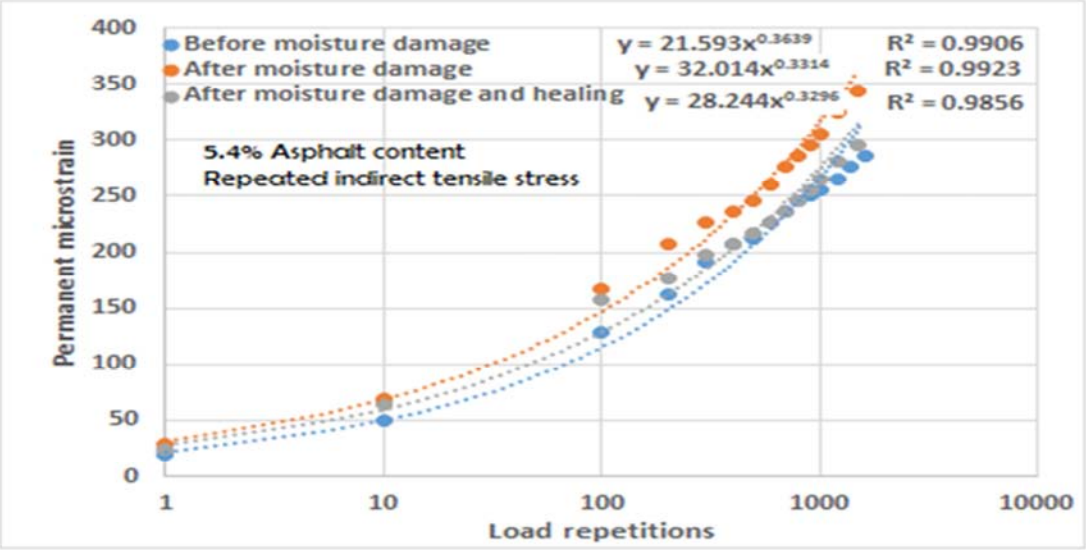

Fig. 6. Deformation of asphalt concrete under (ITS) at 5.4 % asphalt content.

Figure 7 presents the accumulation of permanent deformation under punching shear stresses for specimen of 4.4% asphalt content. At 1000 load repetitions, the deformation increases by 55% after moisture damage, while the healing process was unable to retain the deformation to its original value before moisture damage. The deformation after healing is 20% higher than that before moisture damage. This could be attributed to the fact that shear type of loading causes micro cracking in asphalt concrete specimen and displacement of aggregate particles between the edges of loading and non-loading paths which is permanent and cannot be recovered. Such behaviour is also predicted through the changes in the intercept values.

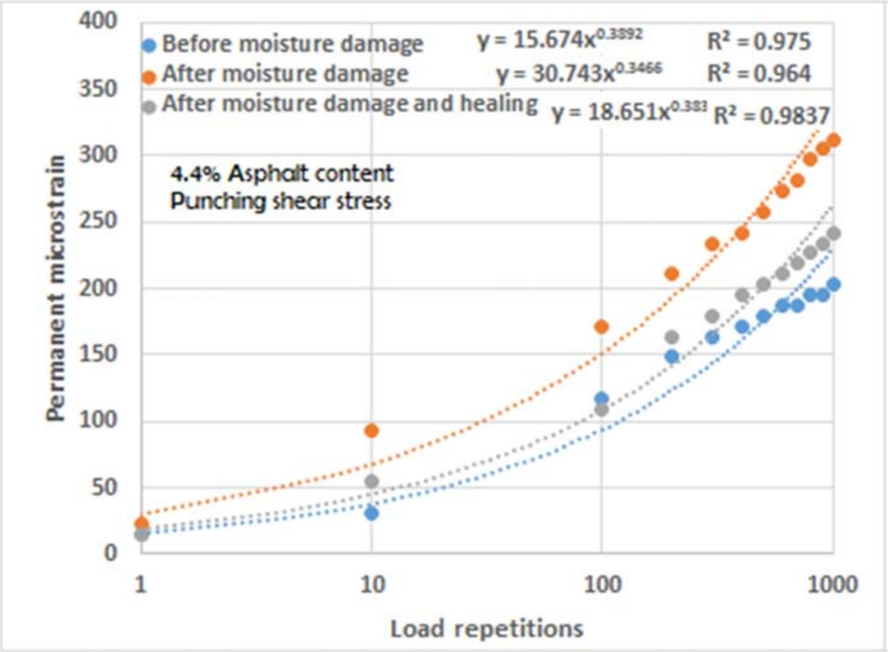

Fig. 7. Deformation of asphalt concrete under (PSS) at 4.4 % asphalt content.

Figure 8 presents the accumulation of permanent micro strain under punching shear stresses for specimen with optimum asphalt content of 4.9%. At 1000 load repetitions, the deformation increases by 45% after moisture damage, while after the healing process, the deformation is still 11% higher than that before moisture damage. It can be observed that the higher asphalt percentage has a positive impact on reducing the permanent deformation as compared to that of mixture at 4.4% asphalt content.

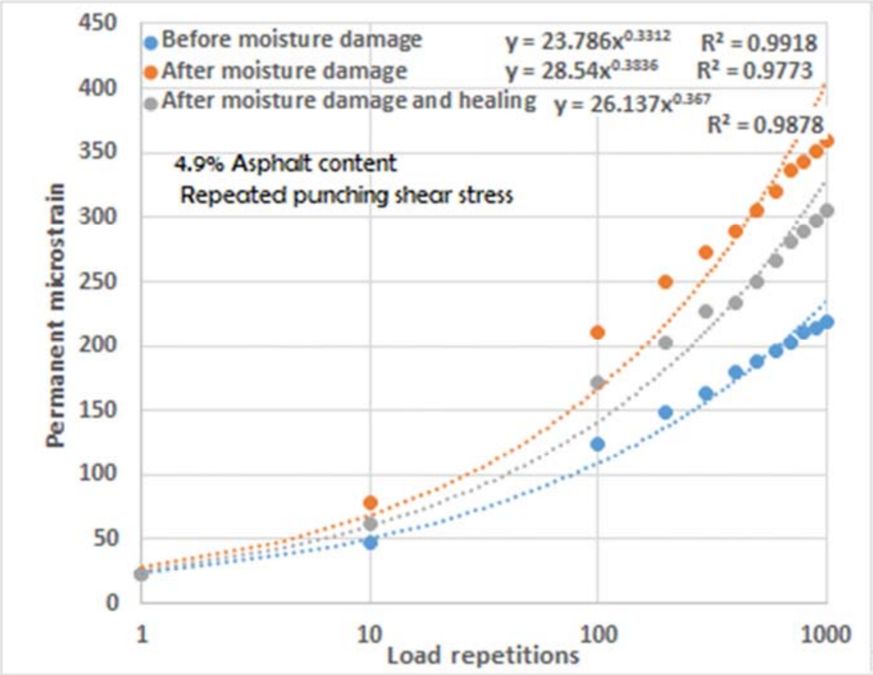

Fig. 8. Deformation of asphalt concrete under (PSS) at 4.9 % asphalt content.

Figure 9 demonstrates the behaviour of asphalt concrete under repeated punching shear stresses for a specimen with high asphalt content of 5.4%. At 1000 load repetitions, the permanent deformation increases by 66% after moisture damage, while after crack healing, the deformation increases by 37.5% as compared to that before moisture damage.

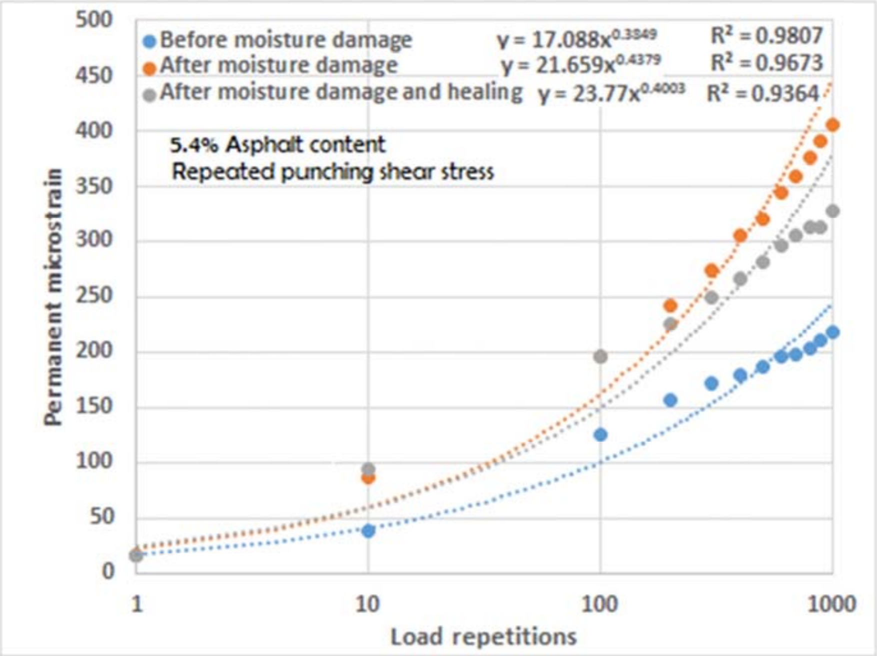

Fig. 9. Deformation of asphalt concrete under (PSS) at 5.4% asphalt content.

4. Conclusions

Based on the testing program, the following conclusions are drawn:

1- Under repeated (ITS), and 4.4% asphalt content, the deformation increases by 42% after moisture damage, while when crack healing was allowed, the deformation decreases by 18% as compared to the cased before moisture damage. The intercept of the deformation-load repetitions relationship decreases after crack healing by 78% as compared to that before moisture damage process.

2- For specimen with 4.9% asphalt content under repeated (ITS), the deformation increases by 9% after moisture damage, while it decreases by 15% after healing as compared to the condition before moisture damage. The intercept of the deformation-load repetitions relationship of moisture damaged and healed mixtures decreases after crack healing by 58% as compared to that before moisture damage process.

3- For specimen with 5.4% asphalt content under repeated (ITS), the mixture was able to almost retain its original deformation before moisture damage, at 1200 stresses application, the deformation increases by 17% after moisture damage.

4- Under repeated punching shear stresses (PSS), specimen with 4.4% asphalt content exhibits deformation increment by 55% after moisture damage, while the deformation after healing is 20% higher than that before moisture damage.

5- For specimen with 4.9% asphalt content under repeated (PSS), the deformation increases by 45% after moisture damage, while after the healing process, the deformation is still 11% higher than that before moisture damage.

6- For specimen with 5.4% asphalt content under repeated (PSS), the permanent deformation increases by 66% after moisture damage, while after crack healing, the deformation increases by 37.5% as compared to that before moisture damage.

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