Experimental Study On Surface Steel-Reinforcement For Asphalt Pavements

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Abstract

The continuous increase of the number of heavy trucks with excessive axle load requires the implementation of new technologies, prolonging the longevity of road pavement. Therefore, Reinforcement grids have recently come into use in pavements in order to retard the distresses in the asphalt surface layers. The main objective of this research is to investigate the improvement of steel mesh used as reinforcement interlayer in asphalt layers to pavement performance through laboratory tests. Beams and slabs specimens of asphalt concrete mix are prepared, and tested with fatigue life and wheel tracking tests. The analysis of test results show that, the absence of reinforcement steel-mesh in Asphalt sample produces an improvement to the number of cycles and deformation rate for reinforced samples over the equivalent unreinforced samples, and the difference is significant at highest temperatures. The bottom location of steel mesh (bottom of wearing course layer) gives minimum deformation and maximum number of cycles to failure as compared with others locations of embedded grid. Depending on the ability of grids to reduce the development and growth of fatigue cracks; steel meshes can be used in asphalt concrete layers over weak layers or soft subgrade. Using steel grids in areas subjected to high shear stress levels such as at intersections, sharp corners and/or steep grades, will reduce the development of permanent deformation.

Keywords: *Asphalt Reinforcement, Steel netting, Fatigue cracking, Rutting, Wheel tracking*

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الخلاصة :

الزيادة المستمرة لعددِ الشاحناتِ الثقيلةِ ذات الحمل المحوري المفرطِ يتطلّبُ تطبيقَ تقنياتِ جديدةِ لإطالة عمر سطح الطريق.لذا دَخلتَ شبكاتُ التسليحِ حيّز الاستعمال مؤخراً في الأرصفةِ السفلتية،لكي تُعيقَ التشققات في طبقاتِ القيرَ السطحيّةَ ،والتي تحدث لأسبابِ مختلفة.الهدفَ الرئيسيَ هذا البحثِ أَنْ يَتحرّى تحسينَ الشبكةِ الفولاذيةِ إلى أداءِ الطبقات الاسفلتية للطريق خلال إختباراتِ معينة اجريت في المختبرِ . إستعملت المواد المتوفرة المحليّة في هذا

العمل ،واستخدمت الشبكات الفولاذية كطبقات بينية للتسليح، واعدت نماذج عتبات وبلاطات كعينات للفحص، واختبرت باستخدام فحص الكلل وفحص العجلة المتحركةبعد تحليل نَتائِجِ الإختبار اكتشف ان وجود شبكةِ التعزيزِ الفولاذيةِ في عيّنةِ القيرِ يُنتجُ تحسيناً إلى عددِ مرات الحمل المتكرر ونسبةِ التشوه للعيناتِ المدعومةِ بعكس العيناتِ الغير مدعومةِ المكافئةِ، والإختلاف واضح جدا في درجاتِ الحرارة العاليةوجد ان موقع الشبكةِ الفولاذيةِ أسفل الطبقة السطحيةِ يَعطي تشويهاً أدنى وعددَ أكبر مِنْ مرات الحمل المتكررِ إلى الفشلِ بالمقارنة مع مواقعَ آخرى لشبكةِ التسليحِ . علاوة على ذلك، يُطيلُ هذاالموقعِ حياةَ رصيفِ القيرَ بشكل ملحوظ ضدّ تَصَدُّعات التقلّمِ في عمر الطريق.أوصتْ الدراسةُ إلى إستعمال الشبكاتِ الفولاذيةِ في طبقات القيرِ الخرسانيةِ المنشأة فوق الطبقاتِ الضعيفةِ أَو الترب الطينية الناعمةإعتمادا على قدرةِ الشبكاتِ لتَقليص تطورِ ونمو تشققات الكلل ، ان استخدام الشبكاتِ الفولاذية سوف يقلل من التشوهات الدائميةِ في المناطقِ التي تتعرض إلى إجهادِ قصٍّ عاليٍ كما في التقاطعاتِ والمنحدرات الحادّةِ .

1. Introduction

Interlayer systems have been successfully utilized to retard cracking. An additional thin layer, called interlayer, is laid down at an interface between the overlay and an existing pavement or within the HMA overlay. Various materials are used for interlayer systems depending on their mechanisms to control propagation of cracks and distresses.

Interlay systems have five distinct functions as; reinforcement, stress relief, separator, filter, and moisture barrier. Among these functions, reinforcement and stress relief are the main functions related to preventing cracking. As for reinforcing a HMA overlay, interlayer systems consist of stiffer materials than the surrounding HMA overlay and compensate for a lack of tensile strength. Woven geosynthetics such as geogrid and metallic grid are typically used as reinforcement. On the other hand, stress relief interlayers made of soft materials are used to dissipate strain energy by deforming themselves (Al-Qadi et al., 2003). The primary effect of grid reinforcement is to hold the two sides of developing crack together. If the two ends are held together it will result a reduction of the stresses and strains at the tip of the crack region. The reduction in stress and strain decreases the propagation rate of the cracks and thus increases the time until a bottom crack reaches the surface.

2. Review of Literature

Many of literature on mesh reinforcing of flexible pavements, show that the main aim of the reinforcing is to prevent reflective cracking in asphalt overlays, although some products may achieve one or more of the following objectives within the pavement:

- Prevents reflective cracking, by acting as a barrier against crack propagation
- Maintains uniform load distribution over a cracked layer
- Provides shear resistance against rutting especially in high stress locations
- Improves the fatigue resistance of the asphalt layer
- Additional bearing capacity

In order to implement steel reinforcement mesh in new road construction and rehabilitation design, recent researches has aimed at quantifying the contribution made by the steel reinforcement to the structural capacity and service life of the pavement.

Vanelstraete and Franken (1993) concluded, from the results of two-dimensional (2D) finite element (FE) analysis, that metallic grid interlayer reduced tensile strain at the bottom of the overlay induced by thermal loading and then delayed crack initiation time *(Baek and wang, 2003).*

The first successful application of steel reinforcement in HMA overlay in the U.S.A. was conducted at the Virginia Smart Road by Al-Qadi et al. (2003). They examined the benefit of the steel reinforcement by field observations and FE analyses. (Al-Qadi and Elseifi, 2004).

They reported that steel reinforcement netting increased the service life of overlays between 50% and 90%. Also, steel reinforcement netting reduced maximum transverse strain at the bottom of an HMA overlay of 100mm thick by 15% due to vehicular loading and by 20% due to one cycle of daily temperature variation of 22^{o}C to 51^{o}C.

Montepara et al, (2005) studied the mechanical performances of steel mesh reinforced pavement through numerical modeling, laboratory and field tests. The laboratory tests were performed using two experimental test setups specifically designed for avoiding size effect problems. The experimental stretch consisted of two sections realized with the same pavement reinforced (at 8 cm depth) and unreinforced; both sections were monitored by strain gages placed with the mesh between binder and base layers; the sections were regularly monitored by means of an equipped vehicle able to highlight the cracks on the surface. The finite element model was developed using the program ABAQUS 6.4; three-dimensional 8 node brick elements were used for the asphalt layers, the steel reinforcement was modeled using 3D beam elements; the modeled portion was 500x500x230 mm as shown in **Figure (2.8).** The comparison between the stress levels of both the reinforced and unreinforced specimens obtained from the FEM analysis and those obtained from laboratory tests shows a very good agreement.

Baek and Al-Qadi (2006) evaluated the role of single steel reinforcement wire in a two-layered beam specimen on delaying crack development by numerical analysis. Crack initiation time was delayed and growth rate decreased since the steel reinforcement held and redistributed concentrated stress around a crack tip. They mentioned that the role of the steel reinforcement was affected by interface conditions, HMA material properties and temperature.

Vacri, (2007) presents an overview of the main results obtained from worldwide researches carried out by Universities around the world on pavements reinforced with steel mesh reinforcements, the main results of the researches are:

- Nottingham university : the fatigue life of a reinforced pavement improves by a factor up to 3
- Cagliari university: the reinforcement increases the pavement life by a factor between 3 and 12

- Virginia Tech. university: the crack initiation factor is improved by a factor between 1.15 and 3.6
- Catania university: the crack initiation factor improvement varies between 1.36 and 1.52
- Parma university: the surface cracking is reduced of 65%
- Palermo University: stresses due to shear actions (rutting) are reduced by 50%.

Table (1) shows an overview of the main parameters adopted by researchers for FE modeling.

Table (1) Details of the Adopted FE Models (Vacri, 2007)

University	FE code	Materials Behaviour [1]	Modelled portion (mm)
Nottingham	Capa-2D	VE	400x200x90
Cagliari	Ansys	EP	960x960x770
Virginia Tech.	Abaqus 5.8	VE	560x38000
Catania	Supersap	E	5940x5845x3040
Parma	Abaqus 6.4	VE	500x500x230
Palermo	Ansys	EP	640x830x640

[1] VE=viscoelastic, EP=elastoplastic, E=elastic

3. Materials properties

The materials used in this study are widely available and currently used in road paving in Iraq except the steel meshes that are available in local market in Baghdad.

3.1. Asphalt Cement

The asphalt cement used in this study is of (40-50) penetration grade, and brought from Daurah Refinery. **Table (2**) shows the physical properties of Asphalt Cement.

Table (2): Physical Properties of Asphalt Cement.

Test	*ASTM Des.*	*Unit*	*Penetration -Grade (40-50)*	*S.C.R.B Limits for (40-50) pen. Grade*
Penetration (25˚C, 100g, 5sec)	D5	1/10 mm	47	40-50
Ductility (25˚C, 5 cm/min).	D113	cm	119	≥ 100
Softening point (ring & ball).	D36	˚C	52	50-60
Flash point (cleave land open cup)	D92	˚C	250	≥232
Solubility in trichloroethylene	-----	%	99.5	>99

3.2. Aggregate

The (crushed) aggregate used in this work is brought from Al-Nibaee quarry. The physical properties of the aggregate (coarse and fine) are shown in **Table (3).** One type of mineral filler is used: ordinary Portland cement. It is thoroughly dry and free from lumps or aggregations of fine particles.

Table (3): Physical Properties of Nibaee Aggregates.

Property	*ASTM Designation*	*Coarse Aggregate*	*Fine Aggregate*
Bulk Specific Gravity	ASTM C127 and C128	2.46	2.6303
Apparent Specific Gravity	ASTM C127 and C128	2.602	2.6802
Percent Water Absorption	ASTM C127 and C128	0.45	0.5
Percent Wear (Los-Angeles Abrasion)	ASTM C131	7.1	……

3.2.1. Aggregate Gradation

Two types of aggregate gradation have been use in his study as shown in **Table (4)** and **Figure (1)**, The selected gradation follows the mid band gradation of the SCRB specification (2003), for Hot-mix Bituminous paving mixtures for (12.5 mm and 19 mm) aggregate maximum sizes (wearing layer and Binder Layer gradations).

Table (4): Gradation of the Aggregate for Surface Course.

Sieve Size	*Sieve Opening (mm)*	*Percentage passing by Weight of total Aggregate*			
		Finer Surface Course			
		Wearing course	*Specification Limit [S.C.R.B]*	Binder course	*Specification Limit [S.C.R.B]*
3/4	*19*	*100*	*100*	*100*	*100*
1/2	*12.5*	*95*	*90-100*	*95*	*90-100*
3/8	9.5	*83*	*76-90*	*83*	*76-90*
No.4	*4.75*	*59*	*44-74*	*68*	*56-80*
No.8	*2.36*	*43*	*28-58*	*50*	*35-65*
No.50	*0.3*	*13*	*5-21*	*36*	*23-49*
No.200	*0.075*	*7*	*4-10*	*12*	*5-19*

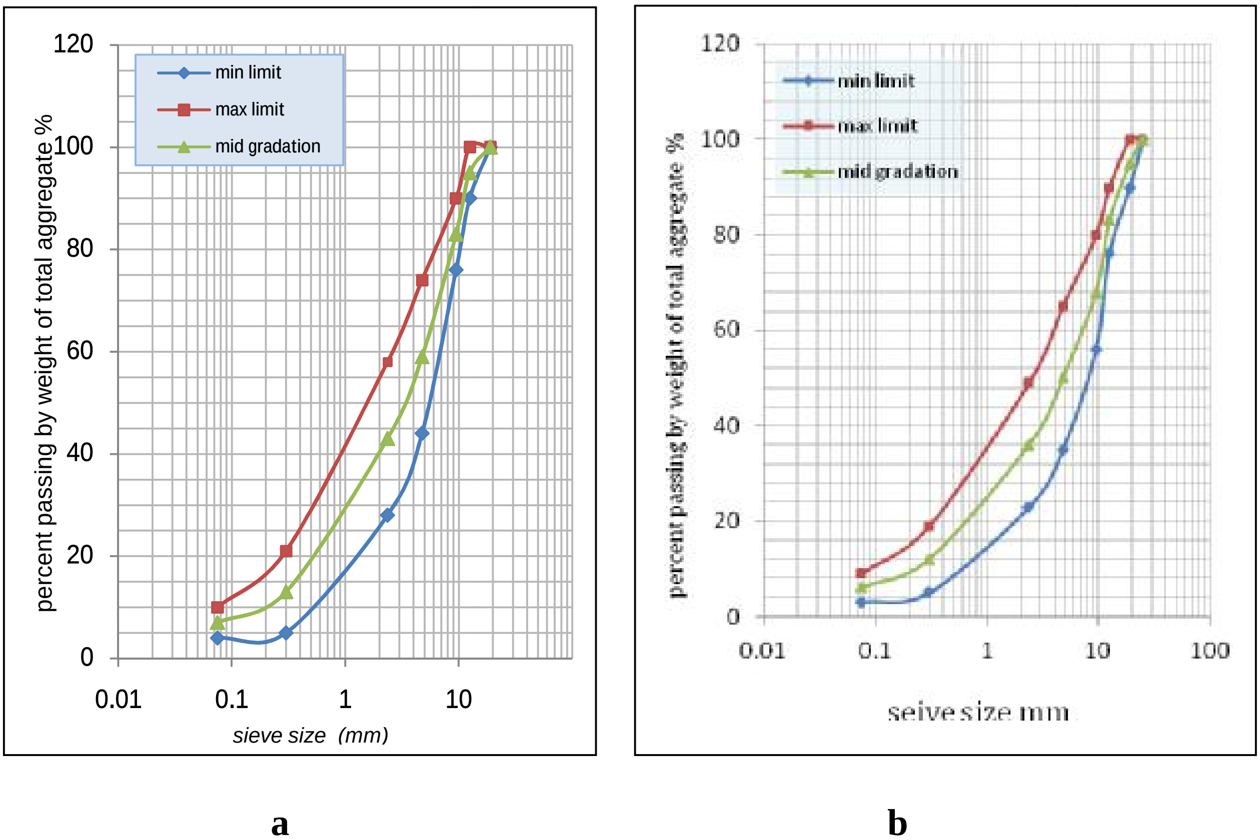

Fig. (1) Specification Limits of (SCRB, 2003) and Selected Mid Point Gradation for (a) Wearing Course Layer (b) Binder Course Layer

3.3. Steel Wire Netting

Configuration of the current reinforcement wire netting consists of a double-twist, hexagonal shape, galvanized steel wire netting. These meshes are available in local markets and proposed to be used in this study as a reinforcement interlayer. **Figure (2)** shows the configuration of the steel meshes used in this research.

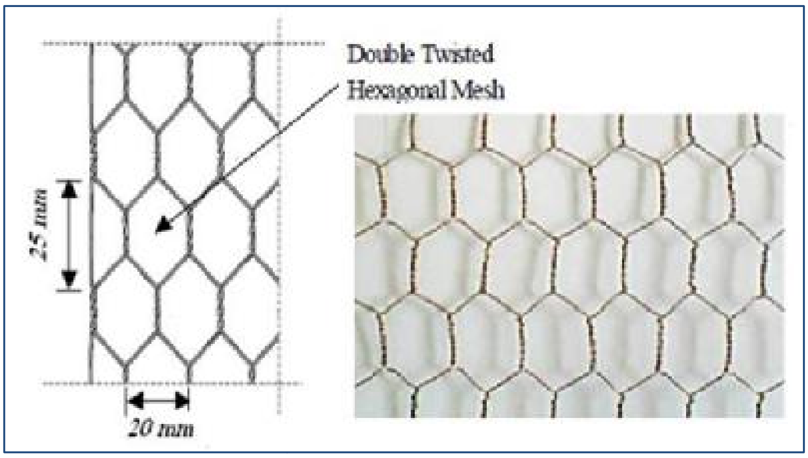

Fig. (2) Configuration of Current Steel Wire Reinforcement Netting

The hexagonal mesh size is 20 by 25 mm (nominal); the wire is protected against corrosion by a zinc coating. The mesh thickness varies between the 2mm wire diameter up to 4.1 mm in the double twist.

3.4. Mix Design

Marshall Mix Design is used to obtain the optimum content of Asphalt binder, This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D 1559).

The optimum asphalt content for wearing and binder layers is found to be 4.9 and 4.8 respectively. Marshall Properties of (wearing and binder) mixes were meeting the standard Iraqi specification requirements (SCRB, R/9 2003) as shown **in Table (5).**

Table (5) O.A.C for Two Layers and S.C.R.B. Specification Limits

Properties	*Wearing Layer*	*S.C.R.B Specification Limits*	*Binder Layer*	*S.C.R.B Specification Limits*
Bulk Density (gm/cm^3)	2.343	———	2.344	———
Marshall Stability (KN)	12.8	8 min.	10.11	7 min.
Marshall Flow (mm)	4.06	2-4	3.85	2-4
Air Voids in Mix (%)	4.30	3-5	3.80	3-5
Voids in Mineral Aggregate (%)	17.94	14 min.	17.36	13 min.

4. Testing Methods

The experimental program conducted in this work was designed through laboratory tests to investigate and evaluate the effects of reinforcing asphalt mixtures with steel wire netting against the main expected distresses in flexible pavement. Specifically the following test methods were considered in the program of this work:

4.1. Fatigue Cracking Test

Several tests methods are usually used for measuring fatigue parameters by using simple flexure tests. The current research used the flexure test of asphalt beam sample under third point bending. The mean advantage of beam fatigue under third point loading is that a larger portion of the specimen is subjected to uniform stress; therefore the result will reflect the weaknesses of HMA (Huang, 2004).

In order to study the fatigue characteristics of the reinforced asphalt mix, asphalt beams samples are made. The asphalt mixture beam has a length of 15 in(38.1 mm), a width of 3 in (76.2 mm), and a total height of 4in (10.16 cm) made of two layer, binder layer height (60 mm) and wearing Layer (40 mm) and steel mesh layer. For reinforced beam samples case, the steel mesh is placed at different locations during the compressed process, one embedded at bottom of binder layer and other embedded between layers, and beam samples with two reinforcement grid layers.

The AASHTO T321-03 (AASHTO 2006) protocol defines fatigue failure point as "the load cycle at which the stiffness of the specimen reduces 50% relative to the initial stiffness". The crack retardation phenomenon in a reinforced Paving system is observed when cracks physically reach the embedded grid (Lee, 2008).

Fatigue life (N_f) of the tested asphalt beams is defined as the number of cycles at which a complete failure of the lower layer of the beam and cracks physically reach the upper Layer of the beam. To calculate the flexural stresses and flexural tensile strain, the equations below are performed in this work (Huang, 2004):

§ *The flexural stress (σ):*

$$\sigma = \frac{3aP}{bh^2} \quad (1)$$

Where: P = Applied load, b = Width of the beam, h = Height of the specimen (i.e., total height of the two layers), a = L/3, and L = Clear span of the flexural specimen.

§ *flexural Tensile Strain (ε):*

$$\varepsilon = \frac{12\delta h}{(3L^2 - 4a^2)} \quad (2)$$

Where: δ = Maximum deflection at the center of beam, h = Height of the specimen, a = L/3, and L = Clear span of the flexural specimen.

The repeated flexural bending was tested by using pneumatic repeated Load system apparatus (PRLS), which was manufactured by Albayati, (2006). The manufactured apparatus have comprehensive testing capabilities that permit fatigue and stiffness (resilient modulus) testing. (Albayati, 2006). Plate (1) and **Figure (3)** show the pneumatic repeated load system apparatus and loading configuration of beam sample.

Plate (1) Pneumatic Repeated Load System Apparatus PRLS

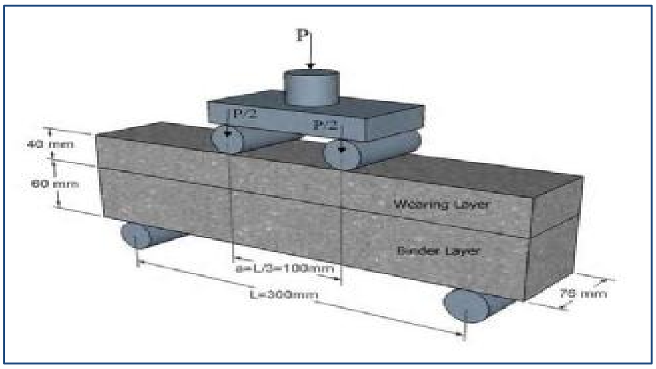

Fig. (3) Loading Configuration of Beam Sample

4.2. Permanent Deformation Test

Rutting is the major distress in flexible pavements in Iraq as a result of increased axle loads, and high local summer temperature. The accumulation of plastic deformations in asphalt layers is now recognized to be one of the major components of rutting in flexible pavements. Asphalt mixture rutting occurs when a lower layer does not rut yet the pavement surface exhibits wheel path depressions as a result of compaction and mix design problems.

Asphaltic slab samples are prepared for measure the rutting of reinforced and unreinforced asphalt mixture. The asphalt mixture slabs has a length of 350 mm, a width of 250mm, and a thickness of 50 mm, and prepared of one wearing Layer and the steel mesh as reinforcement grid. The wheel tracking apparatus is used for rut depth test of asphaltic mixtures samples reinforced with steel mesh. The response data of wheel tracking test is the number of cycles to reach rut depth of 25 mm (Nf) and the rate of deformation (TR) for the reinforced and unreinfor ced slabs.

The wheel tracking apparatus consists of a loaded wheel, which bears on a sample held on a moving table. The table reciprocates with simple harmonic motion through a distance of 230 ± 5 mm with a frequency of 53 passes per minute. The wheel is fitted with a solid rubber tire of outside diameter 200 mm. The wheel load under standard conditions is 700 ± 10 N. The wheel tracker is fitted with a temperature controlled cabinet with a temperature range of 30°C to 65°C, and a 25 mm stroke LVDT transducer is included for monitoring rut depth in the centre of a sample during a test, as shown in **plate (2).** The deformation and sample temperature is recorded by the internal data acquisition and control system.

Plate (2) Sample Hold under Wheel and LVDT Transducer to Monitoring Rut Depth

5. Testing Results Analysis and Discussion

5.1. Fatigue Life Test Results

The effect of test condition (temperature and stress levels), asphalt binder content, and embedded depth of reinforcement grid, on number of repetitions that causing fatigue failure for the asphalt mix specimens are explained in the followed figures.

Figure (4) shows the relationship between the stress level and the number of repetitions to failure for unreinforced and different reinforced samples at 25°C testing temperatures.

It can be seen from the above mentioned figures that; when the stress level increases, the fatigue life reduces. This can be related to the decreasing of sample stiffness and the absence of reinforcement mesh in sample, which gives additional strength to the beam specimen against the increasing of stress level.

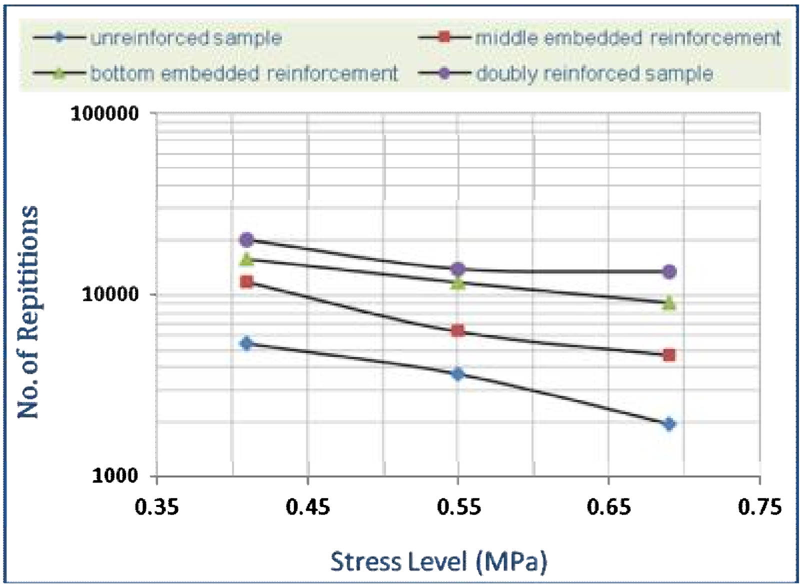

Fig. (4) Effect of Stress Level on Fatigue Life at 25°C

Figure (5) shows the relations between number of cycles to failure and flexural tensile strain at each stress level under testing temperature of 15°C and 25°C, respectively.

When the temperature increases to be more than 20°C, the effectiveness of the reinforcement and its role to increase fatigue life will be clear. In addition, when the reinforcement mesh embedded at the bottom of sample for the binder mix, the cracks will be enforced to initiate and propagate bottom-up.

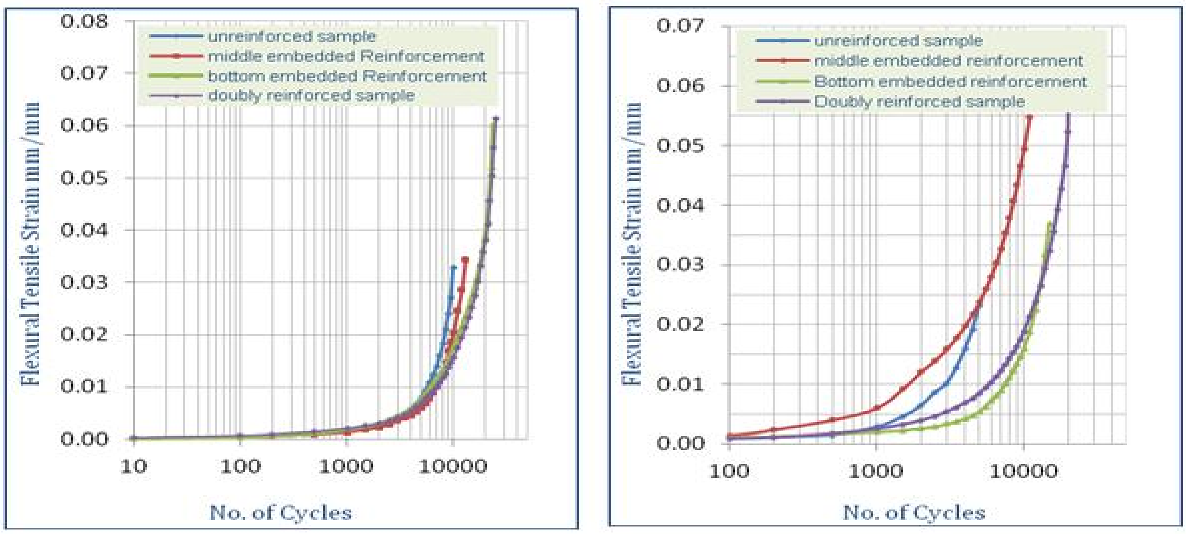

Fig. (5) Relation between Flexural Tensile Strain and Number of Cycles for Testing Temperatures 25°C (Right) and 15°C (Left)

Figure (6) shows the effect of increasing in asphalt content on the average fatigue life at testing temperature of 25° C. It can be seen that fatigue life increases as the asphalt content increases. This can be related to the increasing in thickness of asphalt film which leads to decreases in tensile strain at the bottom of beam sample for binder mixes then increasing the number of repetition to failure accordingly.

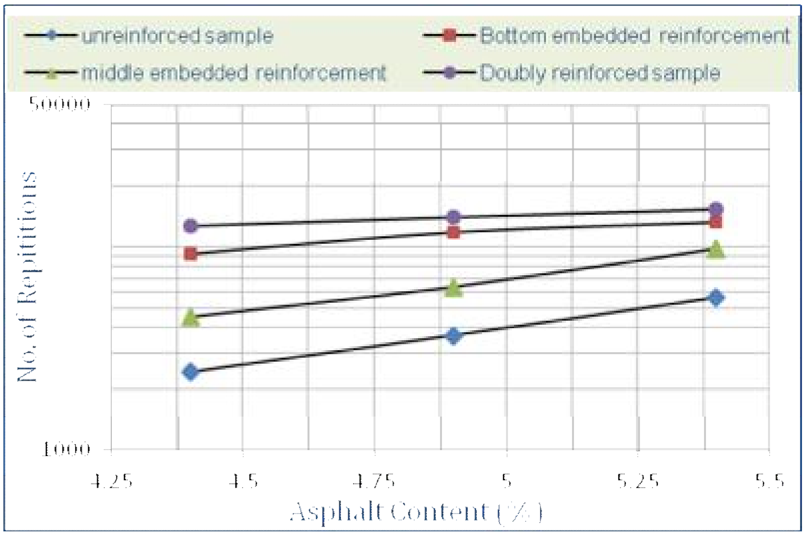

Fig. (6) Effect of Asphalt Content on Fatigue Life at 25°C

Increasing in asphalt content from 4.4% to 4.9% will increase number of repetitions by 16.9 %, 43.5%, 28.5% and 14.8% in unreinforced sample, middle embedded mesh, bottom embedded mesh and doubly reinforced sample respectively. In addition, increasing of asphalt content from 4.9% to 5.4% will increase number of repetitions by 7.4%, 9.4%, 8.2% and 7.9% for unreinforced sample, middle embedded mesh, bottom embedded mesh and doubly reinforced sample respectively.

Mesh reinforcement had great role in increasing of fatigue life (No. of repetitions to failure) of asphalt mix for each temperature, which can be seen more evident in **Table (6).**

Table (6) Increasing Percentage factor in the Number of Repetitions for each Stress Level and Embedded depth of Reinforcement grid at 25°C Testing Temperature.

Stress level (MPa)	Reinforcement embedded between layers	Reinforcement embedded at bottom of layers	Double reinforced sample
0.41	120	195	273
0.55	72	221	281
0.69	141	366	593

Middle embedded mesh between layers in beam samples decreases the tensile stresses under wearing mixes and above the binder mixes which then increase the fatigue life accordingly. Bottom embedded mesh at binder mixes shows an increasing in the number of cycles more than that for middle embedded mesh.

Embedded the reinforcement mesh at the bottom of asphalt concrete mixture for the binder course enforces the initiation and propagation of cracks to be bottom-up. This decreases the tensile strain at the bottom of asphaltic mix and increasing the number of cycles to initiate the cracks, as shown in **Plate (3).**

Plate (3) Failures of Beams Samples: A-Unreinforced Sample, B-Bottom Embedded Reinforcement, C- Middle Reinforced Samples, D-Doubly Reinforcement

5.2. Permanent Deformation Test Results

The effect of test condition (testing temperatures), asphalt binder content, and embedded depth of reinforcement grid, on number of cycles to reach a 25mm rut depth for the asphalt mix specimens are explained in the followed figures.

Figure (7) shows the variation of number of cycles due to the change in testing temperatures for the reinforced and unreinforced samples at optimum asphalt binder content. The results of the optimum asphalt binder samples show that the increasing of testing temperature from 30°C to 45°C decreases the number of cycles by 79.6% 72% and 67.3% for unreinforced, middle and bottom embedded grid samples respectively. Furthermore, increasing the temperature from 45°C to 60°C decreases the number of cycles by 75.1% 62.4% and 58.7% for unreinforced, middle and bottom embedded grid samples respectively.

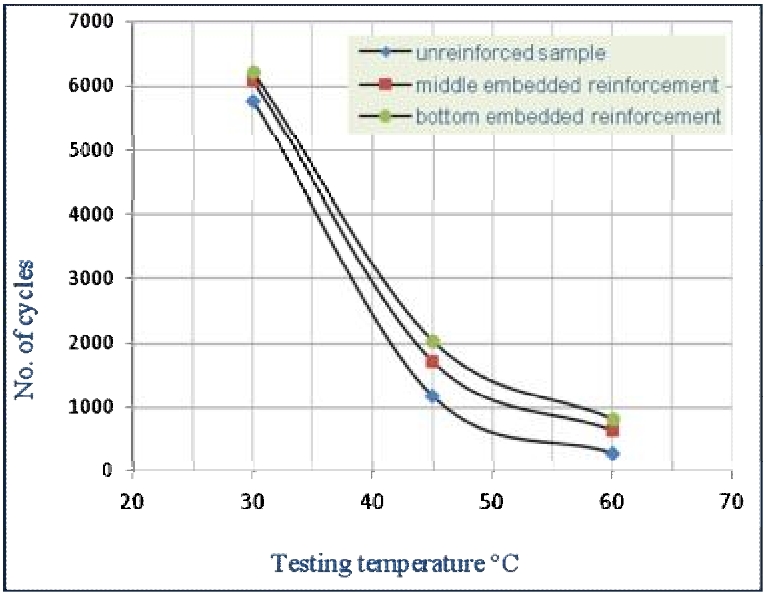

Fig. (7) Effect of Testing Temperatures on the Number of Cycles to 25 mm Rut Depth

Figure (8) shows the effect of testing temperatures on the rate of deformation for reinforced and unreinforced samples.

It can be seen from the mentioned figures the role of reinforcement grid in increasing the number of cycles and controls the rate of deformation as the increasing progress of temperatures.

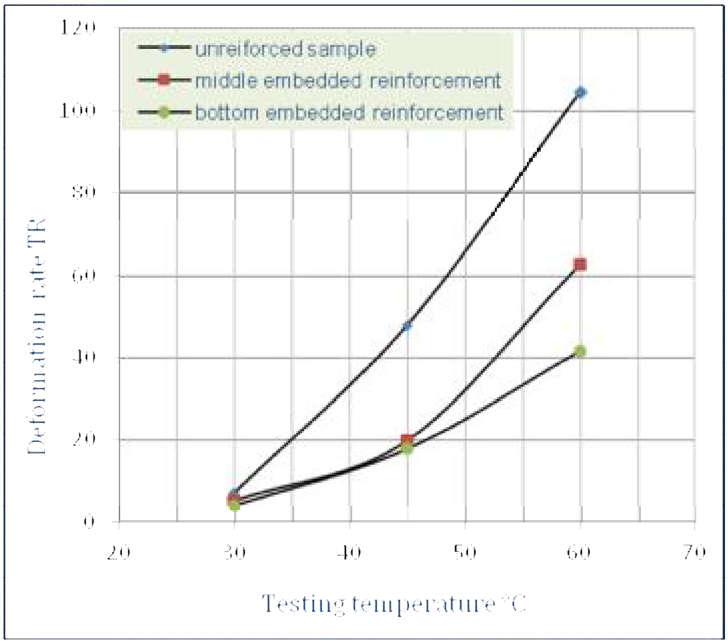

Fig. (8) Effect of Testing Temperatures on the Rate of Deformation to 25 mm Rut Depth for 4.9% Asphalt Content.

Figures (9) shows the effect of depth of embedded grid for the reinforced slabs at each testing temperature, which represented by the traffic benefits ratio (TBR).

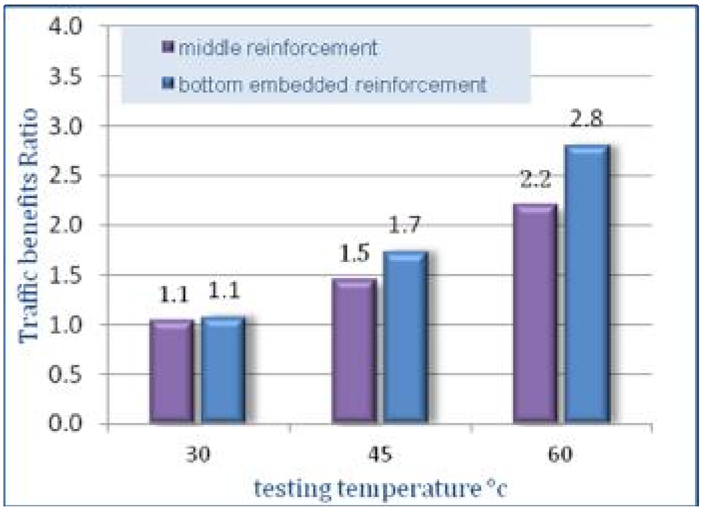

Fig. (9) Effect of Reinforcement grid location on Traffic Benefit Ratio (TBR) for Different Temperatures

The last mentioned figure show that; at intermediate temperatures, approximately the same effectiveness of reinforcement location can be noticed, while the effectiveness of reinforcement grid increases at highest temperatures. **Plate (4)** shows the tested slab samples after wheel tracking test.

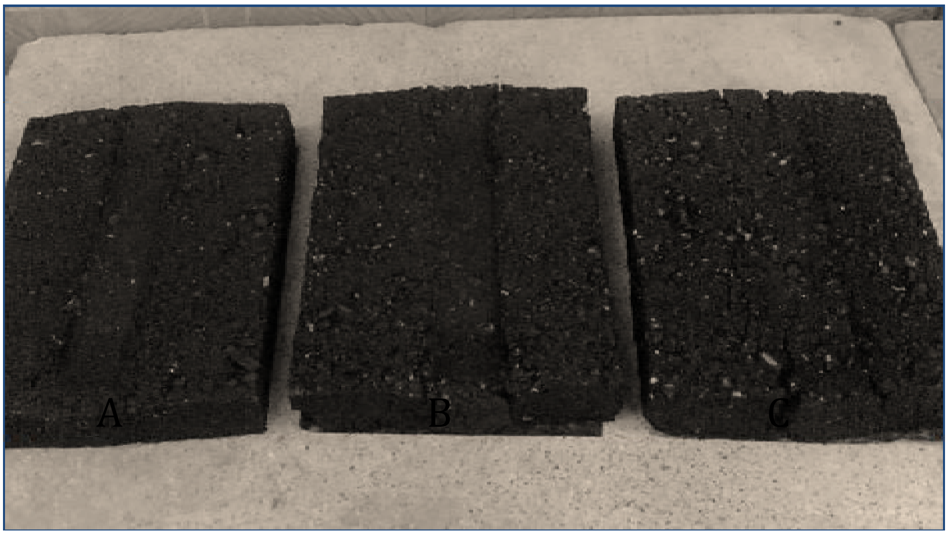

Plate (4) Slab Samples after Testing with Wheel Tracking Device: A-Bottom Embedded Reinforcement, B-Middle Embedded Reinforcement, C-Unreinforced Samples

Table (7) lists the values of wheel cycles for reinforced and unreinforced samples at each asphalt content. This table shows that the increasing in asphalt content show decreasing in number of cycles to failure.

Table (7) Number of Cycles for Samples at 4.9% and 5.4% Asphalt Content

Asphalt Content	*Temperature °C*	*Unreinforced sample*	*Middle embedded grid*	*Bottom embedded grid*
4.9 %	*30*	*5772*	*6089*	*6226*
	45	*1274*	*1718*	*2032*
	60	*292*	*646*	*818*
5.4%	*30*	*5671*	*5972*	*6138*
	45	*986*	*1664*	*1916*
	60	*230*	*581*	*774*

6. Conclusions

Within the limitations of materials and testing program used in this work, the following principal conclusions are made based on the findings of this investigation:

1. The following items describe the results of the fatigue test;

§ The inclusion of reinforcement in beam sample produces increasing in number of cycles especially at a testing temperature higher than 20°c. This can be related to the decreasing in stiffness of asphaltic mix for wearing and binder courses which present the role of reinforcement to be more effective

§ Mesh reinforced samples tended to produce multicracks because it distributed stresses over a wide Area while unreinforced specimens showed single cracks in a localized area.

§ Embedded the reinforcement mesh at the bottom of asphalt concrete mixture for the binder course enforces the initiation and propagation of cracks to be bottom-up. This decreases the tensile strain at the bottom of asphaltic mix and increasing the number of cycles to initiate the cracks.

2. The overall results of wheel tracking test show that;

§ The results show an improvement in the number of cycles and deformation rate for reinforced slab samples over the equivalent unreinforced slabs ,and the difference is most significant at the highest temperatures,

- The failure of the unreinforced slabs was manifested as shear distress with the asphalt forced out beneath the machine wheel and slabs edge to such an extent, that it was pushed out of the holders confining the asphalt slabs.
- Excessive shear, as in the unreinforced slab, was not observed. The reinforced slabs were intact after the rutting tests indicating a positive contribution of the grids to the rut resistance of the slab.
- Rut development in the reinforced slabs was evident; furthermore the rut on the slabs with the bottom embedded mesh being slightly less than that on the slabs with the middle embedded mesh but this was a result of consolidation.

3. The improvement provided by steel mesh reinforcement is manifested primarily at intermediate and high temperatures rather than low temperatures. At high temperatures, HMA is compliant and exhibits a viscous behavior, so the asphalt mixture performance decreases, allowing the grids to work by increasing both the maximum strength and the failure strain.

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