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EFFECTS OF TEMPERATURE AND CREEP ON THE PERFORMANCE OF SUBGRADE LAYER

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Abstract: The creep of clayey subgrade soils is understood to be a process of deformation progressing in time under a constant stress and temperature. Owing to the creep of subgrade layer, stress redistribution occurs with a subsequent drop of the strength, and hence decreases in the value of the safety factor of the pavement structure. In addition, the seasonal variation in temperature in the subgrade layer tends to change throughout the pavement's life. The influence of temperature on the behavior and properties of subgrade soils influences pavement performance, and distress of pavement structures. Experimental investigation of creep in a clayey subgrade layer under constant stress, with consideration of variation of temperature and dry density is a very difficult task. Therefore, despite of urgency of the problem, little has been published on this matter. Therefore it is important to investigate, and study effects of combined temperature and creep characteristics of the response of subgrade pavement layer performance by using oedometer apparatus to analysis creep behavior of pavement layers under effect of different temperatures. Based on the results of this study it is concluded that, the increase in the temperature from 20 ^{o}C to 70^{o}C causes an increase of (52, 55.9 and 56.1%) in the creep strain of the seventh day from applying load for soil sample, asphalt sample and combined sample respectively. The higher creep strain value can be noticed in the asphalt specimens, while the lowest strain can be shown in soil samples. If the creep strain is recorded after seven days from applying constant stress for asphalt and combined samples and compared with soil specimens, it is noticed that the strain increases with: (50% and 37.5% for 20 ^{o}C, 49.6% and 40.2% for 40 ^{o}C, 56% and 46.3% for 60 ^{o}C and 53.9%, 42.7% for 70 ^{o}C) for asphalt and combined (soil under asphalt layer) samples respectively.

Keyword: *Creep, Temperature, Secondary Settlement and Subgrade*

تأثير الحراره والزحف على اداء طبقة تربة التبليط

الخلاصة: مفهوم الزحف للتربه الطينيه التحتيه هو عمليه تشوه تتقدم في الوقت تحت ضغط وحراره ثابته. نتيجة لزحف طبقة التربه التحتيه, يحدث أعادة توزيع الاجهادات ويلاحقه أنخفاض في المقاومه, وبالتالي يقل عامل الأمان لمنشأ التبليط. وبالاضافه الى ذلك, فان التغييرات الموسميه في درجة الحراره لطبقة التربه التحتيه تؤثر على عمر التبليط. تأثير الحراره على تصرف وخواص التربه التحتيه تؤثر على أداء التبليط, والضرر لمنشأ التبليط. التحريات المختبريه للزحف لطبقة التربه الطينيه التحتيه تحت الاجهاد الثابت, مع الأخذ بنظر الاعتبار الكثافه الجافه والاختلاف في درجة الحراره هي مهمه صعبه للغايه. لذلك على الرغم من خطورة المشكله, تم نشر القليل بشأن هذه المسأله. لذلك من المهم التحري, ودراسة تأثير اتحاد خصائص الزحف والحراره

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على أستجابة أداء طبقة تربة التبليط من خلال استخدام جهاز Oedometer لتحليل تصرف الزحف لطبقات التبليط تحت تأثير درجات الحراره المختلفه. اعتمادا على نتائج هذه الدراسه تم استنتاج, بأن الزياده في درجة الحراره من 20°C الى 70°C يسبب زياده في التشوه لفحص الزحف. الزياده في درجة الحراره من 20°C الى 70°C يسبب زياده بقيمة الزحف بنسبة (52, 55.9 and 56.1%) لليوم السابع من تسليط الحمل لعينة التربه, عينة الاسفلت والعينه المركبه على التوالي. اعلى قيمة للزحف يمكن ملاحظتها في عينات الاسفلت, في حين ادنى قيمه للتشوه تظهر في عينات التربه. اذا تم تسجيل تشوه الزحف بعد سبعة أيام من تسليط الاجهاد الثابت لعينات الاسفلت والعينات المركبه ومقارنتها مع عينات التربه, نلاحظ بان التشوه يزداد ب: (50 and 37.5)% for 20°C,(49.6 and 40.2)% for 40°C, (56 and 46.3)% for 60°C and (53.9%, 42.7)% for 70°C لعينات الاسفلت و العينات المركبه (تربه تحت طبقة الاسفلت) على التوالي.

1. Introduction

Flexible pavement system consists of an asphalt concrete layer, a base layer and a sub-base layer placed on the subgrade [1]. Pavement structural layers responses such as; stresses, strains and deflections, are highly dependent on the support provided by the subgrade soil. A large percentage of the surface deflection of a pavement layers is a direct result of the support provided by the subgrade soil. Subgrade layer may distort underneath heavy traffic load and lead to distress in the upper layers of pavement structure. So, the major purpose of subgrade layer is to supply support to pavement structure [2].

The strength of the flexible pavement is determined by the quality of the materials used and the stiffness of flexible pavement is also affected by changes in the weather or season in the area.

Temperature variation in pavement layers plays an important role in the performance of flexible pavement system. The surface layer is usually made of hot-mix asphalt (HMA), which is a viscoelastic material and its behavior is highly related to its temperature, i. e., HMA responds like an elastic solid under low temperature and strain conditions; on the other hand, it also acts as a viscous material at high temperature in the sense that the deformation due to traffic loading cannot fully recover within a finite time period under the unloading condition.

Also, temperature variation within pavement subgrade layer influence pavement load carrying capacity and Loss of support conditions (i.e., a reduction in stiffness) in this layer and is one of the contributors to pavement distress [3].

In subgrade soil, the major component of strain is the alteration of particles spacing, these spacing may be changed not only by means of applied stress, but also due to environment alteration [4].

When the load is applied to subgrade soils, it will be shared between water and soil, this load will gradually be transferred from water to soil such that the entire load will be carried by soil particles resulting in consolidation associated with subgrade soil settlement. The time involved in this transfer is the hydrodynamic time lag which is related to water volume drained out of the soil during consolidation, length of drainage path, soil permeability, compressibility and applied stresses. Soil compression continues to occur even after dissipation of the excess pore water pressure and no change in the applied stresses take place. This is called the secondary compression (creep) whose occurrence is related to the time-dependent strain properties of soil skeleton.

The exact reasons of this compression may be related to continuous reorientation of particles which are influenced by water bleeding out of soil skeleton. As the soil remains under constant effective stress for longer time it becomes denser and more stable with reserved resistance against further compression [4]. After watching the unacceptably large distortions, and its impact on normal exploitation of roads and structures, creep deformations in clayey soils began to be important by scientists and researchers. It can say that the creep of clayey soils became interesting problem in soil mechanics through the last century, and generally through the last few years [5]. Since most soils in Iraq are clay soils and because of the hot climate in most seasons of the year, therefore, it is necessary to study the effect of combined temperature and creep characteristics of the response of pavement layers performance.

In this study, oedometer apparatus was used to analysis creep behavior of pavement layers under constant load over a specified period of time at various degrees of temperature (20, 40, 60 and 70˚C). Finally, the pavement must provide smooth riding quality with adequate skid resistance and have adequate thickness to ensure that traffic loads are distributed over an area so that the stresses and strains at all levels in the pavement and subgrade are within the capabilities of the materials at each level.

2. Aims And Scope Of The Study

The main objective of the presented study is to evaluate the effect of creep characteristics on the response of subgrade pavement layer under the influence of static stress with variation in degrees of temperature.

3. Soil Creep

Terzaghi [6] reported two different types of creep movements, namely seasonal creep who affects only shallow surface layers during seasonal change in moisture and temperature, and the “mass creep” or “continuous creep.” The “mass creep” or “continuous creep” is a consequence of the ground stresses (gravitational force).

Landslide displacement and slope stability of cohesive soils are correlated to the creep deformation and creep strength behavior of the soil [7].

Paritzek and Woodruff [8] suggested that the term soil creep includes downslope processes which are not readily recognizable, but which are deduced as being present.

Godfrey [9] noted that the average rate of movement was 2.71 cm per year on a 35 degree slope. In summary, Godfrey [9] work reveals the downward slope creep rate increases as the slope angle increases.

Creep is a continuous deformation of soil under constant loading [10]. According to the acting stress it is possible to divide creep behavior into volumetric and deviatoric (or shear) creep. Volumetric creep is caused by the constant volumetric stress and deviatoric creep is caused by the constant deviatoric stress. There is also a different way of dividing the creep behavior, shown in Figure (1), which is based on the type of the strain-time behavior. According to the shape of the strain-time curve, one can divide creep into the primary, secondary and tertiary phases [5]. The primary phase, in some literature also called transient or fading, can be defined as a creep deformation during which the strain rate decreases continuously with time. Deformation at a constant rate (material flow) is denoted as the secondary phase, and sometimes also called non-fading. In the case of the tertiary or the accelerated phase the strain rate is continuously increasing and this leads to the creep rupture [5]. Generally, volumetric creep consists only of the primary phase of the creep deformation, i.e. it tends to stabilize. Deviatoric creep may or may not consist all three phases, depending on the shear mobilization. If the deviatoric stress is low, then the only primary creep phase will appear, but after crossing some level of the shear mobilization, primary phase will be followed by the secondary phase which can lead to the tertiary phase and creep rupture [5].

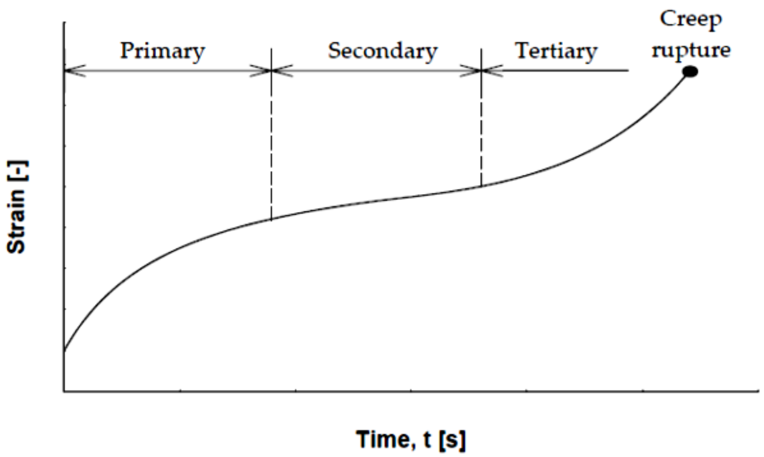

Figure 1. Primary, Secondary and Tertiary Phases of the Creep [5].

The most common type of creep tests may be done by means of odometer tests generally used to investigate the behavior of the so-called “secondary” compression [11]. Only a few tests were performed on direct simple shear apparatus [12]. Other than the tests stated above, most of the tests used for investigating the creep behavior of soil are triaxial compression tests.

4. Secondary Settlement

This type of settlement is defined as the reduction of volume at the influence of the continuous increase of effective stress due to adjustment of the soil structure which continues even after the essential dissipation of the excess pore water pressure. In the time-dependent deformation (secondary consolidation), the coefficient of secondary consolidation $C\alpha$, is helpful in determining the creep settlement at the end of primary consolidation and is often considered to be the slope of the linear portion of the void ratio (or compression) versus the logarithm of time curve in the secondary compression region. The value of secondary compression (creep) for a variety of natural soil deposits expressed by Mesri [13] in terms of:

$$\varepsilon\alpha = C\alpha / (1+e) \quad (1)$$

$$C\alpha = \Delta e / \Delta \log t \quad (2)$$

Where (e) is the void ratio for soil ranges between 0.1% and 10%.

Based on the coefficient of secondary consolidation, Mesri [13] classified the secondary compressibility, and this is summarized below in table 1.

Table 1 Classify the Secondary Compressibility [13].

$C\alpha$	secondary compressibility
<0.002	Very low
0.002-0.004	Low
0.004-0.008	Medium
0.008-0.016	High
0.016-0.032	Very high

5. Laboratory Tests

5.1 General

The experimental work is carried out on soil sample obtained from AL- Sader city in the east of Baghdad city. This sample is taken from (2-4m) depth below the natural ground surface then packed in nylon bags. The soil sample transferred to the soil mechanics laboratory, Faculty of Engineering, Al-Mustansiriya University, as well to Andrea Engineering Testing Lab. to conduct testing, where it is mixed well by hand before conducting the tests to be more homogeneous.

The physical properties of soil are shown in Table 2.

Table 2 Physical properties of Soil used

Index property	No. of standard specification	Index values
Liquid limit (L.L.) %	ASTM D4318	39
Plastic limit (P.L.) %	ASTM D4318	24
Plasticity index (P.I.) %	ASTM D4318	15
Specific gravity (Gs)	ASTM D854	2.65
Gravel (larger than 4.75mm) %	ASTM D422-63	0
Sand (0.075 to 4.75mm) %	ASTM D422-63	20
Silt (0.005 to 0.075 mm) %	ASTM D422-63	59
Clay (less than 0.005mm) %	ASTM D422-63	21

AASHTO Classification	AASHTO M145-82	A-6
Unified Soil Classification System (U.S.C.S.)	ASTM D2487	CL
Maximum dry unit weight (kN/m3)	ASTM D1557-12	18.8
Optimum moisture content (%)	ASTM D1557-12	13.5

5.2 Creep Test

The consolidation apparatus for soils is employed to perform this test. The creep test specimens, 75mm in diameter and 19 mm in height, are prepared in accordance with ASTM D2435 at optimum moisture content of the modified compaction curve.

The soil specimen is placed inside a steel rigid ring to avoid an occurrence of lateral expansion, by press the cutting ring, sharp cutting edge downwards into the compaction mold until its upper most rims are just below the soil surface. By means of hydraulic jack, eject the sample gently and cut the soil at the level of the cutting edge of the cutter of the consolidation ring, then, trim the excess soil with top and bottom edges of the ring, using straightedge.

Drainage is achieved by two porous discs, located at the top and bottom of the consolidation ring. The bottom disc functions as a base and the top as a piston, transmitting an external load to the specimen. Saturated filter papers were placed between the specimen and the porous stones to prevent any clogging of the porous stone by clay particles. To avoid friction between the ring and soil specimen, oil is used. All the specimens had been allowed to be saturated under the effect of various temperatures (20, 40, 60 and 70˚C); each degree of temperature remained constant until the end test for each specimen. Then, the samples are loaded with (100 kPa) static constant stresses. Creep tests continued under the effect of the constant stated stress and temperature for period seven days. This test is carried out to study the effect of static load and temperature over a specified period of time and measurement of the resulting strain.

6. Result and Discussion

The coefficient of secondary compression Cα represent the slope of the last part of the curve for the relationship between log time and deformation, defined as the unit strain above one decade of the log time scale, and calculated from equation below:

$$C\alpha = \frac{\Delta H/H}{\Delta \log t} \qquad (3)$$

Figure (2) displays the deformation-log time curves for defining the coefficient of secondary consolidation under constant pressure100 kPa for various temperatures, the value of Cα at 70˚C is found to be (0.021) and reductions gradually with temperatures (60, 40and

20°C) to (0.018, 0.014 and 0.011) respectively, as indicated that by Craig [14] when the temperatures increases and thickness of the oedometer sample decreases, the value of secondary compression increases. Also, in Head [15] observed that when the temperature increases will cause increases in the amount of the secondary compression.

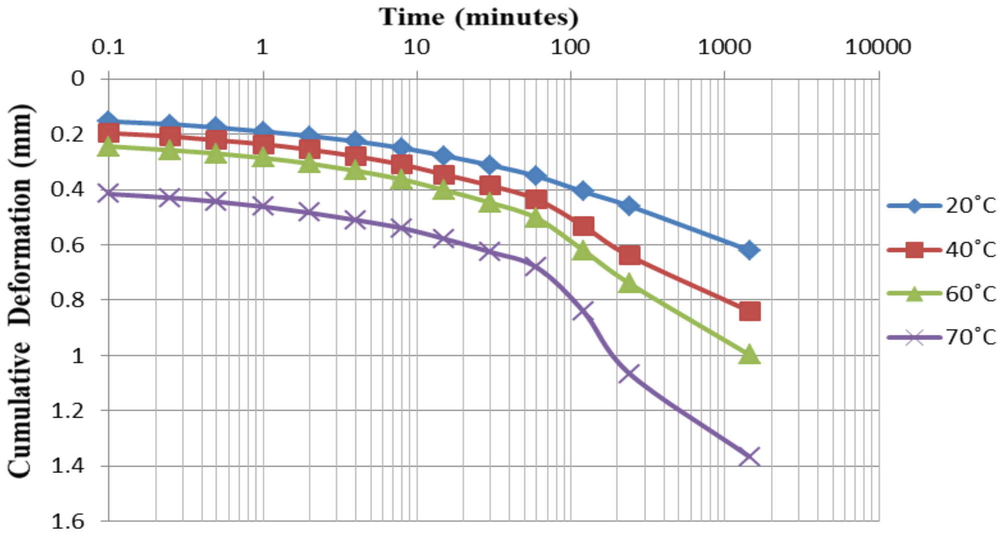

Figure 2. Log Time-Deformation Curve at Different Degrees of Temperature for Constant Stress 100kpa.

In this test three types of samples are prepared; (soil, asphalt , soil under asphalt layer) each sample is loaded with constant pressure 100 kPa for seven days under the effect of various temperatures; (20, 40, 60, 70°C).

Figures (3), (4) and (5) show the correlation between the cumulative strain and log time for soil, asphalt, soil under asphalt layer (combined samples) respectively at different degrees of temperature. For 70°C the strain is the highest one if compared with the other temperatures and reductions gradually with temperatures; (60, 40and 20°C) respectively for all samples.

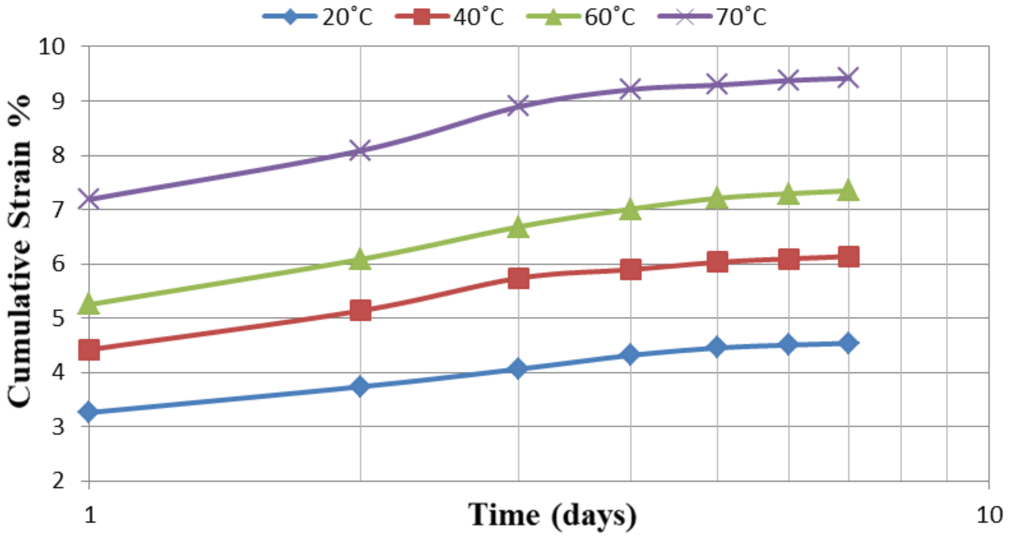

Figure 3. Cumulative Strain versus Log Time for soil Samples.

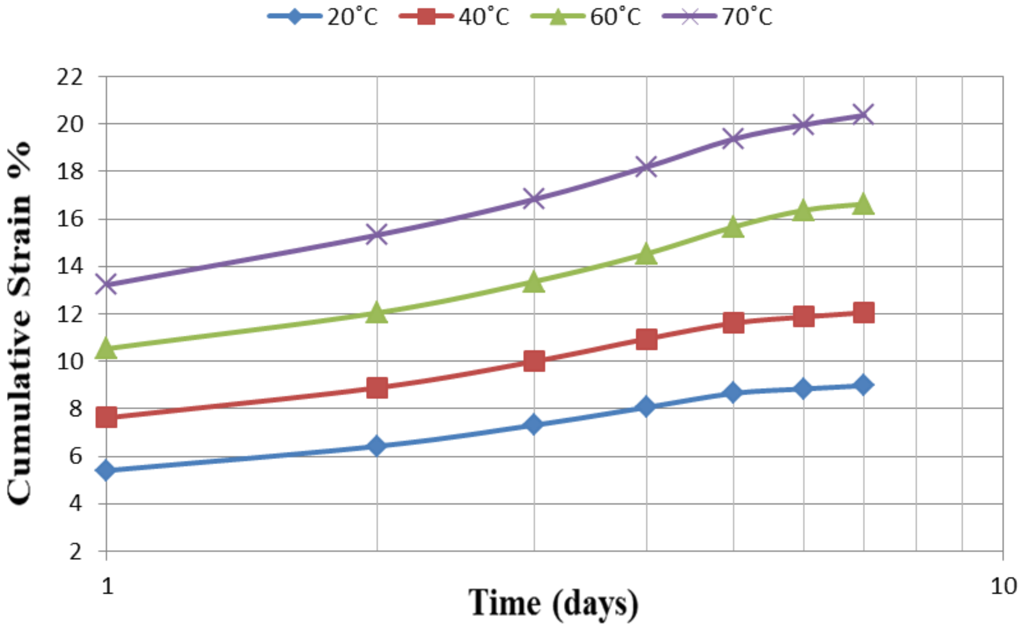

Figure 4. Cumulative Strain versus Log Time for Asphalt Samples.

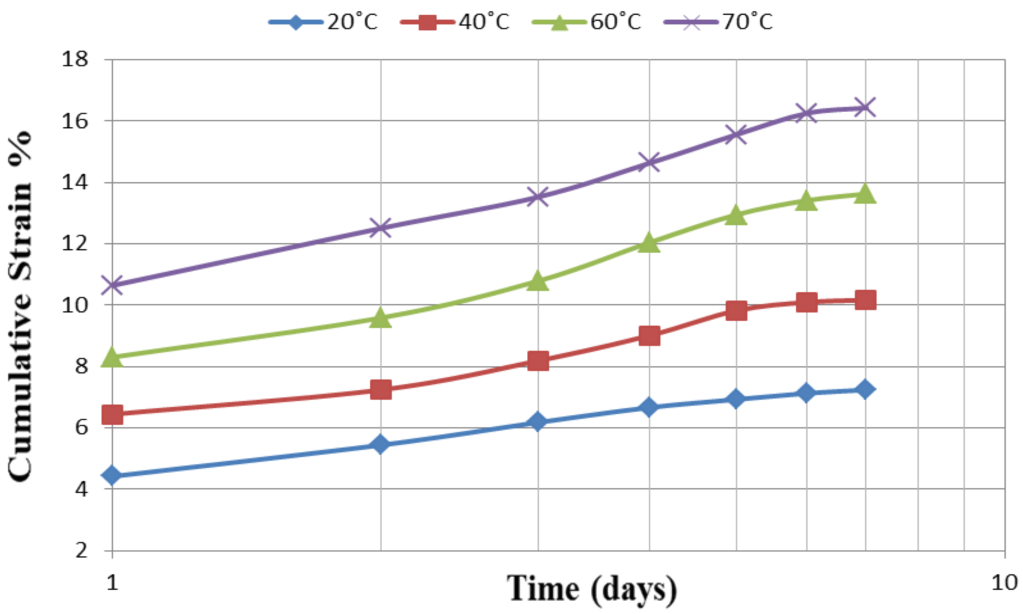

Figure 5. Cumulative Strain versus Log Time for Combined Samples.

In the above figures (3), (4) and (5) it is clearly noticed that the creep in high temperatures is higher than creep in low temperatures for all samples. Creep strain at the seventh day from applying load increases with (52%, 55.9% and 56.1%) when increasing the test temperature from 20°C to 70°C for soil, asphalt and combined samples respectively. The higher creep strain value can be noticed in the asphalt specimens, while the lowest strain can be shown in soil samples. If the creep strain is recorded after seven days from applying constant stress for asphalt and combined samples and compared with soil specimens, it is noticed that the strain increases by: (50% and 37.5% for 20°C, 49.6% and 40.2% for 40°C, 56% and 46.3% for 60°C and 53.9%, 42.7% for 70°C) for asphalt and soil under asphalt layer samples respectively. The reason for the increases creep with increases temperatures for soil samples may be caused by continued reorientation of particles which are influenced by water bleeding out of soil skeleton. Viscosity depends on temperature, and the viscosity of water at 35˚C is about half that at 5˚C [15]. So, when increases temperatures the viscosity of the water decreases and the time for dissipation of pore water pressure from soil skeleton was faster, allowing the solid particles to move closer together, and hence increases settlement. For asphalt samples, also it is observed that the creep in high temperatures is higher than creep in low temperatures because the paving asphalt has two basic properties, elastic and viscous, depending on temperature and time of loading. Under fast traffic even on a warm day it works as elastic but in parking areas and under a stationary tire load, it works as viscous which flow under the load and trend the pavement to rut. As a result of increased temperature, a decrease in asphalt stiffness due to a decrease in viscosity, and hence increases rutting. It is noticed that the creep results in asphalt samples higher than the combined samples (soil under asphalt layer) because subgrade soils is to provide support to asphalt layer.

7. Conclusions

1. It is concluded that; the strain values for creep test increases when increasing test temperature from 20°C to 70°C.
2. Creep strain at the seventh day from applying load increases with (52%, 55.9% and 56.1%) when increasing the test temperature from 20°C to 70°C for soil, asphalt and combined samples respectively.
3. Higher creep strain value can be noticed in the asphalt specimens, while the lowest strain can be shown in soil samples. If the creep strain is recorded after seven days from applying constant stress for asphalt and combined samples and compared with soil specimens, it is noticed that the strain increases by: (50% and 37.5% for 20°C, 49.6% and 40.2% for 40°C, 56% and 46.3% for 60°C and 53.9%, 42.7% for 70°C) for asphalt and soil under asphalt layer samples respectively.

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