
Comparing the Influence of Micro Crack Healing Process on Asphalt Concrete Deformation under Repeated Stresses

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ABSTRACT

The Initiation of micro cracking in Asphalt concrete pavement usually start and continue throughout the service life of the pavement due to the impact of loading and environment. However, micro cracks can exhibit healing by themselves in a slow process under repeated loading and rest period at high ambient temperature. The aim of the present investigation is to assess the influence of the micro crack healing process of asphalt concrete specimen on the deformation parameters under the action of repeated flexural and compressive stresses. Cylindrical and beam specimen of asphalt concrete were prepared at optimum asphalt content requirements and tested at 25°C environment for resilient, permanent, and total deformation under repeated compressive and flexural stress level of (138) kPa. The loading cycle implemented consists of 0.9 seconds of rest period followed by the load duration application for 0.1 second. The repeated loading was conducted for a range of 900 – 660 load repetitions for cylindrical and beam specimens respectively with the aid of the Pneumatic repeated load system (RPLS) apparatus to allow for the initiation of micro cracking. After application of the specific load cycles for each type of specimens, the load application was stopped, and the specimens were withdrawn from the RPLS testing chamber and stored in the oven at 60 ° C for 120 minutes to allow the micro crack healing process by external heating. Specimens of asphalt concrete were then subjected to another loading cycles. It was noted that the deformation behavior of asphalt concrete varies based on the test technique. It was concluded that the deformation decreased by (28.6 and 84.2) % under repeated compression and flexure stresses respectively after healing. Significant variation in the deformation behavior under repeated flexure and compressive stresses due to healing was observed. The intercept decreases by (54.1 and 87.2) % after healing under compressive and flexure stresses respectively.

Keywords: Asphalt concrete, flexure, Compressive stress, repeated load, deformation

INTRODUCTION

Flexible Asphalt concrete pavement is subjected to repetitions of multi-level vehicular wheel loads which implement stresses in the form of tensile, compressive, and shear stresses accompanied with various durations of rest periods. The three major mechanisms of failure that may occur are fatigue failure, which is caused by damage accumulation during loading, the time-dependent behavior is usually related to the viscoelastic nature of asphalt concrete; and the chemical healing process across micro-crack and macro-crack faces during rest periods as revealed by Sarsam, [1]. Vo et al., [2], reported that the micro crack healing level reduced with healing cycles, and decreased with the increment in the maximum temperature of performance grade asphalt cement. Garcia et al, [3] reported that asphalt binder can repair itself by closing microcracks, under a high temperature ranging from (30 to 70)°C

accompanied with enough resting period. Mazzoni et al., [4] revealed that the effectiveness of healing in hot mix asphalt concrete decreases with every healing cycle until the asphalt concrete is unable to show any sign of recovery. This may indicate that overheating of binder, swelling, aging, and binder drainage issues can reduce the healing performance. Garcia, [5] stated that asphalt binder is usually degraded by environmental factors until it loses its flexibility and the ability to bind the aggregates surface particles together. Such process results in micro-cracks which allow damage by moisture which percolates into the lower pavement levels. This will create surface roughness, potholes, degradation, and eventual structural failure. Occasionally, when signs of ageing are visible, a practice is followed by the engineers to implement a sealant is applied to the pavement surface that protects asphalt concrete surface from environmental degradation and moisture damage. Such procedure may increase the lifetime of asphalt pavement for several years before rehabilitation or reconstruction is required. The disadvantage of such process is that it only work in the first centimeters from the surface and then can reduce sliding resistance as reported by Garcia, [6]. The existing self-healing techniques as reported by Xiao, [7] include heating-induced healing methods and polymer healing methods. Both methods may effectively increase the service life of asphalt concrete pavement, enhance the healing performance of asphalt concrete, and reduce the need for maintenance of road surface. Sarsam and AL-Lamy, [8] stated that asphalt concrete pavement distress usually starts with micro cracking due to the influence of load repetition and environmental impact. Such micro cracks can heal by themselves slowly under repeated loading, provision of rest period at ambient temperature, and external or internal heating. A study by Liu et al., [9] addressed that asphalt concrete mixture should be flexible enough at low service temperature to prevent micro cracking process and to be stiff enough at high service temperature for prevention of rutting. The characteristic of strain recovery in asphalt concrete mixture may reflect the rutting resistance property of the material based on the repeated-load test. The rutting resistance evaluation method was evaluated by analyzing the repeated-load test data. The residual strain ratio of the mixture is not influenced by the aggregate skeleton and can be used for the rutting resistance evaluation of the materials. Aging of asphalt under weather and traffic was assessed by Bochove, [10], it was reported that ageing is associated with the possible formation of micro cracks in the mastic fraction. It was revealed that the addition of a conductive material of mineral origin such as iron fillings or steel wool fibers in the asphalt concrete production can provide the possibility of heating up the mastic of the asphalt concrete by an induction device. Application of short heat shot through the iron fillings or the steel fibers, causes melting and flow of the asphalt cement binder and the microcracks in the asphalt concrete layer could be closed. The asphalt concrete mixture may reset and start a new life. This may be conducted several times during the pavement service life. Healing of microcracks may occur due to temperature increases within or surrounding the pavement layer while in the microcracking range, it can increase the useful life of the pavement as reported by Ajam et al. [11]. Rudensky, [12] revealed that accumulated dynamic deflection in the asphalt concrete layer can present most closely and simulate the real behavior of material under traffic load impact on asphalt concrete surface. Sarsam and Husain, [13] addressed that the microcrack healing potential of asphalt concrete mixture can retain the quality of the pavement and may influence the load spreading capability of the asphalt concrete mixture, it may increase the structural strength and can extend the expected service life of the flexible pavement. As shown in Figure 1, Ziari et al., [14], there are 3 primary stages in the life cycle of a mix under repeated loading before failure. During the primary stage, the rate of deformation is high at initial loading repetitions, but it gently decreases. In the secondary stage, the deformation rate

is regarded as being constant and gentle, while deformation increases steadily. And in the tertiary stage, deformation increases rapidly, till failure occurs.

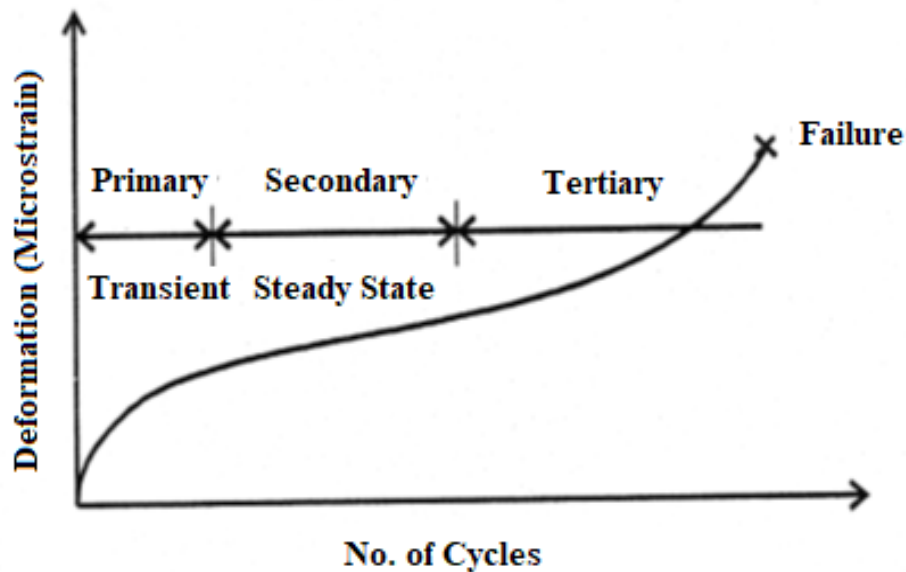


Fig. 1. Performance of a typical Asphalt Concrete specimen, Ziari et al., [14]

Roque et al., [15] developed a test to evaluate the healing behavior of asphalt concrete mixtures. The testing procedure consists of damage tests by repeated loading followed by a healing phase. The resilient modulus tests are performed during the healing phase to measure the recovery of modulus (healing). The decline of the resilient modulus of asphalt concrete with the increment in the number of repeated load cycles is a significant indication of micro-damage accumulation during the damage phase. The recovery of resilient modulus property during the healing phase is an indication of healing process or damage recovery. Little et al., [16] demonstrate that micro-damage healing occurs and that it can be measured in the laboratory and in the field, it was Confirmed that the same fracture properties that control propagation of visible cracks control the propagation of microcracks, and identify the asphalt constituents, that influence micro-damage and micro-damage healing. Appropriate correlations were established between micro-damage and micro-damage healing in the laboratory. Grossegger, [17] stated that self-healing alone is not the solution to an infinite damage-recovery cycle because of the huge uncertainties during the process. Uncertainties influencing the self-healing of asphalt include the damage level and the point in time when self-healing occurs, the contribution of self-healing during the damage periods, type of crack (adhesive or cohesive), ageing stage and environmental conditions, such as humidity and temperature, and degree of foreign substances filling the crack. The aim of the present investigation is to compare the influence of microcrack healing process on the deformation parameters of asphalt concrete beam and cylindrical specimens subjected to repeated compression and flexure stresses.

MATERIALS AND METHODS

Asphalt Cement

Asphalt cement with a penetration grade of (40-50) was obtained from Daura Refinery and implemented in the present investigation. Table 1 shows the physical properties of the asphalt cement.

Table 1. Physical Properties of Asphalt Cement

Property as per ASTM,[18]	Result	Unit	SCRB, [19] Specification
Penetration (25°C,100g,5 sec) ASTM D5-97	44	1/10mm	40-50
Softening Point (Ring & Ball) ASTM D5-36	48.9	°C	50-60
Ductility (25°C, 5cm/min) ASTM D113-07	120	cm	>100
Kinematic viscosity at 135°C ASTM D-2170	365	Cst.	-----
Flash point (Cleave land open cup). ASTM D-92	323	°C	Min232
Specific gravity at 25 °C ASTM D-70	1.04	-----	(1.01-1.05)
After Thin-Film Oven ASTM D1754			
Retained penetration of original, % D946	60	%	>55%
Ductility at 25°C,5 cm/min.	75	cm	>25
Loss in weight (163°C,50g,5h) ASTM D1754	0.34	%	< 0.75

Coarse Aggregates

The implemented crushed coarse aggregates were obtained from Al-Nibae quarry. The gradation of coarse aggregate is passing sieve size 19.0 mm and retained on sieve size (4.75 mm) according to SCRB R/9, [19] specification. The physical properties of the coarse aggregates are listed in Tables 2.

Fine Aggregates

Fine aggregates are obtained from Al-Nibae quarry. The gradation of fine aggregates is passing sieve size 4.75mm and retains on 0.075mm sieve. Table 2 list the physical properties of the fine aggregates.

Table 2. Physical Properties of Al-Nibae Coarse and Fine Aggregates

Property as per ASTM, [18]	CoarseAggregate	FineAggregate
Bulk Specific Gravity (ASTM C127 and C128)	2.680	2.630
Percent Water Absorption (ASTM C127 and C128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C131)	21.7	

Mineral Filler

Portland cement was implemented as mineral filler. The physical properties are shown in Table 3.

Table 3. Physical Properties of Portland cement

Test	Physical properties
% Passing Sieve No.200 (0.075 mm)	98
Apparent Specific Gravity	3.10
Specific Surface Area (m ² /kg)	315

Selection of Overall Aggregate Gradation

The gradation that was implemented in this assessment follow SCRB R/9, [19] specification for wearing course asphalt concrete mixture with aggregates nominal maximum size of (12.5 mm). Table 4. lists the gradation of aggregates for wearing course layer.

Table 4. Gradation of Aggregate for Wearing Course as per SCRB, [19]

Sieve size mm	19	12.5	9.5	4.75	2.36	0.3	0.075
Gradation	100	95	83	59	43	13	7
SCRB limits	100	90-100	76-90	44-74	28-58	5-12	4-10

Preparation of Asphalt Concrete Beam Specimens

The aggregates and mineral filler mixture were heated to 160°C, while the asphalt cement binder was heated to 150°C. The asphalt binder was introduced into the aggregates mixture and mixed mechanically for three minutes so that the aggregates surface was coated with a thin film of asphalt binder. The beam mold of 76.2 mm width, 76.2 mm height and 381.0 mm length consist of four portable sides was heated to 150°C. The hot asphalt concrete mixture was transferred and poured into the heated mold, spread uniformly with a spatula, then the mixture was subjected to static compaction of 30 kN applied through steel base plate of 80 mm thickness. The applied load was maintained on the specimen for three minutes at the compaction temperature of 150°C to achieve the target specimen's bulk density and thickness. The mold was left to cool overnight, and then, the beam specimen was extruded from the mold. Figure 2. exhibits the preparation process of beam specimens, while Figure 3 shows the PRLS chamber, the testing scheme, and part of the prepared asphalt concrete beam specimens. However, Table 5 illustrates the details of the prepared asphalt concrete beam specimens. Similar procedure for specimen preparation could be found in Sarsam and Alwan, [20].



Fig.2. Preparations of Beam specimens

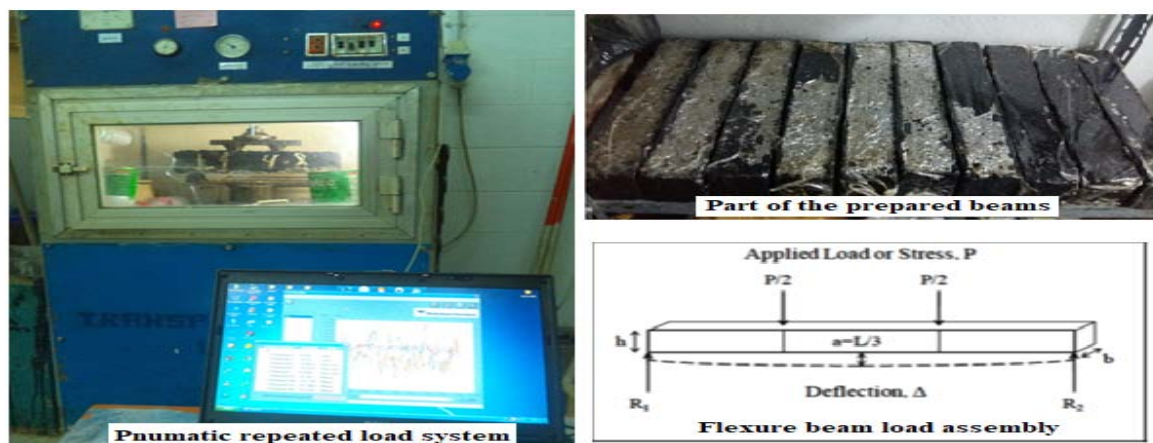


Fig.3. Pneumatic Repeated Load System Apparatus PRLS

Preparation of Asphalt Concrete Cylindrical Specimens

The combined aggregates mixture was heated in the oven to 160°C, while the asphalt cement binder was heated to 150°C. The required binder was then added to the aggregates and mixed thoroughly for three minutes using mechanical mixer until asphalt binder had sufficiently coated the surface of the aggregates. The cylindrical molds of 102 mm diameter and 127 mm height were heated to 150°C. Slight layer of mineral oil was applied to the internal surface of the mold to prevent sticking. The asphalt concrete mixture was poured into the heated mold, laid, and spatted uniformly with a heated spatula, then subjected to static compaction of 30 kN which is applied through steel plate of 80 mm thickness. The applied load was maintained for three minutes at 150°C to achieve the target specimen's bulk density and thickness. The mold was left for 24 hours to cool, and then the specimen was extruded from the mold. Cylindrical asphalt concrete specimens have been prepared with the optimum asphalt content requirement. Table 5 shows detailed information of the prepared beams. Figure 4 exhibit part of the prepared specimens, the PRLS chamber, and the testing setup technique adopted.

Table 5. Details of the Prepared Beam and Cylindrical Specimens

Property	Test Value
Bulk Density gm/ cm ³	2.340
Optimum asphalt content %	4.8
Volume of voids %	3.9
Volume filled with asphalt %	73



Fig.4. The Repeated Compressive Stress Testing Apparatus

Testing of Asphalt Concrete Specimens Under the Repeated Flexural Bending Stresses

The prepared asphalt concrete beam specimens were subjected to the repeated flexural bending test in the Laboratory using pneumatic repeated Load system apparatus (PRLS). To capture the deformation and micro cracking potential in the flexural beam fatigue test, four-point loading with free rotation beam holding fixture at all loading and reaction point was implemented. The number of load cycles that initiates micro cracks of the beam is usually considered as an indicator of fatigue cracking potential. The specimens were stored in the conditioning chamber at the testing temperature of (25°C) for one hour to allow for the

uniform distribution of temperature within the specimen. The position of applied loading was marked on the specimens. The deformation (total, permanent, and resilient) was monitored of the beam under each load cycle with the aid of LVDT (Linearly Variable Differential Transformer) which are positioned and pasted onto the specimen and set to zero.

The stress level adopted was 138 kPa. The repeated loading cycle of flexural stress consist of 0.9 second of rest period followed by 0.1 second of load duration and the flexural deformation at the central third of the specimen is measured under each load repetitions as recommended by Sarsam, [21]. The repeated load testing starts to allow for the initiation of micro cracks up to 660 load repetitions, then the loading was stopped, and the test was terminated.

Repeated Compressive Stresses test

The prepared cylindrical specimens have practiced the repeated compressive stresses at 25 °C under the adopted stress level of 138 kPa with the aid of the pneumatic repeated load system PRLS. The load assembly is designed to apply repeated compressive stresses on the cylindrical specimen in the form of rectangular wave and a constant loading frequency of (60) cycles per minutes. A heavier sine pulse of 0.1 second of load duration and 0.9 second of rest period was implemented throughout the test duration.

Before the test, the LVDT apparatus was positioned onto the specimen and set to zero. The asphalt concrete specimens were tested in triplicate and the average deformation of specimens was calculated and considered for obtaining the permanent deformation and resilient modulus. Similar procedure was reported by Sarsam and Jasim, [22]. The load repetitions start to allow for initiation of micro cracking and after 900 load repetitions, the test was terminated.

Microcrack healing process

The repeated flexure or compressive stress test was continued for 660 and 900 load repetitions. When the test was completed, the deformation monitoring was terminated. Asphalt concrete beam and cylinder specimens have been withdrawn from the PRLS chamber and stored in an oven for 120 minutes at 60°C to allow for the microcrack healing process by external heating. Specimens were then returned to the PRLS chamber, conditioned for 60 minutes at 25±1°C and subjected to another round of load repetitions. The average deformation of three specimens was considered for analysis as recommended by Sarsam, [1]. Data were analyzed, and the plot of strain-load repetitions was conducted. Permanent, total, and resilient deformations were detected through LVDT for both testing techniques after microcrack healing process.

RESULTS AND DISCUSSIONS

Impact of Healing on Permanent Deformation Parameter

Figure 5 shows the influence of healing cycle on permanent strain parameters under flexure and compressive stresses. A significant variation in the deformation behavior under repeated flexure and compressive stresses due to healing can be noted. The intercept which represents the microstrain after the first load repetition decreases by (54.1 and 87.2) % after healing under compressive and flexure stresses respectively.

The slope, which represent the rate of deformation of asphalt concrete specimens throughout the repeated loading period exhibit nonsignificant variation under flexure stress due to healing while it increases by 35 % under compressive stresses due to healing.

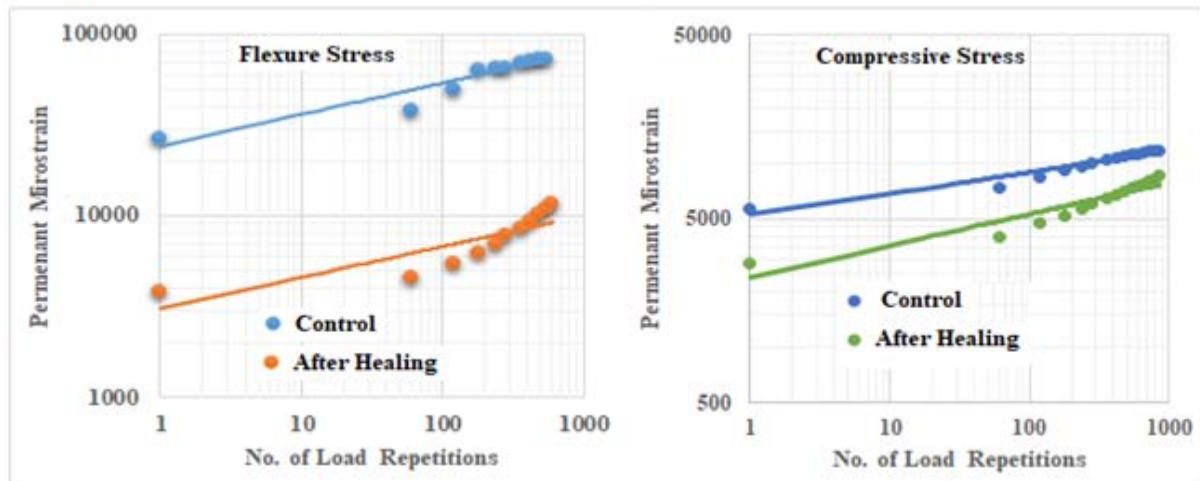


Fig.5. Influence of healing on permanent deformation

Impact of Healing on Deformation Behaviour

As demonstrated in Table 6, the permanent deformation of specimens under repeated compressive stresses is lower than that under flexure stresses by 84.2 %. This may be attributed to geometry of the specimen with free bending deformation in case of beam specimen while the cylindrical specimen exhibits restricted vertical deformation. After the microcrack healing process, the variation in permanent deformation between the two testing techniques is 28.6 %. Such reduction in the permanent deformation may be attributed the stiffening of the binder due to healing period. On the other hand, the impact of healing process of asphalt concrete on the reduction in permanent deformation was (28.6 and 84.2) % under compressive and flexure stresses respectively.

Table 6. Permanent Microstrain After Load Repetitions

Testing Technique	Under Compressive Stress	Under Flexure Stress
Permanent Deformation before healing (microstrain)	11500	72930
Permanent Deformation after healing (microstrain)	8200	11500

Figure 6 demonstrates the deformation parameters under flexure stress. It can be noted that after 660 of load repetitions on the control specimen, the permanent deformation is almost equal to the total deformation while the influence of resilient deformation is minimal after 420 load repetitions.

On the other hand, the deformation parameters decline after possible microcracks healing process. Significant variation between total and permanent deformation could be noted. The negative impact of healing on the resilient deformation could be observed. This could be attributed to the stiffening occurred in asphalt binder throughout the external heating and healing process.

It can be noted that for control mixture, there is no visible limit for indication between the primary and the secondary stages of the life cycle when the total and permanent deformations are considered. Only the resilient deformation exhibits normal behavior. On the other hand, after microcrack healing, the deformation parameters behave normally.

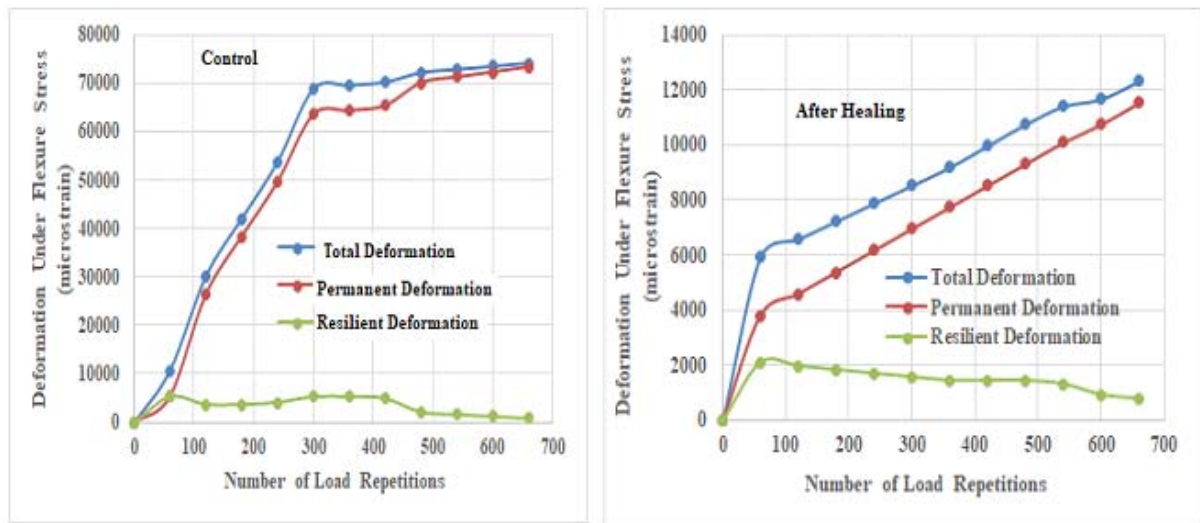


Fig.6. Influence of Healing on Deformation Behaviour Under Flexure Stress

Figure 7 exhibits the deformation parameters of specimens under compressive stress. It could be observed that after 900 of load repetitions on the control and healed specimens, there is no significant variation between the total and the permanent deformation. This could be attributed to the geometry of the cylindrical specimen. The influence of resilient deformation is minimal after 420 load repetitions for control specimen. On the other hand, the deformation parameters decline after possible microcracks healing process. Significant variation between total and permanent deformation could be noted. The resilient deformation decreased by five folds after the healing process. This may be attributed to the stiffening of asphalt binder throughout the external heating which presents healing process. It can be noted that under repeated compressive stresses, no significant influence of the microcrack healing on the life cycle behavior of asphalt concrete could be observed. Only the resilient deformation exhibits normal behavior. Such findings agree well with Ziari et al.,[14].

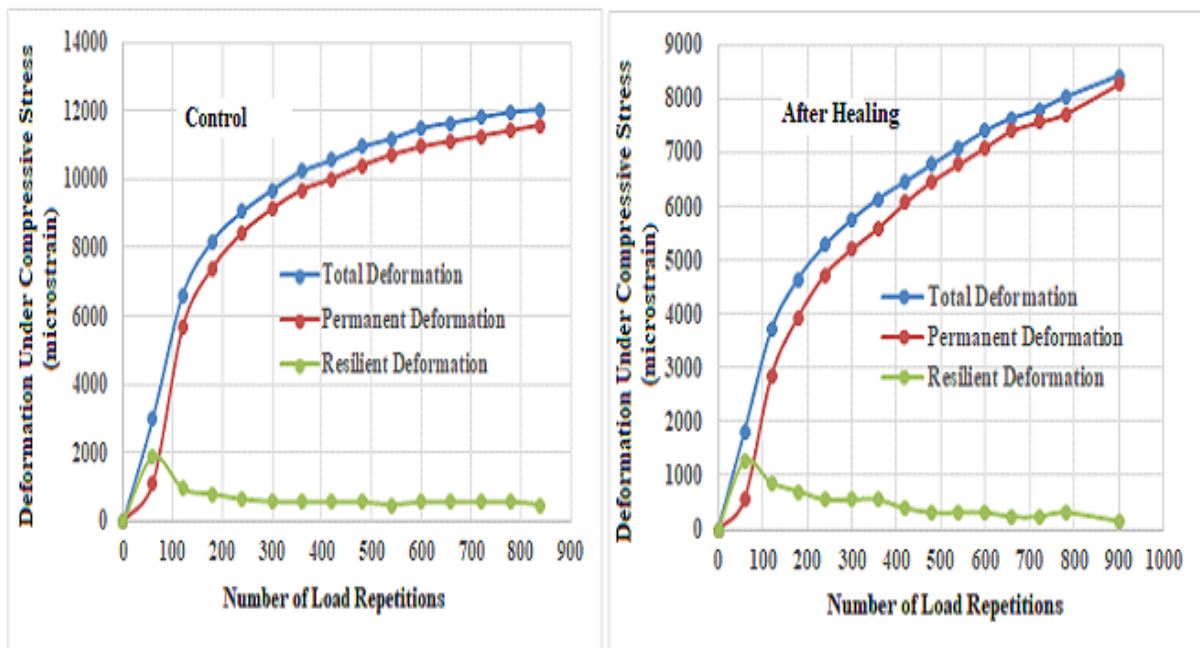


Fig.7. Influence of Healing on Deformation Behaviour under Compressive Stress

CONCLUSIONS

Based on the limitations of materials and the testing program, the following conclusions may be addressed:

- 1) Significant variation in the deformation behavior under repeated flexure and compressive stresses due to healing was observed. The intercept decreases by (54.1 and 87.2) % after healing under compressive and flexure stresses respectively.
- 2) The slope exhibits non-significant variation under flexure stress due to healing while it increases by 35 % under compressive stresses due to healing.
- 3) The impact of healing on the reduction in permanent deformation was (28.6 and 84.2) % under compressive and flexure stresses respectively.
- 4) Under repeated flexure stresses and after 660 load repetitions, significant variation between total and permanent deformation could be noted. The negative impact of healing on the resilient deformation could be observed.
- 5) Under repeated compressive stresses and after 900 load repetitions on the control and healed specimens, there is no significant variation between the total and the permanent deformation. The resilient deformation decreases five folds after the healing process.

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