BEHAVIOR OF PERMANENT DEFORMATION IN ASPHALT CONCRETE PAVEMENTS UNDER TEMPERATURE VARIATION

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ABSTRACT
Rutting is recognized to be the major distress mechanism in flexible pavements as a result of increase in tire pressures and axle loads. Rutting is caused by the accumulation of permanent deformation in all or some of the layers in the pavement structure. The accumulation of permanent deformation in the asphalt surfacing layer is now recognized to be the major component of rutting in flexible pavements. This is a consequence of increased tire pressures and axle loads, which subjects the asphalt surfacing layer nearest to the tire-pavement contact area to increased stresses.
This research evaluates information on the permanent deformation characteristics of asphalt-aggregate mixtures, with an emphasis on laboratory test techniques for measuring mixture resistance to permanent deformation.
A comprehensive laboratory study was carried out using aggregate gradation for asphaltic surfacing course according with specification limit of SORB/R9, four percentage of asphalt cement were trialed in order to determine the optimum asphalt content for asphalt mixes, four levels of temperatures to accommodate the influence of temperature conditions and three levels of stresses. Uniaxial creep loading strain chosen as performance test to measure the permanent deformation of asphalt mixes. The results show that the temperature has a significant effect on permanent strain and, therefore, temperatures employed for design are relatively high to reproduce the most unfavorable pavement conditions.

KEY WORDS: Asphalt Paving Mixture, Permanent Deformation, Creep Test.

الخلاصة
ظاهرة التخدد من المشاكل الرئيسية في الطرق الإسفلتية نتيجة لزيادة في ضغط الإطارات والحمولات المحورية ويتكون نتيجة لتراكم التشوهات الدائمية في كل أو بعض من طبقات الرصف الإسفلتي . يتناول هذا البحث دراسة لخصائص التشوهات الدائمية في الخلطات الإسفلتية باستخدام الفحوصات المختبرية اللازمة لذلك .
تم اختيار تدرج الركام للطبقة السطحية وفقا للمواصفات العامة للطرق والجسور (الجزء التاسع) ومن بين أربع نسب للإسفلت تم إيجاد المحتوى الأمثل له بالإضافة إلى ذلك تم اخذ أربع درجات حرارة لمعرفة تأثيرها على التشوهات الدائمية تحت تأثير الاحمال المختلفة كما وبينت النتائج التأثير الكبير لدرجات الحرارة على اداء الخلطات الاسفلتية وعلى ضوء ذلك وضعت الاستنتاجات.

INTRODUCTION
Permanent deformation in the form of rutting is one of the most important distress (failure) mechanisms in asphalt pavements. With the increase in truck tire pressure in recent years, rutting has become the dominant mode of flexible pavement failure. Pavement rutting, which results in a distorted pavement surface, is primarily caused by the accumulation of permanent deformation in all or a portion of the layers in the pavement structure. Rutting can also be caused by wear of pavements resulting from use of studded tires. Longitudinal variability in the magnitude of rutting

causes roughness. Water may become trapped in ruts resulting in a reduced skid resistance, increased potential for hydroplaning and spray that reduces visibility. Progression of rutting can lead to cracking and eventually to complete disintegration or failure. Rutting accounts for a significant portion of maintenance and associated costs in both main highways and secondary roads (**Rabbiva Garba, 2002**).

Premature rutting in the form of shear flow of asphalt concrete, being the consequences, has directly been effecting the pavements service life, riding quality and their economic life cycles cost. True prediction of asphaltic material behaviors and their precise selection on the basis of performance can be one of the solutions towards this chaotic problem. At higher temperatures i.e. 40 °C and above, the rutting susceptibility of asphalt mixes needs to be studied in the laboratory before its laying at site. Comprehensive laboratory investigation is required, to study the influence of physical and mechanical properties of aggregates on rutting resistance or the permanent deformation behavior of asphalt mixes (**Imran Hafeez, 2009**).

The economics of truck transportation has caused the average gross weight of trucks to increase so that a majority of trucks are operating close to the legal axle loads limits. In countries where enforcement of the legal axle load limits is relaxed or non-existent (typical of developing countries), trucks operate at axle loads, which by far exceed the legal axle load limit. As axle loads have increased, the use of higher tire pressures has become more popular in the trucking industry. Higher tire pressures reduce the contact area between the tire and the pavement, resulting in high stress which contributes to greater deformation in flexible pavements, manifested as severe wheel track rutting. As a consequence of the increased tire pressure and axle load, the surfacing asphalt layer is subjected to increased stresses, which result in permanent (irrecoverable) deformations (**Rabbiva Garba, 2002**).

Rutting of hot mix asphalt (HMA) pavement at or near intersections is very common both in cold and hot climates. Obviously, the problem is more acute in hot climates compared to cold climates because the stiffness of HMA decreases with increase in pavement temperature. In most cases, there is no significant rutting in the same asphalt pavement structure away from the intersections under fast moving traffic (**Prithvi S. Kandhal, 1998**).

OBJECTIVES:

The objectives of this study are to:

- Evaluate of available information about the permanent-deformation characteristics of asphalt concrete. Particular emphasis is placed on methodologies which permit prediction of the amount of rutting which develops in asphalt-bound layers under the repetitive action of traffic.
- Describe the mechanism and problems of permanent-deformation of asphalt paving mixtures.
- Describe the factors which can be minimize permanent deformation in asphalt mixture and using uniaxial creep test method which is utilized to assess the resistance of asphalt mixtures to permanent deformation with variation in degrees of temperature.
- Describe the effect of temperatures and applied stresses on permanent deformation in asphalt mixture.

PERMANENT DEFORMATION IN FLEXIBLE PAVEMENT:

Permanent deformation in asphalt (flexible) pavements, commonly referred to (rutting and shoving): rutting, usually consists of longitudinal depressions in the wheel paths, which are an accumulation of small amounts of unrecoverable deformation caused by each load application as shown in **Figure 1** (**Asphalt Institute,1996**). If an asphalt mixture ruts, it is normally because the mixture has insufficient shear strength to support the stresses to which it is submitted (**Sousa *et al.* 1991**).

Eisemann and Hilmar studied asphalt pavement deformation phenomenon using wheel tracking device and measuring the average rut depth as well as the volume of displaced materials below the tires and in the upheaval zones adjacent to them. They concluded that:

1. In the initial stages of trafficking the increase of irreversible deformation below the tires is distinctly greater than the increase in the upheaval zones. Therefore, in the initial phase, traffic compaction or densification is the primary mechanism of rut development.
2. After the initial stage, the volume decrease below the tires is approximately equal to the volume increase in the adjacent upheaval zones. This indicates that most of the compaction under traffic is completed and further rutting is caused essentially by shear deformation, i.e., distortion without volume change. Thus, shear deformation is considered to be the primary mechanism of rutting for the greater part of the lifetime of the pavement.

There are three mechanisms that might be involved in a rut developing, that is, plastic movement, mechanical deformation, and consolidation. Plastic movement can occur either in the subgrade on which the pavement is placed, or in the asphalt concrete mixture itself. Plastic movement is normally identified by a depression near the center of the applied load with slight humps on either side of the load. The distance of the humps from the center of the rut will be an indication of the depth at which the plastic movement is occurring.

Mechanical deformation can occur when an element under the pavement surface loses its integrity for one reason or another, and is displaced under the load. A rut resulting from this type of action will generally be accompanied by substantial pattern cracking provided the distress is allowed to progress sufficiently. A rut caused by consolidation will normally be identified by a depression in the canalized path of the applied load without an accompanying hump on either side of the depression. It occurs because the layer in which the consolidation is occurring was not sufficiently compacted during construction, and receives further densification under repeated traffic loads. It can occur either in the sub grade, in the untreated base, or in the asphalt mix itself.

Shoving is defined as the horizontal displacement of an asphalt mixture. There are two principal mechanisms by which shoving can occur. The first is due to instability of the asphalt mixture which results in plastic flow of the mix under horizontal thrust. The instability, and the resultant shoving under load, most frequently is because of an excess amount of asphalt binder (low air voids) which is acting as a lubricant in the mix rather than as the binder. The second mechanism that can cause shoving is slippage in the mix under horizontal thrust. In this case, the adhesion between two layers of mix is insufficient to provide the proper shear strength along the plane between the two layers. Locations at which severe horizontal thrust occurs are braking areas (traffic coming to a stop sign), and uphill lanes on highways, particularly with large volumes of truck traffic. The principal contributing factor to instability in an asphalt mixture is excess asphalt content. The most common cause of a mix with insufficient shear strength is an over sanded mix, with insufficient filler, and with a low viscosity asphalt binder.

Asphalt pavements have a higher resistance to rapidly applied loads compared to slowly applied loads.

MINIMIZE PERMANENT DEFORMATION IN ASPHALT MIXTURE:

The following considerations in the asphalt mix design would generally minimize the rutting and shoving (permanent deformation) problems:

1. Lower Asphalt Content: Higher asphalt content is needed for improved fatigue life and durability of the asphalt mix, but it tends to enhance the rutting and shoving problems. The mix needs to be maximized for fatigue and permanent deformation through a compromise.
2. Coarser Gradation: Finer gradations or over sanded mixes are more susceptible to permanent deformation.
3. Angular and Rough Textured Aggregate: This is especially applicable to the fine aggregate fraction. It has been demonstrated by Kalcheff and Tunicliff and Brown and Cross that mixtures utilizing angular manufactured sand are more resistant to permanent deformation than mixes produced with rounded or sub rounded natural sand as refers by (**Prithvi S. Kandhal, 1998**) .

4. Increased Air Void Content: Mixtures with low voids in the mineral aggregate (VMA) and higher asphalt contents have a tendency to have very low air void contents after densification by traffic. Such mixtures lose stability after reaching a critical compaction level and start to rut and shove.
5. Higher Viscosity Asphalt Binder: An asphalt binder with a high viscosity at 60°C will be more resistant to horizontal thrust as far as plastic flow in a mix is concerned compared to a low viscosity asphalt binder.
6. Higher Fines Content: Increase in the minus 75 microns fraction of the mix will tend to stiffen (increase the viscosity) the binder.
7. Larger-Size Aggregate: At proper asphalt content larger-size aggregate (such as 19.5 mm) mix in the wearing course tends to be more resistant to permanent deformation.
8. Reduced Overlay Thickness: If the existing pavement is structurally sound (for example, Portland cement concrete), thicker asphalt mix overlays are unnecessary in the critical areas like intersections. Thinner overlays (for example, binder course can be eliminated) in these areas will minimize the problem.
9. Improved Bond between Pavement Layers: A lack of good bond between the pavement layers (especially in top 150 mm of the pavement) can cause slippage due to horizontal thrust.

BEHAVIOR OF PERMANENT DEFORMATION IN FLEXIBLE PAVEMENT

Researches in the history showed that rutting in the Hot Mix Asphalt (HMA) layer will generally occur within the top 3- to 5-in. If a poor quality HMA mixture is being used, increasing the thickness of this poor quality layer will not decrease the rutting in the HMA layer. In fact, improving the material properties and mix characteristics will be significant in decreasing the rut depth (**Kennedy. *et al*, 1996**).

For normal cross slope values, a rut depth of 12.5 mm (0.5 inch) is typically accepted as the maximum allowable rut depth (**Huang, 1993 & Kennedy, et al, 1996**).

Mechanistic-Empirical Design Guide (MEPDG) has defined three distinct stages for the permanent deformation behavior of pavement asphalt materials under a given set of material, load and environmental conditions. Primary stage has high initial level of rutting, with a decreasing rate of plastic deformations, predominantly associated with volumetric change. Secondary stage has small rate of rutting exhibiting a constant rate of change of rutting that is also associated with volumetric changes; however, shear deformations increase at increasing rate. While the tertiary stage has a high level of rutting predominantly associated with plastic (shear) deformations under no volume change conditions as shown in **Figure 2 (AASHTO Design Guide, 2002)**.

If an asphalt material is loaded with a stress that is above the flow strength of the material, at that temperature the material will start to deform (**Stumpf, 2007**). First the material will deform rapidly, then, after some strain hardening has taken place, the material gets to a stage with a lower creep rate as shown in **Figure 2**. This stage is known as secondary creep, or steady state creep. In the third stage the material becomes unstable and rapid collapse is the result (**Imran Hafeez, 2009**).

The proportion of permanent deformation taking place is as shown in **Figure 2**. In the different creep phases is important. The critical rut depth is generally set at 10 mm, if this depth is reached in the primary phase or in the first part of the secondary phase, the functional life of the Hot Mix Asphalt (HMA) layer is reduced drastically. In secondary phase, the rate of deformation slows down considerably.

EFFECT OF TEMPERATURE ON PERMANENT DEFORMATION

Temperature has been found to have a significant effect on rutting. **Hofstra and Klomp (1972)** determined from test-track measurements that rutting increased by a factor of 250 to 350 with a temperature increase from 68° F to140°F (20 °C to 60 °C). **Linden and Van der Heide (1987)** reported a significant increase in rutting in Europe during the very hot summers of 1975 and 1976. Researchers have recognized the need to conduct laboratory tests at temperatures within the high-

temperature range of those encountered in the field. **Bonnot (1986)** selected a test temperature 60°C for wearing-course asphalt concrete and 50°C for base courses.
These temperatures were chosen to be relatively high to reproduce the most unfavorable conditions expected in France.
Similarly, **Mahboub and Little (1988)** conservatively selected the hottest pavement profile to represent critical conditions (as refers by **Jorge B. Sousa 1991**). Other assumptions about the accumulation of permanent deformation in Texas pavements included the following:
1) Permanent deformation occurs daily over the time interval from 7:30 a.m. to 5:30 p.m.;
2) Permanent deformation occurs only in the period from April to October, inclusive; and
3) Permanent deformation can be ignored at temperatures below 50 °F.
At the same time, it must be emphasized that the states of stress and strain caused by traffic loading also significantly influence pavement rutting.

MATERIAL CHARACTERIZATION:

Hot Mix Asphalt generally consists of combination of different size of aggregates with mineral fillers, uniformly mixed and coated with asphalt cement, each having its own particular characteristics, which will be more suitable to specific design and construction purposes. Before designing asphalt paving mixes, selection, proportioning and characterization of individual material are imperative to obtain the desired quality and properties of finished mix. For the current study, crushed aggregates were obtained from the local source (Nibaee quarry) with maximum nominal size 12.5 mm, asphalt cement used with grade penetration (40-50) and Portland cement as mineral filler. Aggregates were sieved and recombined in the laboratory to obtain the selected gradation according to the SORB / R 9 as shown in **Figure 3**.

TEST METHODES:

Various test methods and procedures have been developed and used by researchers over several decades to characterize the permanent deformation behavior of asphalt concrete. These test methods may in general be classified in to five types.

- Uniaxial stress tests- unconfined cylindrical specimens in creep, repeated or cyclic loading.
- Triaxial stress tests- confined cylindrical specimens in creep, repeated or dynamic loading.
- Diametrical tests- cylindrical specimens in creep or repeated loading
- Shear stress tests -cylindrical specimens in shear creep or repeated loading
- Wheel track tests- slab specimens or actual pavement cross sections.

In this study Uniaxial Creep Test is used

UNIAXIAL CREEP TEST:

Creep test mostly involves the application of static load over a specified period of time and measurement of the resulting strain. This is considered to be the simplest way to investigate the permanent deformation characteristics of bituminous mixtures and is the most widely used test method for determining material properties because of its simplicity and the fact that many laboratories have the necessary equipment and expertise. Researchers conducted extensive studies using the unconfined creep test as the basis for predicting rut depth in asphalt concrete (**Van de Loo, 1974**). It was reported that the creep test must be performed at relatively low stress levels (within the linear range of the material) to obtain good comparisons between rut depths observed in test tracks and those calculated using creep test data. The need to use stress levels within the linear range has been attributed to the fact that the loading time in the field is small compared to the loading time in the creep tests.
Strain, measured as a function of the loading time at a fixed test temperature, is the usual output of the creep test. Results of the creep test, when expressed as relative deformation (measured change in height divided by the original height), are found to be independent of the shape of the specimen and of the ratio of height to diameter, provided the specimen’s ends are parallel, flat and well lubricated.

Specimens, 2 in. (50.8 mm) in diameter and 4 in. (101.6 mm) in height are prepared in accordance with ASTM - D1074. Then they are left to cool at room temperature for 24 hrs. The test period consist of 1 hour of loading followed by 1 hour of unloading.

RESULTS AND DISCUSSTION

A series of tests for Marshall stability, flow and density –voids analysis are carried for selecting the optimum asphalt content for mixtures using 7 percent Portland cement (by weight of total aggregate) as a filler and four different asphalt contents of (40-50) penetration grade from (4 to 6.4) percent (by weight of total mix) with an increment intervals of 0.8 percent, these specimens are prepared and tested for each mix variable. Marshall Properties at the selected optimum asphalt content (4.6) are shown below together with their corresponding test properties.

Bulk density ……………………………..2.338
Air voids…………………………………4.24 %
Stability……………………………….11.8 KN.
Flow…………………………………….2.9 mm.
Stiffness…………….……..……4.069KN/mm.

In order to evaluate the permanent deformation on asphalt concrete mixture, uniaxial creep test is conducted at three stress levels (0.034, 0.069, 0.103) MPa. The typical test temperatures (10 °C, 20 °C, 40 °C, & 55 °C) are adopted in the laboratory for research study to accommodate the influence of temperature conditions, the accumulative strain results at the certain time are summarized in **Tables 1, 2, and 3** as shown below.

All tables show that permanent strain increases with the increase in stress levels and temperature. The effect of temperature variation is significant as compared to stress levels. Results of Tables have been shown graphically in **Figures (4, 5, and 6).**

CONCLUSION

This summary research deals primarily with the ability of asphalt-aggregate mixtures to sustain imposed loads without permanent deformation. It considers the basic factors to minimize permanent deformation, laboratory tests for measuring mixture resistance to permanent deformation,. The following conclusions are based on the information presented herein.

- Rutting in pavements develops gradually with increasing wheel load applications and usually appears as a longitudinal depression in the wheel path with small shoulders to the sides. Rutting is caused by a combination of densification (decrease in volume and, hence, increase in density) and shear deformation: however, shear deformation rather than densification is considered to be the primary cause of rutting in properly constructed pavements.
- Rutting can be reduced by using materials that better resist permanent deformation and/or by controlling loading conditions either by varying the pavement structure or the vehicular characteristics (e.g., tire pressures) to avoid the critical states of stress that intensify rutting.
- Temperature has a significant effect on rutting and, therefore, temperatures employed for design are relatively high to reproduce the most unfavorable pavement conditions.
- At low temperature permanent strain increases by 55% with the increase in stress levels from low to highest value.
- permanent strain increases by 79% at the degree of temperature is 40 °C with the increase in stress levels from low to highest value.
- At degree of temperature is 55 °C the resistance of sample until 30 mints for loading time under effect of highest stress.

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Sieve No.		Surfacing Course Specification Limits	Passing Percentage %
inch	mm		
3/4	19	100	100
1/2	12.50	90-100	95
3/8	9.50	76-90	83
No.4	4.75	44-74	59
No.8	2.36	28-58	43
No. 50	0.30	5-21	13
No. 200	0.075	4-10	7

Table 1 Mean Accumulated Strain *10^-3(mm/mm) (εp) of Mixes at stress equal to 0.034 MPa

Time (min.)	Temperature, °C			
	10	20	40	55
0.10	0.2013	0.2282	0.5298	1.2519
0.25	0.2324	0.3449	0.6234	1.5828
0.50	0.3022	0.5012	0.9204	2.1149
1.00	0.4338	0.7898	1.0838	2.4021
2.00	0.5628	0.8619	1.2392	2.7132
4.00	0.6744	0.9737	1.5360	3.0873
8.00	0.7578	1.1086	1.8238	3.5573
15.00	0.9211	1.3507	2.2524	4.4918
30.00	1.0675	1.5763	2.3671	5.3422
45.00	1.1344	1.6558	2.4188	5.6225
60.00	1.1549	1.6849	2.4739	5.7534
unloading				
0.10	0.8367	1.1955	1.8290	4.2248
0.25	0.8142	1.1763	1.7619	4.1868
0.50	0.8093	1.1612	1.7435	4.1552
1.00	0.8074	1.1542	1.7267	4.1398
2.00	0.8001	1.1398	1.7047	4.1077
4.00	0.7945	1.1348	1.6943	4.0859
8.00	0.7860	1.1239	1.6869	4.0576
15.00	0.7830	1.1196	1.6782	4.0376
30.00	0.7815	1.1165	1.6681	4.0142
45.00	0.7790	1.1130	1.6602	4.0007
60.00	0.7780	1.1109	1.6569	3.9914

Table 2 Mean Accumulated Strain *10^-3(mm/mm) (εp) of Mixes at stress equal to 0.069 MPa

Time (min.)	Temperature, °C			
	10	20	40	55
0.10	0.2034	0.2552	1.7684	2.5922
0.25	0.2387	0.4648	1.9833	3.0154
0.50	0.3325	0.5882	2.5032	3.6854
1.00	0.5336	0.8098	3.1264	4.5866
2.00	0.7028	1.0602	3.6681	5.2532
4.00	0.8253	1.2385	3.9843	5.9441
8.00	0.9567	1.7752	4.4067	7.1188
15.00	1.0653	2.2280	4.9143	8.3165
30.00	1.2076	2.8950	6.3087	8.8348
45.00	1.3211	3.3154	6.9554	9.3241
60.00	1.4578	3.6114	7.5318	9.6328
unloading				
0.10	1.2456	3.3941	6.1351	6.8478
0.25	1.2159	3.3579	5.9566	6.6324
0.50	1.2023	3.3300	5.9138	6.5379
1.00	1.1976	3.2961	5.8854	6.4922
2.00	1.1945	3.2731	5.8497	6.4475
4.00	1.1891	3.2411	5.8133	6.4164
8.00	1.1822	3.2256	5.7724	6.3811
15.00	1.1781	3.1655	5.7432	6.3567
30.00	1.1732	3.0834	5.7068	6.3305
45.00	1.1690	3.0103	5.6715	6.3211
60.00	1.1631	2.9956	5.6143	6.3145

Table 3 Mean Accumulated Strain *10^-3(mm/mm) (εp) of Mixes at stress equal to 0.103 MPa

Time (min.)	Temperature, °C			
	10	20	40	55
0.10	0.5671	1.1895	2.4532	3.4521
0.25	0.7221	1.2933	2.9035	3. 8544
0.50	0.9074	1.4264	3.8567	4.6933
1.00	1.0351	1.9511	4.3611	5.3654
2.00	1.1691	2.2056	4.9033	7.6523
4.00	1.3270	2.7581	5.5632	9.1711
8.00	1.5253	3.1094	6.3854	11.0345
15.00	1.8037	4.0521	8.1385	12.8485
30.00	1.9752	4.7281	9.6351	14.3723
45.00	2.0844	5.1283	10.4365	
60.00	2.1351	5.3655	10.7352	
unloading				
0.10	1.8293	3.7266	8.5214	
0.25	1.7947	3.6436	8.2738	
0.50	1.7710	3.6186	8.2145	
1.00	1.7652	3.5910	8.1074	
2.00	1.7541	3.5472	8.0257	
4.00	1.7468	3.5138	7.9623	
8.00	1.7421	3.4988	7.9285	
15.00	1.7403	3.4772	7.8932	
30.00	1.7390	3.4614	7.8815	
45.00	1.7378	3.4524	7.8784	
60.00	1.766	3.4578	7.8632	

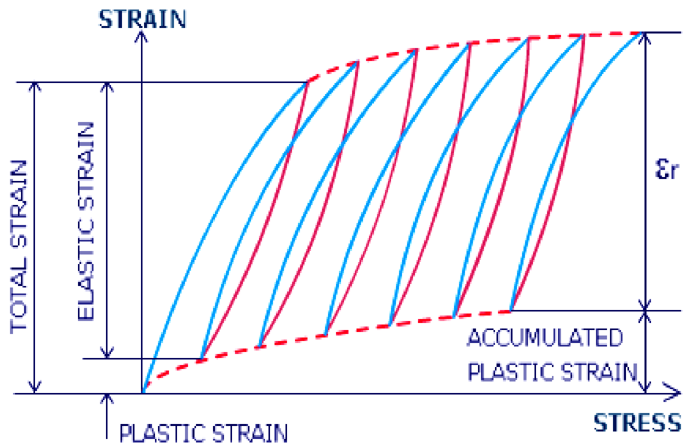

Figure 1 Accumulated Plastic strains in Pavements **(After Asphalt Institute, 1996)**

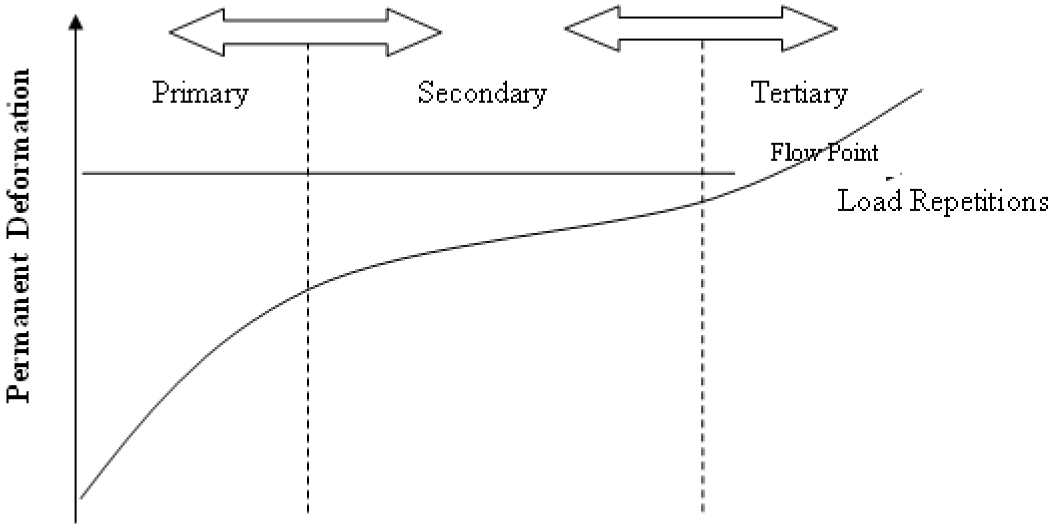

Figure 2 Typical Repeated Load Permanent Deformation Behaviors of Pavement Materials **(AASHTO Design Guide, 2002)**

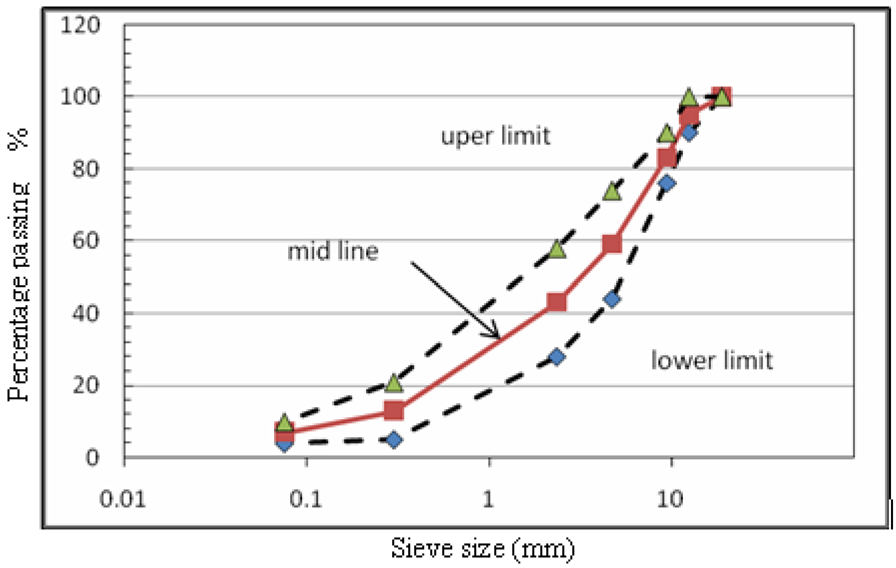

Figure 3 Gradations of aggregate according to the SORB / R 9 Asphalted Surfacing Course

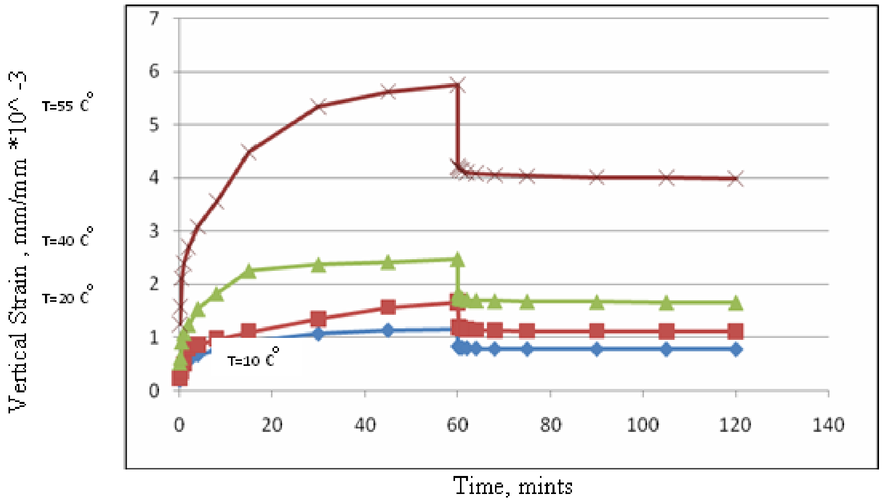

Figure 4 Influence of Temperature on Accumulated Strain at Stress Equal to 0.034 MPa

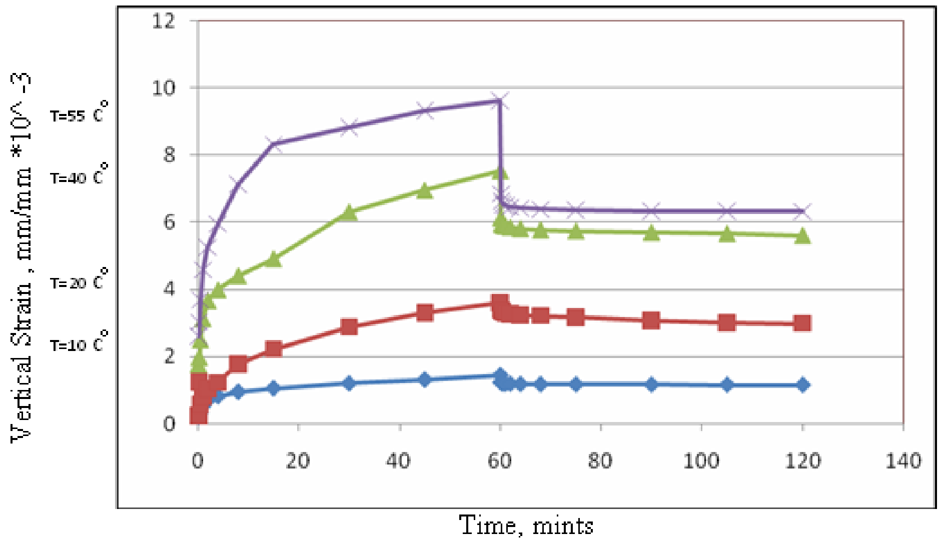

Figure 5 Influence of Temperature on Accumulated Strain at Stress Equal to 0.069 MPa

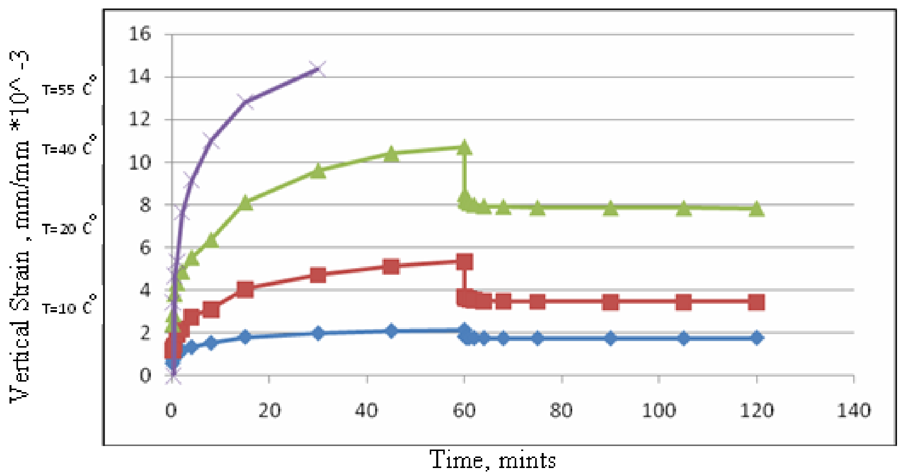

Figure 6 Influence of Temperature on Accumulated Strain at Stress Equal to 0.103 MPa