

**APPLICATION OF CREEP TEST FOR PREDICTING
RUTTING IN LOCAL ASPHALT MIXTURE**

**A THESIS SUBMITTED TO THE COLLEGE OF
ENGINEERING
OF BABYLON UNIVERSITY IN PARTIAL
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OF MASTER OF SCIENCE IN
CIVIL ENGINEERING**

BY

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تخمين التحدد في المزيج الإسفلتي
المحلي باستخدام فحص الزحف

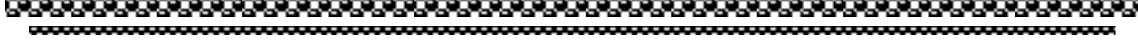
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في جامعة بابل

كجزء من متطلبات نيل شهادة
الماجستير

في علوم الهندسة المدنية
إعداد

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ



وَقُلْ إِنِّي كُنْتُ مِنَ الْمَدِينَةِ
الَّتِي كَفَرَتْ بِالرَّبِّ الْعَظِيمِ

وَأَنذَرْتُهَا نَارَ الْكَافِرِينَ
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صِرَافُ اللَّهِ الْعَظِيمِ

تخمين التحدد في المزيج الإسفلتي المحلي باستخدام فحص الزحف

أخلاصه :

التشوهات الدائمة من أهم المشاكل الرئيسية التي تعاني منها الطرق الإسفلتية ولعدة سنوات وخاصة عند ارتفاع درجات الحرارة في الصيف , زيادة الحمولات المحورية كذلك عدم كفاءة التصميم والتنفيذ والمواد المستخدمة في الإنشاء .

الهدف الأساسي من هذا البحث هو تخمين مقدار التشوهات الدائمة (التحدد) الحاصلة في مزيج الرصف الإسفلتي تحت تأثير الظروف المحلية. في هذه الدراسة تم استخدام فحص الزحف المتكرر لتمثيل علاقة التشوهات الدائمة مع الزمن باختلاف درجات الحرارة بالاطافة إلى فحص التحدد وفحص مارشال لتحديد خصائص المزيج الإسفلتي المناسب لتقييم التشوهات الدائمة (التحدد) تحت تأثير الظروف والمتغيرات المختلفة ولهذه الأسباب تم انتخاب ثلاث درجات للحرارة و ثلاث مستويات للإجهاد تحت تأثير كل درجة . تم تقييم الاجهادات المتغيرة باستخدام (KENLAYER software) لمنشأ مكون من خمس طبقات.

يستخدم نموذج التحدد لتخمين مقدار التحدد الحاصل في الطرق الإسفلتية بالاعتماد على محددات التشوهات الدائمة و المحسوبة من فحص الزحف المتكرر أحادي المحور.

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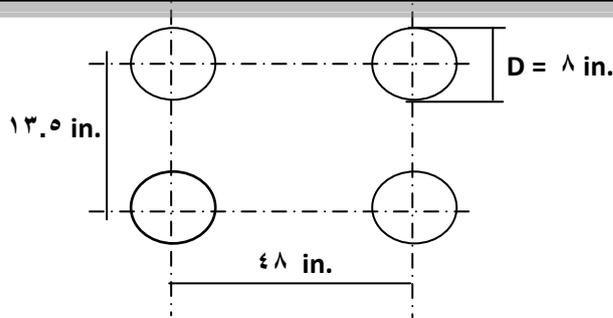
Appendix a

Permanent Strain * 10⁻³

T °C Stress (PSi)	20	40	60
ε	0.012	0.1	0.21
λ	0.02	0.2	0.42
12	0.05	0.30	0.70

Appendix C

ACKNOWLEDGEMENT



Praise be to " **ALLAH** "and to his prophet "**MOHAMMED**" (God's blessing and peace upon him). This research has been completed under their blessing.

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APPLICATION OF CREEP TEST FOR PREDICTING

RUTTING IN LOCAL ASPHALT MIXTURE

Abstract: Permanent deformation in asphalt pavements has been a major problem

for many years due to higher degree of temperature in summer, heavier axle loading and tire pressure and improper selection, design, construction of materials. The main objective of this work is to applicate a prediction model for permanent strain occurred in asphalt concrete pavement under the local conditions.

The cyclic creep- recovery test has been employed for characterizing the deformation- time relationship at various temperatures. Wheel track test in addition to Marshall test have been conducted on the selected asphalt paving materials in order to evaluate their rutting(permanent deformation) susceptibility under different variables.

Rutting model is constructed to predict layer rutting depending on the permanent deformation parameters calculated from uniaxial repeated cyclic creep- recovery test, therefore, three levels of stresses are applied under three levels of temperature to cover all conditions . The pavement response under various loading has been evaluated by using KENLAYER software for pavement structure which consisted of five layers.

LIST of CONTENTS

Subject	Page
ACKNOWLEDGEMENT	I
ABSTRACT	II
LIST OF CONTENTS	III
LIST OF ABBREVIATIONS	VI
LIST OF TABLES	VIII
LIST OF FIGURES	XI
CHAPTER ONE (INTRODUCTION)	
۱.۱ Introduction	۱
۱.۲ The objectives of this work	۲
۱.۳ Scope of the Work	۳
CHAPTER TWO (REVIEW OF LITERATURE)	
۲.۱ Introduction	۴
۲.۲ Mechanisms of Rutting	۶
۲.۳ Permanent Deformation (Rutting) Criteria	۸
۲.۴ Effect of restricted zone on rutting	۹
۲.۵ Pervious Models to Predict Permanent Strain	۱۰
۲.۶ Factors Affecting Rutting	۱۴
۲.۶.۱ Traffic Characteristics	۲۴
۲.۶.۲ Temperature	۱۰
۲.۶.۳ Mixture Variables	۱۶

LIST of CONTENTS

Subject	Page
۲.۷ A brief Introduction to The Present Model	۱۹
۲.۸ Analysis of Strain Components	۲۰
۲.۸.۱ Elastic strain	۲۱
۲.۸.۲ Plastic Strain	۲۱
۲.۸.۴ Visco- Elastic Strain	۲۲
۲.۸.۴ Visco- Plastic Strain	۲۲
CHAPTER THREE (MATERIALS, TESTING AND RESULTS)	
۳.۱ Materials	۲۳
۳.۱.۱ Asphalt cement	۲۳
۳.۱.۲ Aggregates	۲۳
۳.۱.۳ Mineral Filler	۲۶
۳.۲ Test Methods	۲۷
۳.۲.۱ Mixture Preparation	۲۷
۳.۲.۲ Resistance to Plastic Flow (Marshall Method)	۲۷
۳.۲.۳ Uniaxial Repeated Cyclic Creep Test	۲۸
۳.۲.۴ Wheel Tracking Test	۳۰
۳.۳ Test Program of Asphalt Paving Mixture	۳۲
۳.۴ Properties of Asphalt Concrete Mixtures	۳۵
۳.۴.۱ Marshall Stiffness	۳۵
۳.۴.۲ Uniaxial repeated Cyclic Creep Test.	۳۹
۳.۴.۳ Wheel Tracking	۴۸

LIST of CONTENTS

Subject	Page
CHAPTER FOUR (MODELING OF RUTTING)	
ε.1 Introduction	ο6
ε.2 Modeling of Permanent Strain	ο6
ε.2.1 Mixture Building and Testing	ο7
ε.2.2 Theoretical Formulation	60
ε.2.3 Pavement Structure and Loading	64
ε.2.4 Pavement Temperature	6ο
ε.3 Application of the Proposed Model	68
CHAPTER FIVE (CONCLUSIONS AND RECOMMENDATIONS)	
Conclusions and Recommendations	70
REFERENCES	72
APPENDIX a	a
APPENDIX A	A
APPENDIX B	B
APPENDIX C	C

LIST of ABBREVIATIONS

A-C.....	Asphalt Cement.
AASHTO.....	American Association of State Highway and Transportation Officials.
ASTM.....	American Society for Testing and Materials.
FHWA.....	Federal Highway Administration.
G.....	Specific Gravity.
H.....	Specimen Height.
MMAT.....	Mean Monthly Air Temperature.
MAAT.....	Mean Annual Air Temperature.
RD.....	Rut Depth.
Smix.....	Mixture stiffness.
σ	Applied Stress.
IMO.....	Iraq Meteorological Organization.
R.....	Predicted Rut Depth.
R.....	Reference Rut Depth at T, N..
	Reference Temperature and Load Cycle at R..
	Instantaneous Strain.

T, N.

ϵ

ϵ_t

ϵ_r

ϵ_p

T

N

a, b.....

P_N

LIST of ABBREVIATIONS

D..... Recorded rut depth (deflection) of wheel tracking test.

ϵ_e Elastic strain.

ϵ_{ve} Visco-elastic strain.

ϵ_{vp} Visco-plastic strain.

ds/dT Logarithmic slope of permanent strain versus stress curves.

Z The depth below surface in inches.

M_p The mean pavement temperature.

M_a The mean monthly air temprat

z Correction factor for the difference in the state of stress
between wheel tracking test and practice.

h.....

Rr.....

Nr.....

ή, & ήγ
.....

T_R.....

T_L.....

F/A.....

C.....

LIST OF TABLES

Table	Title	Page
٢.٢.١	Permanent Deformation Mode of Distress in Asphalt Pavement	٤٤
٢.٢.٢	Rut Depth According to FHWA	٨٢
٣.٢.١	Physical Properties of Asphalt Cement	٢٤٤
٣.٢.٢	Physical Properties of Nibae Aggregate	٢٤٤
٣.٣.١	A Key for the Different Mixture Variables	٣٣٣
٣.٤.١	Main Properties of Different Variables of Marshall Test specimens	٣٤٤
٣.٥.١	Main Properties of Creep Test Specimens	٤٤٤
٣.٥.٢	Main Properties of Wheel Track Test Specimens	٤٤٩
٤.١.١	Characterstics of Pavement Structure	٤٤٤
٤.٢.١	Mean Monthly Air Temperature Determination	٤٧٧
٤.٣.١	The Accumulative Permanent Strain	٤٩٤
A٢	Results of Creep Test for Mix No. ١ (T=٢٥ ° C , σ = ٤ PSI)	A٢
A٣	Results of Creep Test for Mix No. ١ (T=٢٥ ° C , σ = ٨ PSI)	A٣
A٣	Results of Creep Test for Mix No. ١ (T= ٢٥ ° C , σ = ١٢ PSI)	A٣
A٤	Results of Creep Test for Mix No. ١ (T = ٤٠ ° C , σ = ٤ PSI)	A٤

LIST OF TABLES

Table	Title	Page
A _{١٢}	Results of Creep Test for Mix No. ١٢ (T = ٤٠ ° C , σ = ٨ PSi)	A _{١٢}
A _{١٣}	Results of Creep Test for Mix No. ١٣ (T = ٤٠ ° C , σ = ٨ PSi)	A _{١٣}
A _{١٤}	Results of Creep Test for Mix No. ١٤ (T = ٤٠ ° C , σ = ٨ PSi)	A _{١٤}
B	The Results of Wheel Tracking Test	B
C	Information About Pavement Structure	C

LIST OF FIGURES

Figure	Title	Page
١٢	Typical Rut Profile as Result of Densification	٧
١٣	Typical Rut Profile as Result of Plastic Flow(Shoving)	٨
١٤	Response Components From Creep-Recovery Test of Avisco-elastic Plastic Material	١٢

٣.١	Gradation of Aggregates Used	٢٥
٣.٢	The Consolidation Apparatus for Creep Test	٢٩
٣.٣	Wheel Tracking Apparatus	٣١
٣.٤	Work Approach	٣٤
٣.٥	Marshall Stiffness for Different Asphalt Cement Content	٣٧
٣.٦	Marshall Stiffness for Different Filler Type	٣٧
٣.٧	Marshall Stiffness for Different F/A Ratio	٣٨
٣.٨	Marshall Stiffness for Different Fines Content	٣٨
٣.٩	Marshall Stiffness for Different Surface Shape	٣٦
٣.١٠	Typical Strain – Time Relation	٣٩
٣.١١	Strain-Time Relation for Different Asphalt Cement Content	٤٢
٣.١٢	Creep Compliance-Time Relation for Different Asphalt Cement Content	٤٢
٣.١٣	Strain-Time Relation for Different Filler	٤٣
٣.١٤	Creep Compliance-Time Relation for Different Filler Type	٤٣
٣.١٥	Strain-Time Relation for Different F/A Ratio	٤٤
٣.١٦	Creep Compliance-Time Relation for Different F/A Ratio	٤٤
٣.١٧	Strain -Time Relation for Different Restricted Zone	٤٥

LIST OF FIGURES

٣.٢٨ ٣.٢٩	Creep Compliance- Time Relation for Different Restricted Zone	٤٥
٣.٢٩ ٣.٣٠	Strain -Time Relation for Different Compaction Effort	٤٦
٣.٢٢ ٣.٢٣	Creep Compliance-Time Relation for Different Compaction Effort	٤٦
٣.٢٢ ٣.٢٣	Strain-Time Relation for Different Crushed Percent	٤٧
٣.٢٢ ٣.٢٣	Creep Compliance -Time Relation for Different Crushed Percent	٤٧
٣.٢٣ ٣.٢٤	Strain - No. of Repetition Relation for Different Asphalt Cement	٥٠
٣.٢٤ ٣.٢٥	Wheel Tracking Strain for Different Asphalt Cement Content	٥٠
٣.٢٥ ٣.٢٦	Strain - No. of Repetition Relation for Different Filler Type	٥١
٣.٢٦ ٣.٢٧	Wheel Tracking Strain for Different Filler Type	٥١
٣.٢٧ ٣.٢٨	Strain - No. of Repetition Relation for Different F/A Ratio	٥٢
٣.٢٨ ٣.٢٩	Wheel Tracking Strain for Different F/A Ratio	٥٢
٣.٢٩ ٣.٣٠	Strain - No. of Repetition Relation for Different Restricted Zone	٥٣
٣.٣٠ ٣.٣١	Wheel Tracking Strain for Different Restricted Zone	٥٣
٣.٣١ ٣.٣٢	Strain - No. of Repetition Relation for Different Crushed Percent	٥٤
٣.٣٢ ٣.٣٣	Wheel Tracking Strain for Different Crushed Percent	٥٤
٣.٣٤ ٣.٣٥	Relationship Between Permanent Strain and Time for Different Levels of Stress at T= ٢٥°C	٥٨
٣.٣٥ ٣.٣٦	Relationship Between Permanent Strain and Time for Different Levels of Stress at T= ٤٠°C	٥٩
٣.٣٦ ٣.٣٧	Relationship Between Permanent Strain and Time for Different Levels of Stress at T = ٥٠ °C	٥٩
٣.٣٧ ٣.٣٨	Relationship Between Stress and Permanent Strain	٦٠
٣.٣٨ ٣.٣٩	Relationship Between Log Slope and Temperature	٦١

٤٠٣	Relationship Between Log of b and Temperature	٦٢
٤٠٤	Cross-section in Pavement Structure	٦٥

CHAPTER ١	Introduction
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CHAPTER ONE
INTRODUCTION

١.١: Introduction

Permanent deformation (rutting) of asphalt pavements has a major impact on pavement performance particularly in hot climates and at intersections. Rutting reduces the useful living service of the pavement and, by affecting vehicle handling characteristics, creates serious hazards for highway users (Jorge et al., ١٩٩١).

The stability properties of an asphalt mix are not well defined, but may be expressed as the resistance of mix to pavement rutting under varying conditions of climate and traffic loading. Therefore, the need has been found for the development of a laboratory test method to predict the amount of rutting that would occur in a pavement (Van

de Loo, 1974). In many instances ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Rutting stems from the permanent deformation in any of the pavement layers or the subgrade, usually caused by the consolidation or lateral movement of the material due to traffic loads (Yang, 1993).

A primary concern of most pavement structural design is procedures to control permanent deformation and fatigue crack . This is achieved by estimating the cover thickness of high quality materials required to protect natural subgrade against the compressive stresses forms, and thus limiting

CHAPTER 1

Introduction

Deformation within acceptable limits of time. Which one this approach has lead to the development of various relationships for acceptable rut depth limit and acceptable crack extent and the various measures of material and traffic properties, enabling the design of adequate pavement structures (Freeme , 1983).

Due to the deterioration and ageing of road networks, the models

(or the principles behind them) were also used for improved management

and planning techniques, and for the economic justification of expenditures and standards in the highway sector. Therefore, in modern

pavement management systems, the routine measurement and prediction of rutting has become an important performance criteria as a result of the influence of rutting on road roughness, dynamic loads and safety

(based on the hazard of bonding water), all of which influence the road

user costs of vehicle operation and accidents (Louw, ۲۰۰۳).

۱.۲ : The objectives of this Study

This study aims to:

۱. Formulate a model to predict the permanent strain by using repeated cyclic creep and recovery test which is developed in asphalt layers under the repetitive action of traffic.
۲. Investigate the main factors related to the permanent strain of asphalt concrete including the number of repetitions, stress state and ambient temperature.

1.3 : Layout of Thesis

This study consists of five chapters in which the following topics are addressed : in chapter one the introduction to the problem is discussed in addition to the objectives of this study.

In chapter two (Review of Literature), topics related to permanent deformation are considered including: introduction, mechanisms of rutting, permanent deformation criteria, effect of restricted zone, pervious methods to predict rut depth and factors influencing rutting.

Through chapter three (Materials and Testing), the emphasis is placed on the properties of the materials used in this work including asphalt cement, mineral filler and aggregate. In this chapter, the test methods and results including Marshall test, uniaxial repeated cyclic creep test and wheel tracking test are also included and conclusions of these results as well.

Chapter four includes the construction of the proposed model to predict permanent strain. The main conclusions and recommendations are presented in chapter five.

CHAPTER TWO

REVIEW OF LITERATURE

۲.۱ : Introduction

The distortion (or permanent deformation) mode of distress in asphalt pavement that results from both traffic and non-traffic associated causes is summarized in Table (۲-۱) (Monismith and Salam, ۱۹۷۳).

General causes	Specific causative factor	Example of distress
	Single or comparatively few excessive loads	Plastic flow (shear distortion)
	Long – term (or static) load	Creep (time dependent) deformation

Traffic associated	Repetitive traffic loading (generally a large number of repetitions)	Rutting (resulting from accumulation of the small permanent deformation associated with passage of wheel load)
Non – traffic associated	Expansive subgrade soil	Swell or shrinkage
	Compressible material underlying pavement structure	Consolidation settlement
	Frost – susceptible material	Heave (particularly differential amounts)

Table (۲-۱) Permanent Deformation Mode of Distress in

CHAPTER ۲	<i>Review of Literature</i>
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In general, rutting in local asphalt pavement has been a major problem for many years especially with greater wheel loads and higher pressures. Permanent deformation or rutting occurs as longitudinal depressions in wheel path. This type of distress may occur due to repeated application of high stresses on the subgrade or by inadequate shear strength of the hot mix asphalt structure. Rutting may be caused by inadequate results from pavement layers which are too thin or weakened subgrade due to moisture or poor compaction. Rutting

can also occur due to low shear strength in the local asphalt pavement, which results in accumulation of irrecoverable strain resulting from applied wheel loads. This results in a combination of consolidation and / or lateral movement of the un local asphalt pavement der traffic. Shear failure (lateral movement) in a local asphalt pavement generally occurs in top 100 mm (4 in) (Eugene et al., 2002).

Rutting decreases the useful life of a pavement and creates a safety hazard. Higher traffic volumes and the increase use of radial tire (higher inflation pressures) have increased the potential for rutting.

Bolk, (1982) classified rutting into two types : Primary rutting which is defined as the total permanent deformation of bituminous bound

layer in the wheel track. Secondary rutting, which is often accompanied by cracking, has its origin in the non – bituminous components of the

pavement. Primary rutting may be a result of plastic and / or viscous deformation of the bituminous materials, and wear of the bituminous top layer. Rutting has effects not only on the serviceability, but excessive rutting affects also on hydroplaning by freezing of pounded water to result in the icing condition that lead to loss of vehicle control and pavement

bearing capacity.

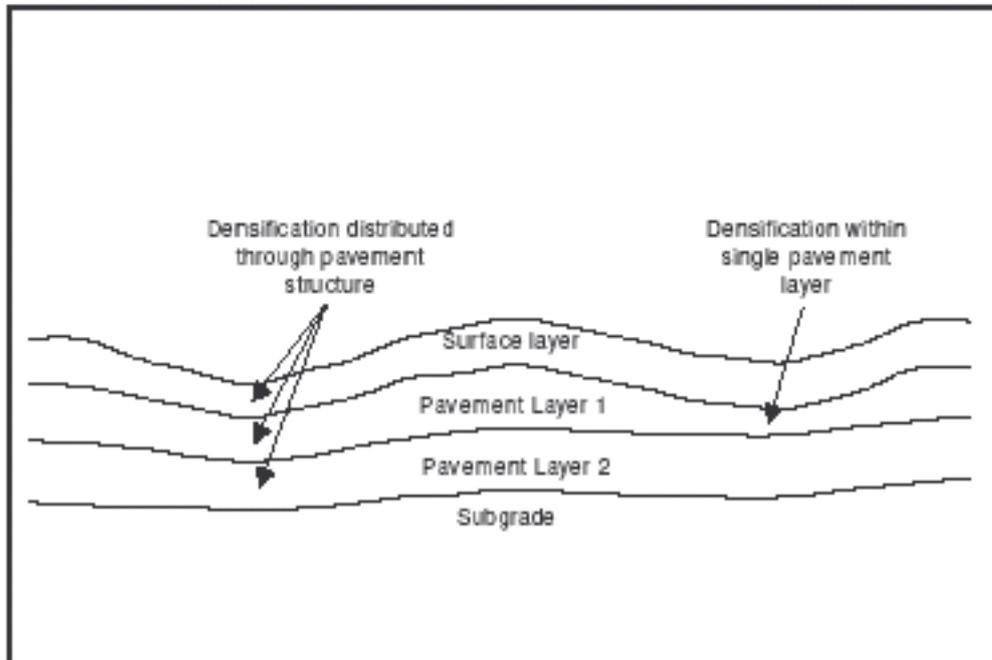
2.2 : Mechanisms of Rutting

Traffic – associated permanent deformation, and rutting in particular,

results from a rather complex combination of densification and plastic

flow mechanisms. Densification, according to Paterson(1978), is the change in the volume of material as a result of the tighter packing of the material particles and some times also the degradation of particles into smaller size. Rutting due to densification is usually fairly wide and uniform in the longitudinal direction with heaving on the surface seldom occurring, as illustrated in Figure 2.1). The degree of densification depends greatly on the compaction specification that should be selected in accordance with expected loadings and pavement type. Failure to reach specified compaction during construction will result in an increase of densification under traffic, most of which occurs early in the life of the pavement.

The deformation within the pavement may be located within a single weak layer, or more frequencies distributed through the depth of the pavement, as illustrated in Figure 2-1).



**Figure ۲-۱: Typical rut profile as result of densification
(Paterson, ۱۹۸۷)**

Plastic flow involves essentially no volume change, and give rise to shear displacement in which both depression and heave are usually manifested. Plastic flow occurs when the shear stresses imposed by traffic exceed the inherent strength of the pavement layers (Paterson, ۱۹۸۷). The rutting in this case is usually characterized by heaving on the surface along side of the wheel paths, as illustrated in

Figure ۲-۲ . Plastic flow is controlled through the structural and material design specification, which are normally based on a measure of the shear strength of the materials used for example, the California Bearing Ratio (CBR) for soils, and Marshall and Hveem stability for bituminous materials.

CHAPTER ۲	Review of Literature
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The best known example of plastic flow is shoving within the asphalt layers, as illustrated in Figure ۲-۲.

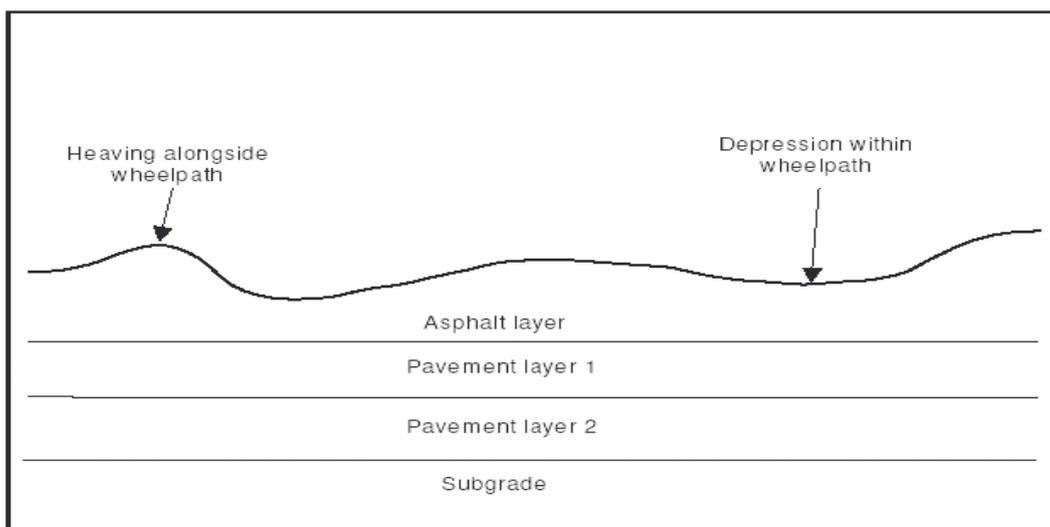


Figure ۲.۲: Typical rut profile as result of plastic flow(shoving)

(Paterson, ۱۹۸۷)

۲.۳ : Permanent Deformation (Rutting) Criteria

The Federal Highway Administration (1979) has classified rutting into four levels of severity as below :

Table (2-2) Rut Depth According to FHWA.

Mean rut depth	Severity Level
0.20 - 0.25 in	hydroplaning
0.25 - 0.50 in	low
0.50 - 1.00 in	medium
> 1.00 in	high

Allowable rut depth may be limited by both safety and structure consideration. For example, pavement failure in United Kingdom is defined as a rut depth of 0.75 to 0.80 in. (19-20 mm) measured by a 6.0 ft (1.8m) straight edge (Lister and Addis, 1976). It is suggested that rut depths up to approximately 0.4 in (10mm) do not cause loss of structural strength. For a cross slope of 2.0 significant percent (generally used in the united kingdom), Lister and Addis(1976) have found that ruts deeper than approximately 0.5 in. (13 mm) result in pounding of water which could cause hydroplaning or loss of skid resistance. This

corroborates Barksdale's finding as noted above. Verstraeten et al. (1977) have determined that the rut slope (ratio of rut depth to one-half its width) should not exceed 2 percent for good riding quality.

2.4 : Effect of restricted zone on rutting

More than ninety percent of local asphalt pavement consists of aggregates. The stability of local asphalt pavement largely depends on aggregate properties.

Gradation of aggregates is the single most important property that determines the stability of mix. Mixes containing different aggregate gradations are likely to have different stability and different rutting potential. Hence, any laboratory rut tester should be evaluated on the basis of its ability to characterize mixes with different aggregate gradations.

The Superior Performing Asphalt Pavements (Superpave) system has specified a restricted zone through which aggregate gradations are recommended that no passing with its to avoid stability problems.

CHAPTER 2	<i>Review of Literature</i>
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with gradations above the restricted zone are known as fine mixes, and those passing below the restricted zone are known as coarse mixes. It is

believed that mixes with gradations passing above, through and below restricted zone would differ significantly in their rutting potential. To obtain relatively stable mixes, superpave recommends the use of below restricted zone gradations for pavements with high traffic volumes.

Apart from gradation and type of aggregate the top size of aggregate is also believed to have significant effect on rutting potential. Experience shows that stiff binder course with bigger aggregates have less rutting potential compared to relatively more flexible wearing courses with finer aggregates and higher binder content (Kandhal and Mallick , 1999).

2. 9: Pervious Models to Predict Rutting

Many procedures are available for the estimation of the amount of rutting from repeated traffic loading as shown below:

Uzan Model : Uzan (1982) has developed a model by using repeated load testing to predict permanent strain. This model is dependent on the number of repetitions, resilient strain and characteristics of materials. The form of this model is :

$$\epsilon_p = \epsilon_r \mu N^{-\alpha} \dots\dots\dots 2-1$$

Rr = Rate of rutting at the last pass (mm/mm/pass) from wheel track.

N_r = Number of passes.

η_1 & η_2 = Viscosity for the wheel tracking and practice mixtures respectively.

David Model: David and Deen (1980) have fitted to their test data a third order polynomial of the form:

$$\log \epsilon_p = C_0 + C_1 (\log N) + C_2 (\log N)^2 + C_3 (\log N)^3 \dots \dots \dots \quad \text{Eq-2}$$

In which the influences of stress state, time of loading and temperature are described by the coefficient C_0 , C_1 , C_2 and C_3 .

CHAPTER 2	Review of Literature
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Mahboub model : Mahboub and Little (1988) have developed a model by using uniaxial creep tests. This is model dependent on the number of cycles and state of stress at peak cyclic. The equation represents this model is :

$$\frac{\epsilon_{vp}}{N} = a \sigma^b \dots \dots \dots \quad \text{Eq-3}$$

Where :

$\frac{\epsilon_{vp}}{N}$ = accumulated, viscoplastic deformation per cycle
(mm/mm/cycle).

σ

= peak cyclic stress (KPa).

a, b = regression parameters.

Carsten model : (Carsten, 1991) has measured rut depth at a given number of loads. Early in testing, the interval between rut measurements is small and increases with the number of load repetitions. In this way, the correlation between rut depth and number of loads is monitored. The rut depth, P_N at N loads estimated by the power function :

$$P_N = a.N^b \dots\dots\dots 2-0$$

Where :

P_N = rut depth at N loads (mm).

N = number of load repetitions (cycle).

a, b = regression coefficients.

Shami model : Shami et al. presented a temperature effect model to predict rut depth based upon testing conducted at a given test temperature and given number of cycles as cited by (Jingna et al., ۲۰۰۲). The equation represents the model for laboratory test over a range of temperatures and number of cycles is:

$$\left[\frac{R}{R_0} \right] = \left[\frac{T}{T_0} \right]^{2.625} \left[\frac{N}{N_0} \right]^{0.276} \dots\dots\dots ۲-۶$$

where :

R = predicted rut depth (mm).

R. = rut depth obtained at the test conditions T. and N. (mm).

T, N = temperature and load cycles (°C, cycle).

T., N. = temperature and load cycles at the R. (°C, cycle).

The factors (۲.۶۲۵, ۰.۲۷۶) are conducted for Georgia wheel tracking.

The previous models are not used for two reasons: first, the used equipments are not available in the laboratory. Second, some of these models are conducted under limited range for degrees of temperature that are not fitting with the climate conditions in Iraq.

۲.۶ : Factors Affecting Rutting

The resistance of pavement structures for rutting is dependent on

a number of factors which are related to applied loads as (traffic type and traffic volume), or the environment as (temperature , moisture), the pavement structure (materials used and their compositions), the construction process, or a combination of the above factors.

The general influence of the factors are based on the laboratory findings and field observations of numerous experiments. These factors are discussed in more detail below :

۲. ۶. ۱: Traffic Characteristics

One of the most important factors that effect the increase of pavement

deformation is the traffic characteristic, truck tire pressure, axle loads

and volume of traffic. On the basis of asphalt pavement strain measurements, Addis et al., (1986) reported that a 20% increasing in tire pressure would increase fatigue damage by 26%. Laboratory measurements by Eisenmann et. al, (1987) on a 220 mm thick asphalt road surface model showed that rut depth development was approximately linearly related to the average contact pressure (independent on load). Experimental measurements of asphalt layer interface strains and surface deflection by Christison et al., (1978) for a variety of axle and tire configurations gave very similar results. Christison's analysis of the measured strains in terms of pavement damage indicated that a single tire theoretically 7-10 times worse than a dual tire for equal load.

CHAPTER 2

Review of Literature

Haas and Papagiannakis (1986) showed that increasing tire contact pressure from 210 KPa to 230 KPa at constant load, increased the theoretical vertical compressive strain near the surface of a 200 mm thick asphalt layer by up to a factor of eight, but hardly affected the strain at the bottom of the layer.

2.6.2: Temperature

AASHTO (1986) indicates that the high temperature will affect creep properties of the asphalt concrete and performance of asphalt pavement by rutting. For practical purpose, temperature influences factors can be divided into extrinsic and intrinsic categories. The extrinsic factors are usually the weather conditions such as air temperature, solar radiation, wind, precipitation, evaporation and condensation. The intrinsic factors generally refer to the emission of long wave radiation from the ground and thermal properties, which include thermal conductivity, heat capacity and latent heat of fusion of the pavement materials and subgrade. Among all extrinsic factors the ambient temperature is the most important factor in the thermal equilibrium of pavement(Bissada, 1980).

Hofstr and klomp (1972) determined from test track measurements that rutting increased by a factor of 20 to 30 with a temperature increase From 68 °F to 140 °F (20 °C to 60 °C).

Sultan(1990) indicated that dynamic modulus of asphalt concrete is very sensitive to temperature, as an example, dynamic modulus of asphalt

maintain 10777 MPa at 40 °C and 7.1 MPa at 70 °C. Also Poisson's ratio

(μ) is 0.26 at 40 °C and 0.49 at 70 °C. Louw (2003) has showed that the dependence of the flow properties of bituminous mixtures on temperature is due to changes in the rheological properties of the binder, the dominant factor being the great dependence of viscosity on

CHAPTER 2	Review of Literature
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temperature and, from simulation tests and general experience it is well known that the resistance to deformation of bituminous materials decreases rapidly as temperature increases, especially if the ambient temperature approaches or exceeds the softening points of the binders used in such mixes.

The results obtained from creep test, , Marshall stiffness and wheel tracking test for pervious research show that the deformation rate of bituminous mixture depends on temperature.

۲. ۶. ۳: Mixture Variables

The main factors associated with the material itself, which affect the resistance to permanent deformations are binder grade, binder quantity, filler, fine aggregates, compaction effort, mixing temperature and aggregate shape. The Superior Performing Asphalt Pavements (Super Pave) mix design system adequately addresses the aggregate and asphalt binder properties that contribute to permanent deformation.

N. Mike and Baldwin, (۱۹۹۹) show that excessive; asphalt cement, excessive fine grained aggregate and high percentages of natural, rounded aggregate particles are considered to be common material – related causes of permanent deformation . Hughes and Charles, (۱۹۹۰) has

suggested that gradation is more important in minimizing rutting

asphalt cement and additive properties. Experimentation has also shown that the susceptibility to plastic deformation increases dramatically when natural fine aggregate particles replace crushed particles in given gradation (Button et al., ۱۹۹۰).

Others have noted that interlocking aggregate particles will resist flow when the binder content is not excessive. However the quality of local aggregate, dictated by the geology of the region , has shown that it has some control over local asphalt pavement rutting susceptibility.

Regions quality of crushed stone and angular natural sand have been observed to exhibit a higher resistance to rutting (Parker and Brown, ۱۹۹۴). Further it has been reported that medium graded mixture provides significantly better performance in resisting permanent deformation than coarse graded mixtures (Matthews and Monismith, ۱۹۹۳).

EL- Basyonny and Mamlouk, (۱۹۹۹) studied two asphalt concrete mixture with nominal maximum sizes of ۱۹ mm and ۳۷.۵ mm and they found that asphalt content affects the rut depth of a specific pavement section as estimated by the **VESYS – ۳AM** software. Mixtures prepared using the aggregate gradation pass below the restricted zone which has the least predicted rut depth among other gradation with

an average of 10 mm in a 10-year analysis period. They pass through and above the restricted zone which has similar predicted rut depth with an average of 11 mm. The mixture with 37.0 mm nominal maximum aggregate size results in a rut depth less than 19 nominal maximum aggregate size. The 4.0 % asphalt content mixtures result in the least rut depth compared with other mixtures with an average of 10 mm.

CHAPTER 2

Review of Literature

The resistance to permanent deformation of an asphalt mix is also dependent upon interaction between particles of the coarse aggregate to form a mechanical interlocking structure; the higher the particle to particle contact within the mix, the more resistant of mix to deformation. Thus both the shape and texture of coarse aggregate are of importance. It also has been found that higher content of stone lead to lower deformation, but the most difficult case is to achieve the required compaction (Louw, 2003).

Air void content within an asphalt mix also influences the behavior of the mix. The higher percent of air voids, the mix more resistance to deformation but due to the increased permeability to air, an increased rate of hardening of the binder will occur, reducing the fatigue life of the asphalt. If the air voids content is too low, the asphalt mix

will become unstable, resulting in plastic flow of the layer under heavy traffic, slow moving loads or high maximum temperature.

According to road note 31 (**TRL**, 1994), numerous studies indicated that the minimum air voids after trafficking should always exceed 3 percent to avoid potential plastic flow, but should less than

percent to keep hardening of the binder (under tropical condition) to a minimum. Also one of the main problems in design of HMA is the selection of a suitable binder content for a given gradation of aggregate. From the point of view of deformation, asphalt mixes should contain enough binder to give cohesion and to enable adequate compaction to be

achieved. The binder content affects the mixture's ability to resist permanent deformation. The Marshall or Hveem method is generally selected as a preliminary design tool in the determination of an

CHAPTER 2	<i>Review of Literature</i>
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asphalt content. Monismith et al., (1980) recommended that the mixtures have an asphalt content such as the air void content would be approximately 4 percent. To exclude problems of instability and, thus, permanent deformation, they recommended an absolute minimum of three percent air voids. These criteria must necessarily be associated

with mixtures of adequate stability resulting from the use of high quality aggregates.

۲. ۷ : A brief Introduction to The Present Model

A constitutive model for bituminous mixture subjected to repeated cyclic loading has been presented to evaluate the elastic, plastic, viscoelastic and viscoplastic components that are simultaneously presented in the loading process for each cycle. The material properties could be obtained from repeated cyclic creep and recovery test that are conducted under various levels of compression stress under different temperatures.

Each component varied with degrees of temperature. The materials behave as a viscoelastic under low temperatures, whereas, in the high temperatures, they behave as a combination of viscoelastic and viscoplastic. Because the environmental conditions in Iraq show higher degrees of temperature, the model derived for this case is to consider the effect of stress state and number of repetitions.

2.1: Analysis of Strain Components

The total strain (ϵ_t) has recoverable and irrecoverable elements, some of which are time dependent and some are time independent. Therefore, the total strain could be resolved into four components for each cycle, as below:

$$\epsilon_t = \epsilon_e + \epsilon_p + \epsilon_{ve} + \epsilon_{vp} \dots\dots\dots 2-6$$

where:

ϵ_e = elastic strain (recoverable and time independent),

ϵ_p = plastic strain (irrecoverable and time independent),

ϵ_{ve} = visco-elastic strain (recoverable and time dependent),

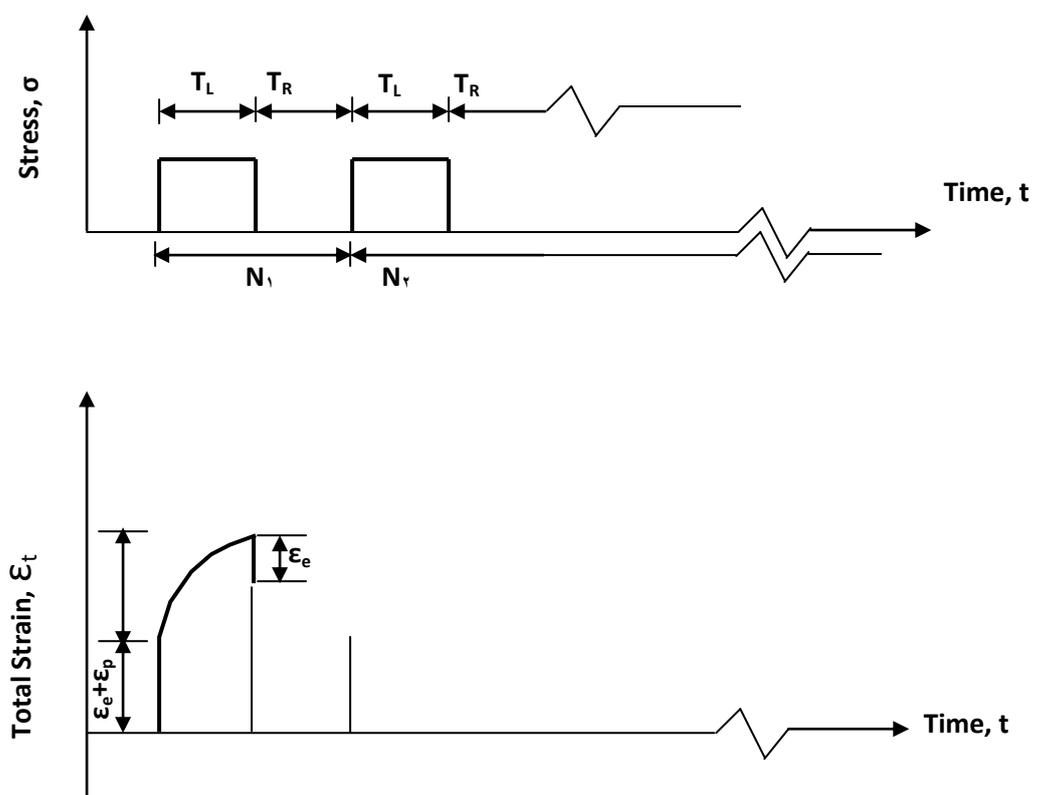
ϵ_{vp} = visco-plastic strain (irrecoverable and time dependent).

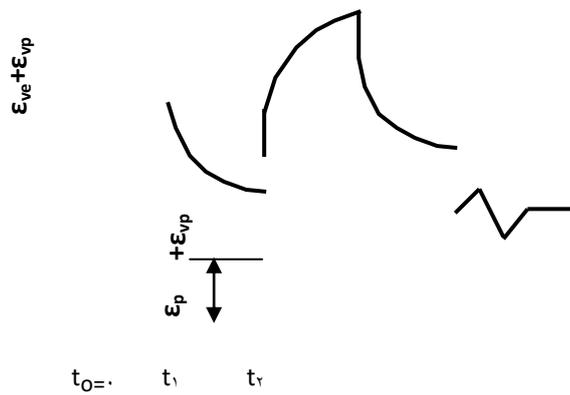
In typical schematic cycle as shown in Figure (2-3), it could be observed that at $t = t_0$, when load is applied, strain, ϵ_0 , containing the elastic and plastic components, appears instantaneously. As the specimen undergoes creep ($t_0 \leq t \leq t_1$), visco-plastic and visco-elastic strain are built

up. Once the load is removed in the period that follows ($t_1 \leq t \leq t_2$), part of the visco-elastic strain is recovered. At the end of the cycle, the residual strain consists of the irrecoverable plastic and visco-plastic strain components.

A brief analysis of each of the strain components and their dependence on stress level, time and number of loading cycles is presented below:

CHAPTER 2	Review of Literature
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Fig(۲-۳):Response Components From Creep-Recovery

Test of a Viscoelastic Plastic Material(Uzan et al., ۱۹۸۳)

۲. ۸. ۱: Elastic strain

The elastic strain is obtained from the recovery curves. It is equal to the instantaneous decreases in the total strain that occurs when the load is removed ($t = t_1$) as shown in the Figure (۲-۳). In the elastic strain, each cycle is a function of stress, this strain was found to be a linear function of stress which is independent from the number of loading cycles.

۲. ۸. ۲: Plastic Strain

The plastic strain component is evaluated through the creep curve. As previously described in the Figure (۲-۳)when specimen is loaded, the strain consists of elastic and plastic. Therefore, the plastic strain is equal to:

$$\epsilon_p = \epsilon_0 - \epsilon_e \dots \dots \dots 2-7$$

The variation of the total plastic strain with the number of cycles is a linear on log-log scale.

2.8.3: Visco-Elastic Strain

A detailed analysis of the experimental findings reveals a nonlinear dependence of the visco-elastic strain on time and stress level. The visco-elastic strain is found to be independent from the number of the loading cycles. Once the load is removed, visco-elastic strain appears as a function of time and stress level.

2.8.4: Visco-Plastic Strain

The Visco-plastic strain component is obtained by subtracting all the previously evaluated strains from the total strain as shown in Figure (2-3).

$$\epsilon_{vp}(\sigma, t, N) = \epsilon_t(\sigma, t, N) - \epsilon_e(\sigma) - \epsilon_p(\sigma, N) - \epsilon_{ve}(\sigma, t) \dots \dots \dots 2-8$$

CHAPTER THREE**MATERIALS, TESTING AND RESULTS****٣.١ : Materials**

The materials used in this study are widely available and currently used in the road paving in Iraq. These materials consist of asphalt cement, aggregate and filler which are discussed in more detail below :

٣.١.١ : Asphalt cement

Penetration grade of asphalt cement used is (٤٠-٥٠) from Daurah refinery. The physical properties and tests of grade are presented in Table (٣.١)

٣.١.٢ : Aggregates

The aggregates (crushed and uncrushed) used in this work were brought from the hot mix plants of Daurah. The source of aggregate is

TEST	UNITS	VALUES
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from Nibaee quarry.

To produce identical, controlled gradation, aggregates were sieved and recombined in the laboratory to obtain the selected gradation according to the restricted zone shown in Figure (٣-١) within the specification of ASTM D ٣٥١٥ for (١٢.٥) nominal maximum size. The physical properties of the aggregates are shown in the Table (٣-٢)

Penetration (۲۵°C, ۱۰۰g, °sec) ASTM D-۵	۱/۱۰۰	۴۱
Absolute viscosity at ۶۰ °C ASTM D- ۲۱۷۱	poise	۲.۶۵
Kinematics viscosity at ۱۳۵ °C ASTM D- ۲۱۷۰	Cts	۴۳.
Ductility (۲۵ °C , ° cm/min) ASTM D- ۱۱۳	cm	>۱۰۰
Softening point (ring and ball) ASTM D-۳۶	°C	۵۰
Specific gravity at ۲۵ °C ASTM D- ۷۰	۱.۰۵۹۳
Flash point ASTM D- ۹۲ (Cleveland Open-cup)	°C	۲۷۳
AFTER THIN FILM OVEN TEST		
Penetration of residue (۲۵°C, ۱۰۰gm, °sec) ASTM D-۵	۱/۱۰۰	۳۱

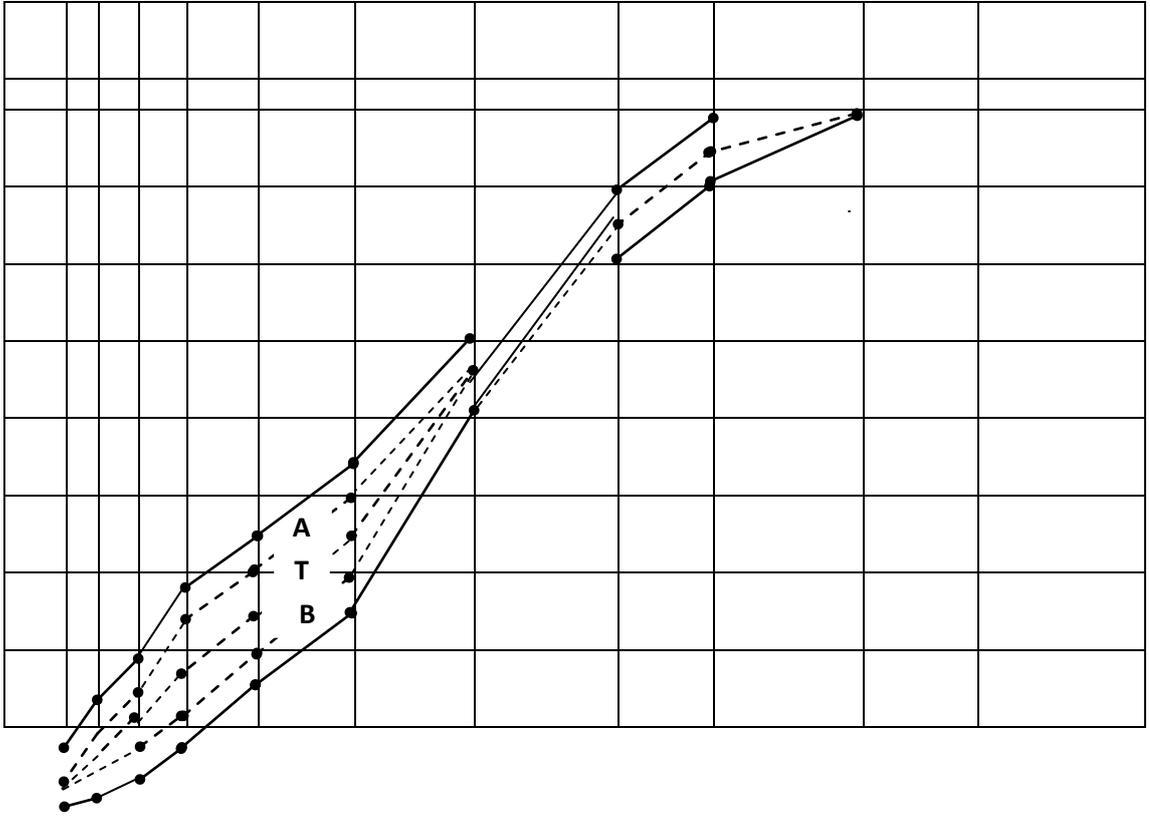


Table (٣-٢) Physical Properties of Nibae Aggregate

PROPERTY	COARSE AGGREGATE	FINE AGGREGATE
Bulk specific gravity (ASTM C- ١٢٧ and C- ١٢٨)	٢.٦٣١	٢.٦٧١
Apparent specific gravity (ASTM C- ١٢٧ and C- ١٢٨)	٢.٦٩٥	٢.٧٠١
Percent water absorption (ASTM C- ١٢٧ and C- ١٢٨)	٠.٤٨	٠.٦٩
Percent wear (Los Angeles abrasion)ASTM C- ١٣١	٢٥	-----

٣.١.٣ : Mineral Filler

Three types of mineral filler have been used including: limestone dust, hydrated lime (both from Lime Factory in Karbala) and ordinary Portland cement .

۳.۲ : Test Methods

۳.۲.۱ : Mixture Preparation

The aggregates are first dried to constant weight at 110°C , separated into the desired size and recombined with mineral filler in order

to meet the required gradation of each specimen.

The aggregates are then heated to a temperature of 100°C before mixing with asphalt cement. The asphalt cement is heated to a temperature, which produces a kinematic viscosity of (170 ± 20) centistokes (up to 163°C as an upper limit) using 100°C . Then, the asphalt cement is weighed to the desired amount and added to the heated aggregates, and mixed thoroughly until all aggregates particles are coated with asphalt.

۳.۲.۲: Resistance to Plastic Flow (Marshall Method)

The procedure of preparation and testing specimens according to this

method are described in **ASTM D-1۵۵۹**. A cylindrical specimen (63.5 mm (۲.۵ in) height with diameter (۱۰۱.۶) mm (۴.۰ in) is compressed on the

lateral surface by means of Marshall apparatus with a constant rate of 0.8 mm/min (1/8 in /min) until the maximum load is reached .

The maximum load resistance and the corresponding strain values are recorded as Marshall stability and flow respectively, at a test temperature of 60 ° C.

The bulk specific gravity and density (**ASTM D - 2922**), theoretical (maximum) specific gravity (**ASTM D - 2041**) and percent air voids (**ASTM D - 2043**) are determined for each specimen. The test specim

are compacted using 20 blows/end.

Three specimens for each combination are tested and the average results are reported.

3.2.3 : Uniaxial Repeated Cyclic Creep Test

The uniaxial load compression creep test has been used for testing asphalt mixes. The consolidation apparatus for soils, shown in Figure (3-2) is employed to perform this test. The creep test specimens, 63.5 mm (2.5 in.) in diameter and 127 mm (5 in.) in height, are prepared in accordance with **ASTM D - 1557**. The test starts about 24 hours after preparing specimens and allowed to cool at room temperature.

The specimens are placed in the chamber at the specific test temperature for 2 hours before testing (**ASTM**). Creep tests are carried out at a temperature of 20, 40, and 60 °C.

Three stresses for each temperature: 28 KPa, 50 KPa and 83 KPa are used for repeated cyclic creep and recovery test . The test consists of seven cycle, the periods of each cycle consist of (1000) second for loading and for unloading. The strains (deformations) are measured at selected time intervals of loading and unloading times (100, 200, 500, 700, and 1000 second). A static compaction of 6000, 4000 and 3000 PSI were used to compact specimens.

Two specimens for each combination are tested and the average results are reported. The total permanent strain versus incremental time of loading is plotted on log - log scale.



Figure (۳-۳) Wheel Tracking Apparatus

۳.۳ : Test Program of Asphalt Paving Mixture

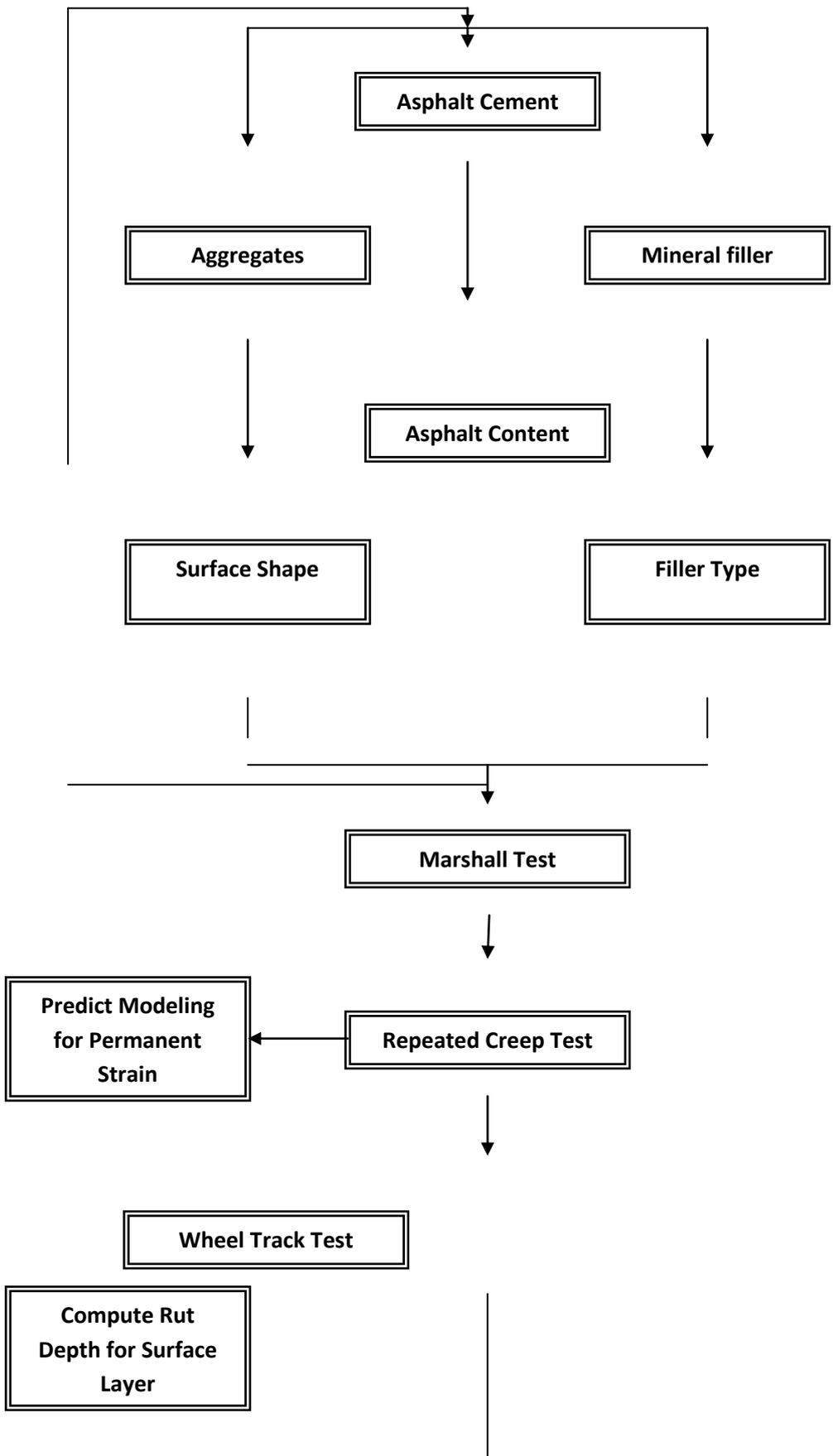
The following variables have been considered in preparing the asphalt concrete mixtures for different tests:

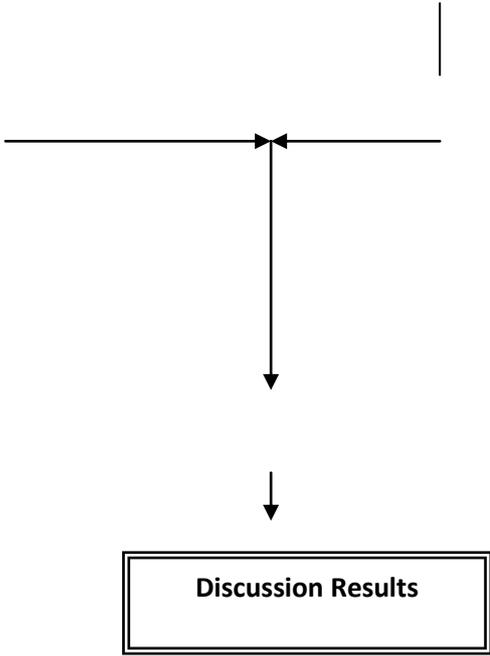
- ۱- Penetration grade is (۴۰-۵۰) from Durah refinery.
- ۲- Four asphalt cement contents (۴.۵, ۵.۵, ۶.۵ and ۷.۵) % by total weight of mix.
- ۳- Three types of mineral filler (limestone dust, hydrated lime and Portland cement)
- ۴- Three F/A ratios (۰.۶, ۰.۹, and ۱.۲) from(Portland cement).
- ۵- Three aggregates - surface shapes (۰, ۵۰, and ۱۰۰ % uncrushed).
- ۶- Three compaction efforts (۳۰۰۰, ۴۵۰۰ and ۶۰۰۰) Psi for ۵ minute of creep test.
- ۷- Three grades of fines(below, through and above) the restricted zone.

More details about the different mixture variables and the flowchart used in this work are presented in Table (٣-٣) and Figure (٣-٤) respectively.

Table (۳-۳) A Key for the Different Mixture Variables Used in the Work

Mix No.	۱	۲	۳	۴	۵	۶	۷	۸	۹	۱۰	۱۱	۱۲	۱۳	۱۴
۴.۵ % A-C		*												
۵.۵ % A-C	*				*	*	*	*	*	*	*	*	*	*
۶.۵ % A-C			*											
۷.۵ % A-C				*										
Portland cement filler	*	*	*	*			*	*	*	*	*	*	*	*
Limestone filler					*									
Hydrated lime filler						*								
۰.۶ F/A ratio							*							
۰.۹ F/A ratio								*						
۱.۲ F/A ratio	*	*	*	*	*	*			*	*	*	*	*	*
Fines below restricted zone	*	*	*	*	*	*	*	*			*	*	*	*
Fines through restricted zone									*					
Fines above restricted zone										*				
۳۰۰۰ PSI compaction effort		*	*	*	*	*					*			
۴۵۰۰ PSI compaction effort							*	*	*	*	*	*	*	*
۶۰۰۰ PSI compaction effort	*													
۱۰۰ % crushed agg.	*	*	*	*	*	*	*	*	*	*		*		
۵۰ % crushed agg.													*	
۰ % crushed agg.														*





٣.٤: Properties of Asphalt Concrete Mixtures

٣.٤.١: Marshall Stiffness

A series of tests for Marshall stability, flow and density – voids analysis are carried out for selecting the optimum asphalt content for mixture. The Marshall stiffness is calculated as the ratio between Marshall stability and corresponding flow for the different mixtures.

In this work, four different asphalt cement contents of (٤٠-٥٠) penetration grade are used from ٤.٥ to ٧.٥ percent (by weight of total mix) with an increment intervals of ١.٠ percent.

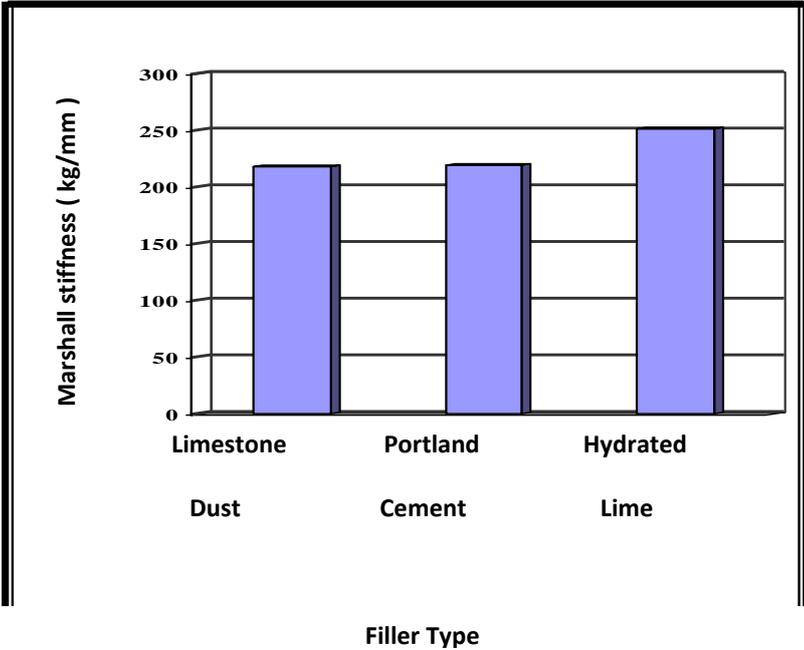
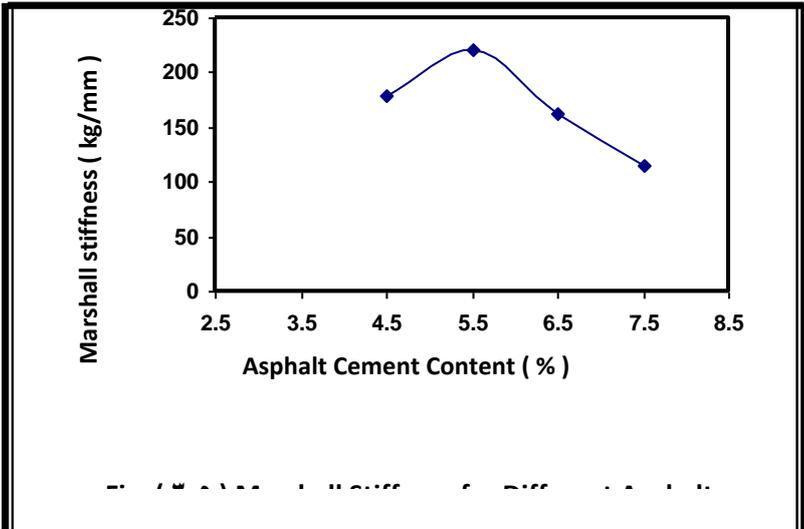
The Marshall test results are shown in Table (٣-٤), from which an optimum asphalt content of ٥.٥% is selected. Increased values of Marshall stiffness have been obtained by using optimum asphalt content, hydrated lime filler , fine aggregate above restricted zone , ١٠٠ % crushed aggregate and ١.٢ F/A ratio as shown in Figures (٣-٥) to (٣-٩)

Table (3-4) Main Properties of Different Variables of
Marshall Test specimens

MIXTURE		BULK G. (gm/cm ³)	THEORETICAL G. (gm/cm ³)	% AIR VOIDS	MARSHALL STABILITY (kg)	MARSHALL FLOW (mm)	MARSHALL STIFFNESS
NO.	VARIABLE						
1	0.0 % A S C	2.360	2.471	4.2	838	3.8	220.028
2	4.0 % A S C	2.303	2.007	8.10	610	3.40	178.260
3	6.0 % A S C	2.382	2.436	2.21	743.9	4.6	161.717
4	7.0 % A S C	2.302	2.402	2.08	099.97	0.2	110.38
1	Portland cement filler	2.360	2.471	4.2	838	3.8	220.028
0	Limestone dust filler	2.383	2.481	3.8	860	3.90	218.987
6	Hydrated lime filler	2.373	2.460	0.2	930	3.7	202.702
7	0.6 F/A ratio	2.306	2.468	7.2	740	4.0	164.444
8	0.9 F/A ratio	2.362	2.469	6	770	4.3	180.232
1	1.2 F/A ratio	2.360	2.471	4.2	838	3.8	220.028
9	Fines through restricted zone	2.372	2.469	3.6	939	3.92	239.04
10	Fines above restricted zone	2.380	2.468	3.1	893	3.06	200.842

1	Below restricted zone	2.360	2.471	4.2	838	3.8	220.028
1	100% Crusher aggregate	2.360	2.471	4.2	838	3.8	220.028
13	50% Crusher aggregate	2.366	2.470	3.72	774.9	4.4	176.113
14	0% Crusher aggregate	2.367	2.481	3.19	762.68	4.63	164.720

CHAPTER 3 *Materials and Testing*



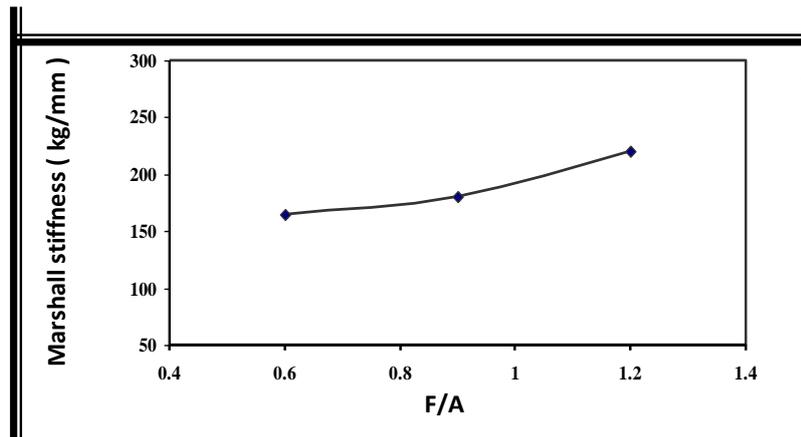


Fig. (3-7) Marshall Stiffness for Different F/A Ratio

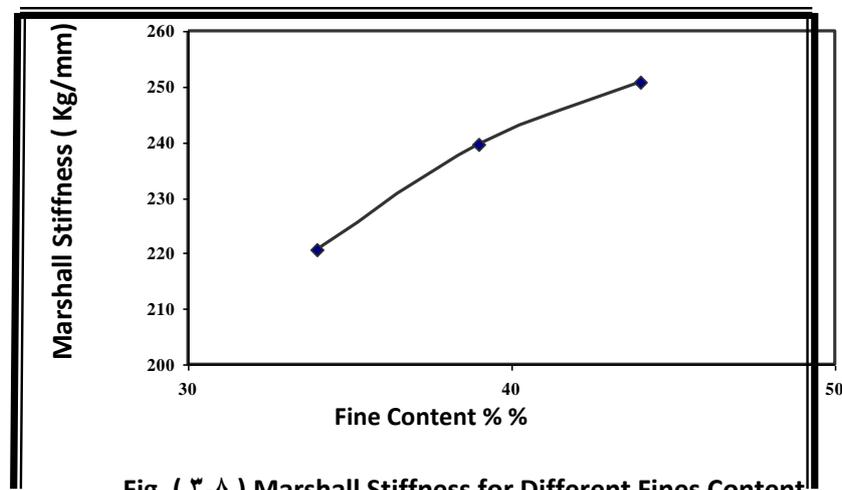


Fig. (3-8) Marshall Stiffness for Different Fines Content

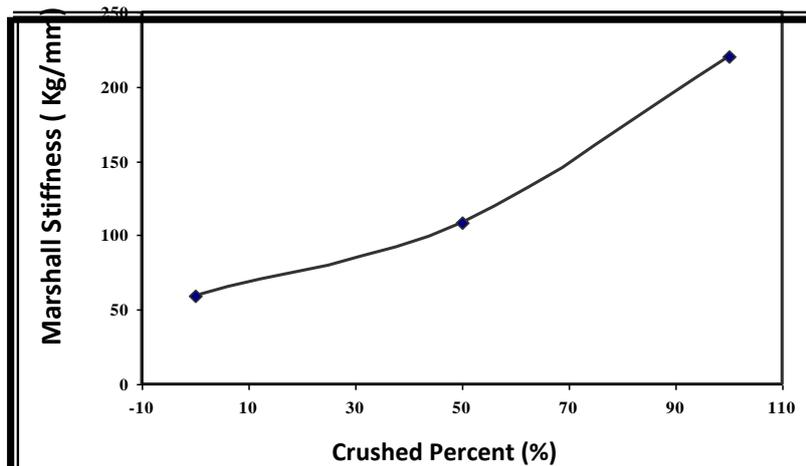


Fig. (٣-٩) Marshall Stiffness for Different Surface Shape

٣.٤.٢ : Uniaxial repeated Cyclic Creep Test

For evaluating the permanent strain with different asphalt concrete mixtures, uniaxial static repeated cyclic creep tests are conducted on mixes prepared with six main variables presented in Table (٣-٣).

Creep compliance as a function of loading time for mixtures with different variables increases as loading time increases for all mixtures and represented the reciprocal of mixture stiffness.

Figure (٣-١٠) shows a typical strain to a step removal of stress at time $t=t_1$. Using the following notations:

σ = Applied stress

A = Instantaneous strain noted with ϵ . (mm/mm)

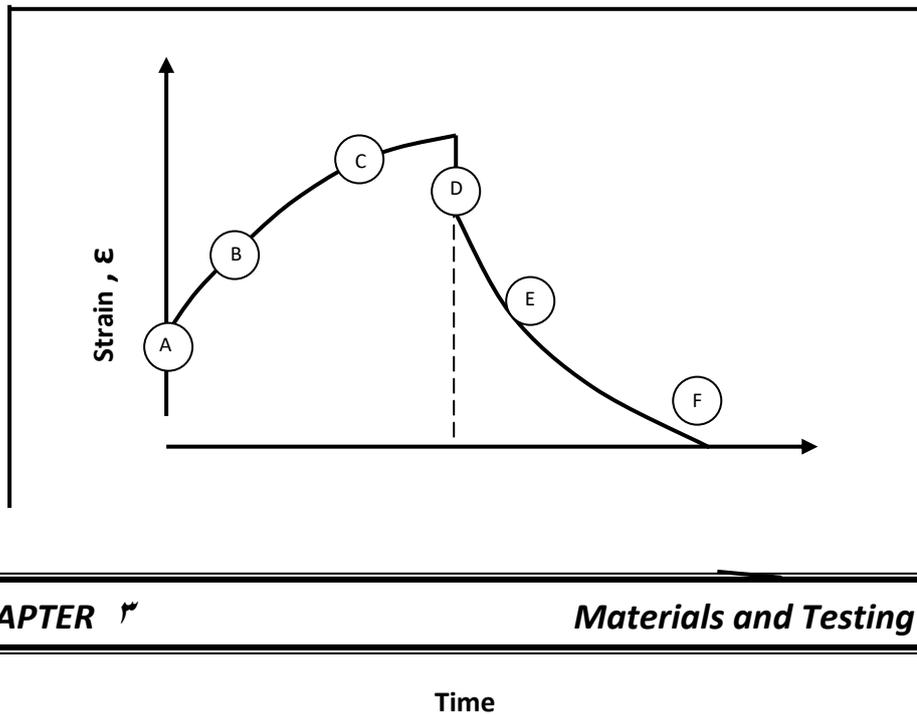
B = Delayed strain

C = Creep under constant stress noted with ϵ_t (mm/mm)

D = Instantaneous recovery noted with ϵ_r (mm/mm)

E = Delayed recovery

F = permanent incremental deformation noted with ϵ_p (viscous)
(mm/mm)



Time

Figure (3-10) Typical Strain – Time Relation

(Collop et al., 1992)

$$S_{mix(t)} = \frac{\sigma}{\epsilon_t} \dots\dots\dots 3-1$$

$$\text{Creep Compliance} = \frac{1}{S_{mix}} \dots\dots\dots 3-2$$

Uniaxial repeated static creep tests are conducted at three different temperatures (20, 40 and 60) °C with three different applied stresses (28, 50 and 83) KPa in order to show the effect of variation in temperatures and stress on permanent deformation of asphalt paving mixture.

The main properties of the different mix as used in this work including bulk specific gravity, theoretical specific gravity and percent of air voids are shown in Table (3-5), where creep test results (recorded strain corresponding creep compliance for each time loading and unloading) are presented in appendix (A).

Decreased values of permanent strain (increased in stiffness of mixture) obtained by using optimum asphalt content, hydrated lime filler , fine aggregate blow restricted zone , 100 % crushed aggregate, 6000 PSi compaction effort and 1.2 F/A ratio as shown in Figures (3-11) to (3-22).

Table (3-5) Main Properties of Creep Test Specimens.

MIXTURE		BULK G. (gm / cm ³)	THEORETICAL G.(gm / cm ³)	% AIR VOIDES
NO.	VARIABLE			
1	0.0 % Asphalt Cement Content	2.370	2.471	4.08
2	4.0 % Asphalt Cement Content	2.301	2.507	8.2
3	6.0 % Asphalt Cement Content	2.306	2.436	5.33
4	7.0 % Asphalt Cement Content	2.309	2.402	3.87
1	Portland Cement (Filler)	2.370	2.471	4.08
0	Limestone Dust (filler)	2.309	2.481	6.96
6	Hydrated lime (filler)	2.348	2.460	4.73
7	0.6 F/A Ratio	2.343	2.468	5.00
8	0.9 F/A Ratio	2.346	2.469	4.97
1	1.2 F/A Ratio	2.370	2.471	4.08
9	Fines Through Restricted Zone	2.374	2.469	3.84
10	Fines Above Restricted Zone	2.376	2.468	3.72

၂	Fines Below Restricted Zone	၃. ၃၇.၀	၃. ၄၇၂	၄. ၀၈
၂၂	၃၀၀၀ PSI Compaction Effort	၃. ၃၀၄	၃. ၄၇၄	၀. ၇၃
၂၃	၄၀၀၀ PSI Compaction Effort	၃. ၃၀၂	၃. ၄၇၃	၄. ၈
၂	၆၀၀၀ PSI Compaction Effort	၃. ၃၇.၀	၃. ၄၇၂	၄. ၀၈
၂	၂၀၀ % Crushed Agg.	၃. ၃၇.၀	၃. ၄၇၂	၄. ၀၈
၂၃	၀၀ % Crushed Agg.	၃. ၃၀.၂	၃. ၄၇၀	၇. ၀၂
၂၄	၀ % Crushed Agg.	၃. ၃၈၆	၃. ၄၈၂	၇. ၈၀

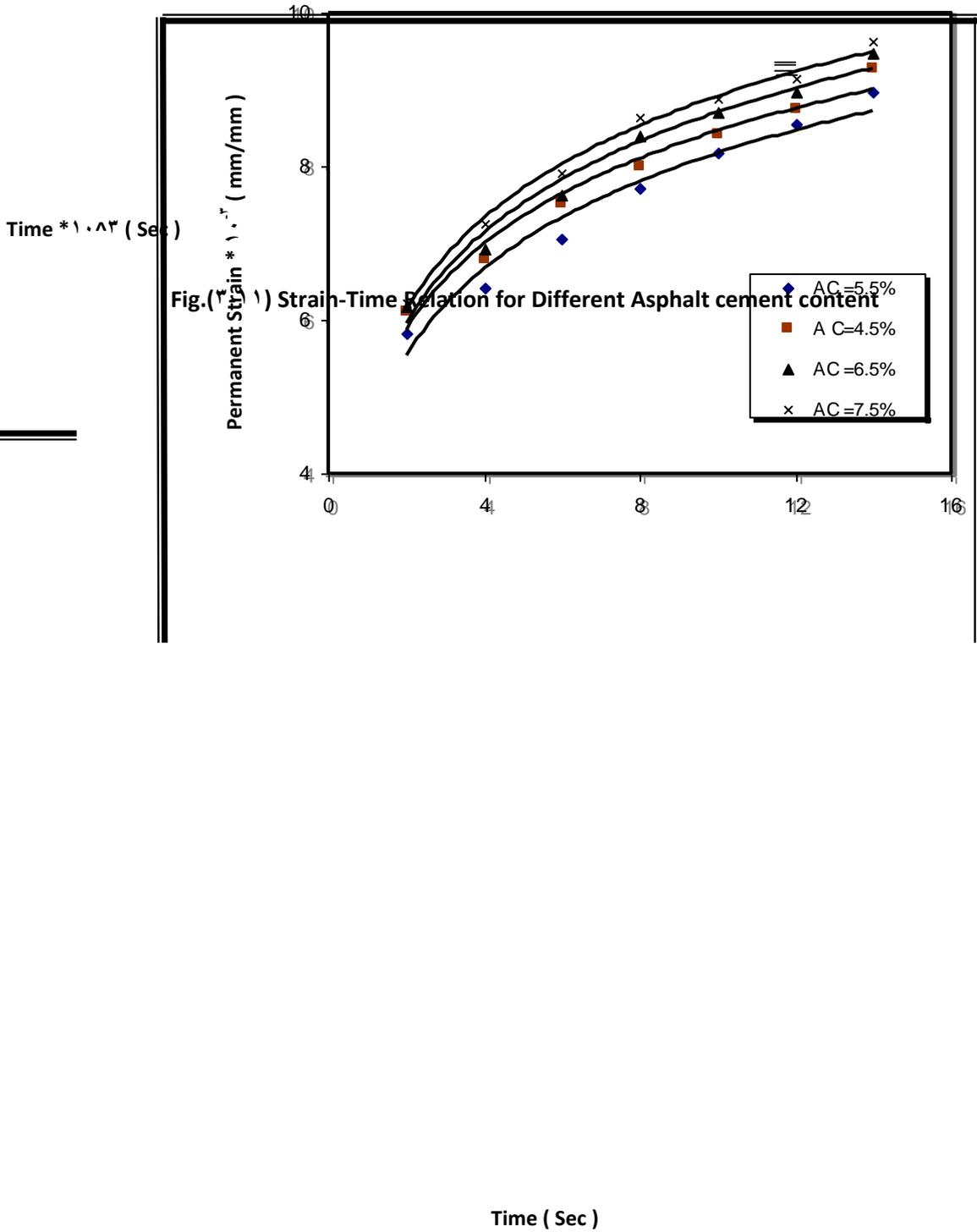
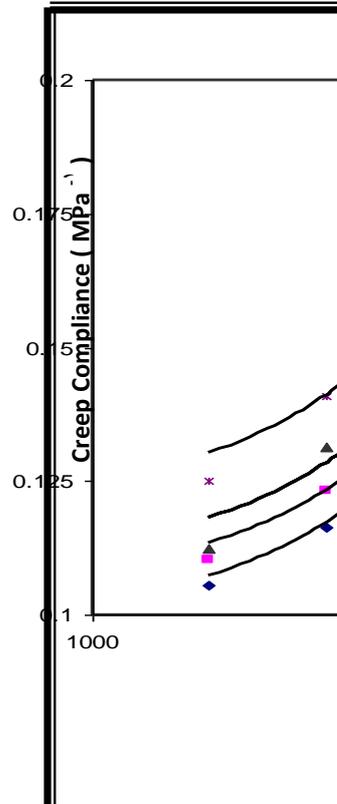
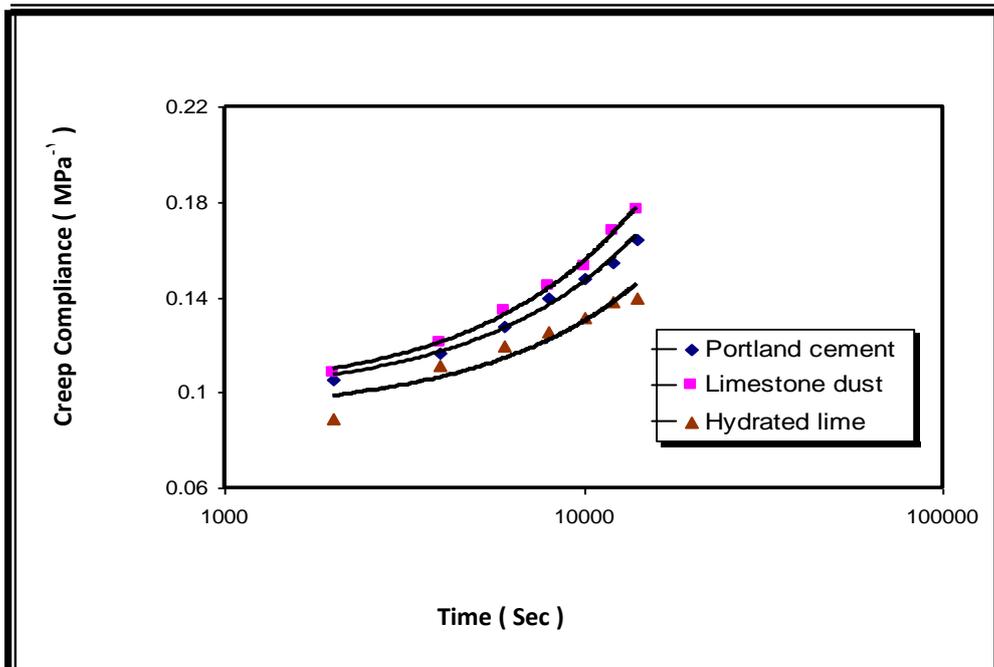
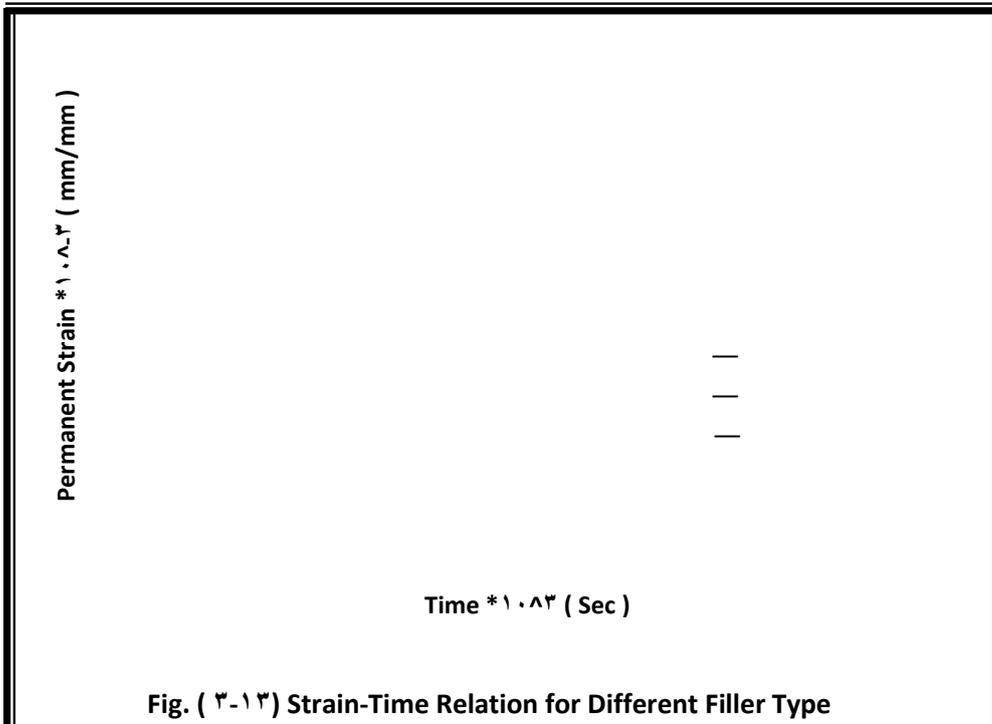
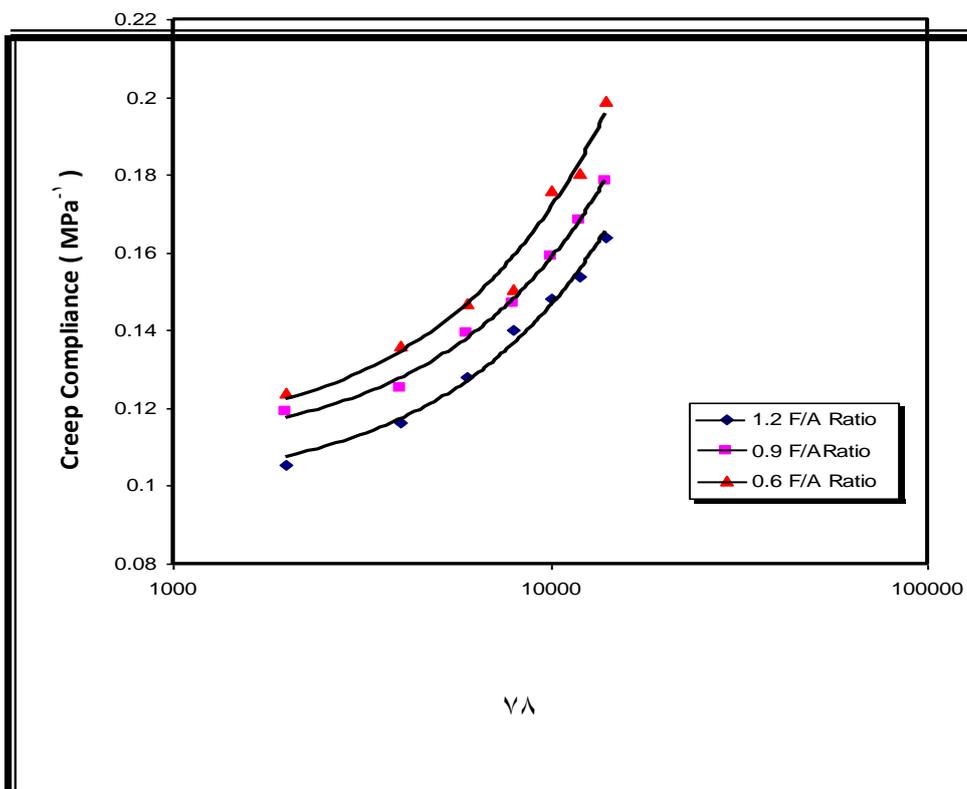
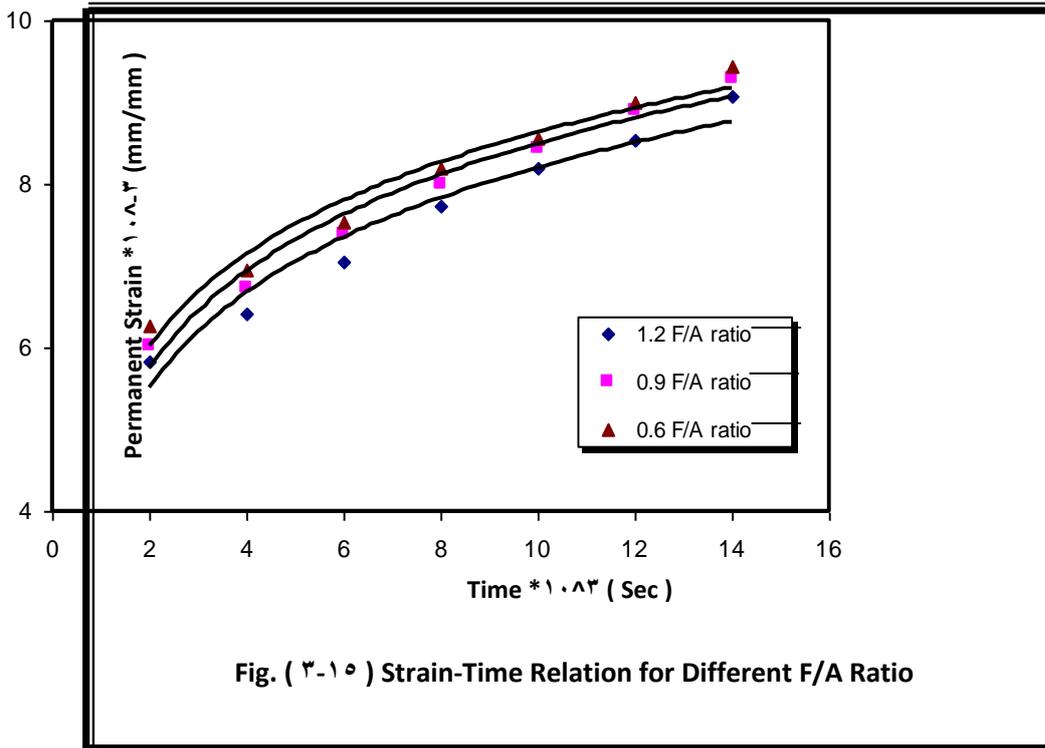


Fig. (3-12) Creep Compliance-Time Relation for Different Asphalt Cement Content

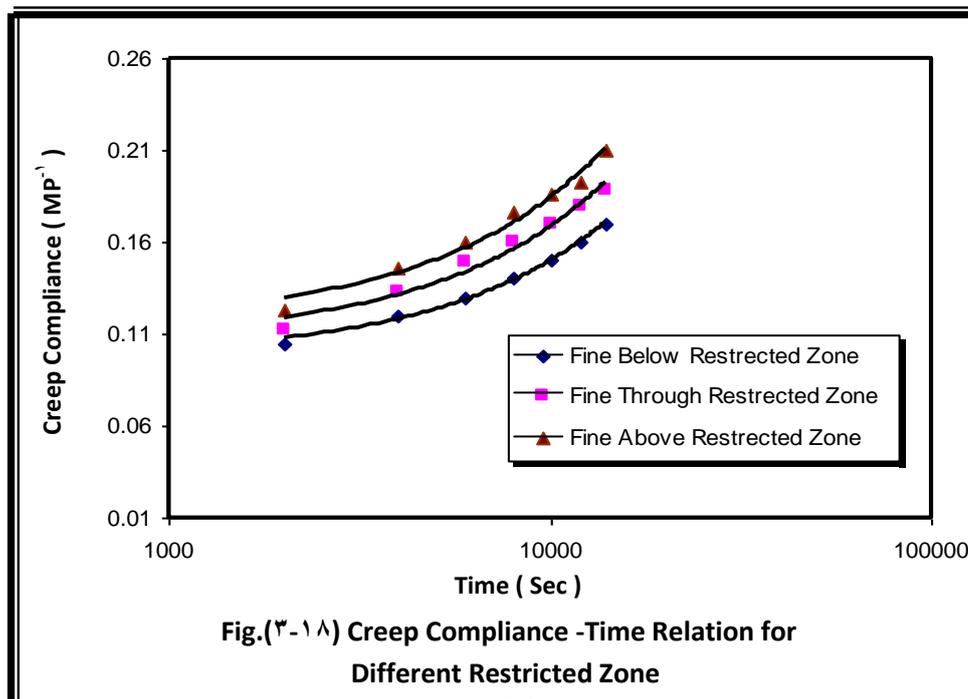
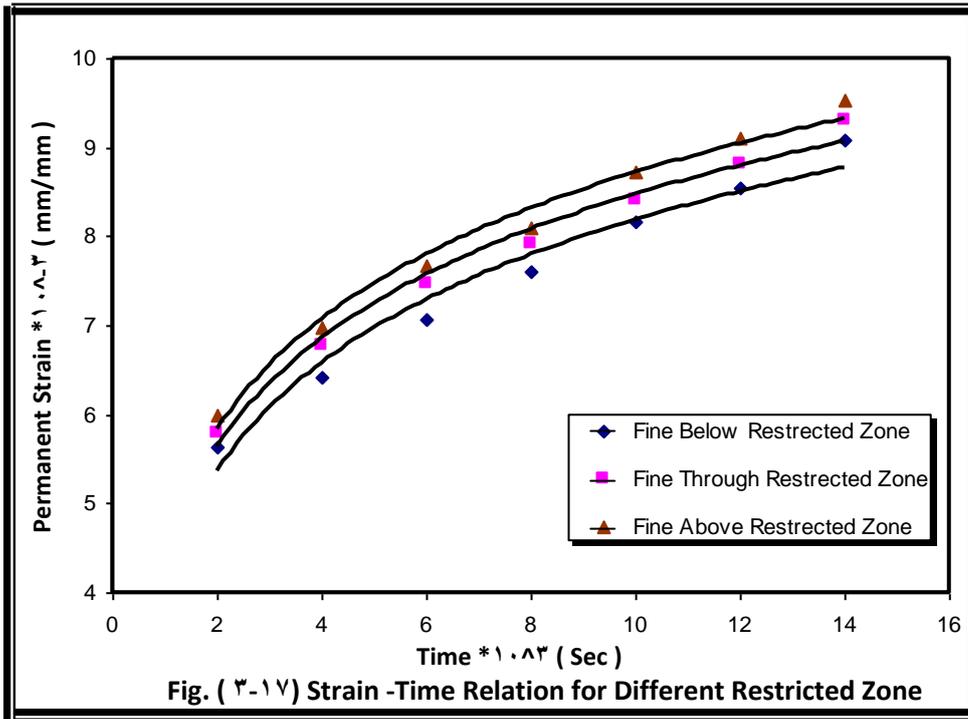






Time (Sec)

CHAPTER 3
Fig. (3-14) Creep Compliance-Time Relation for Different F/A Ratio
Materials and Testing



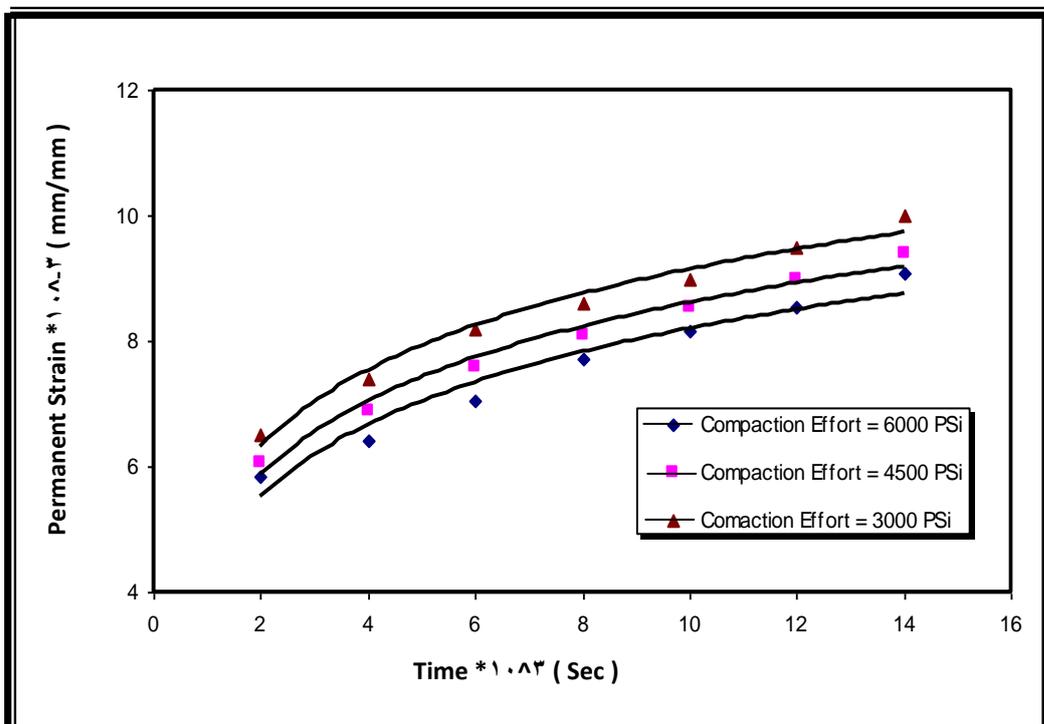
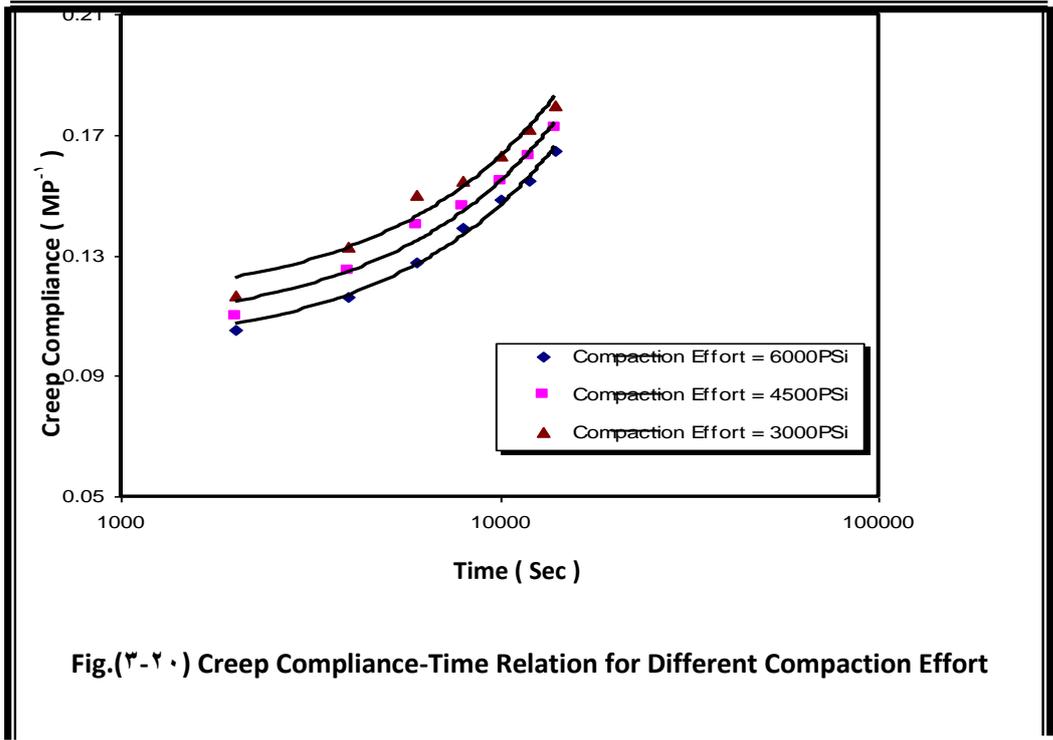
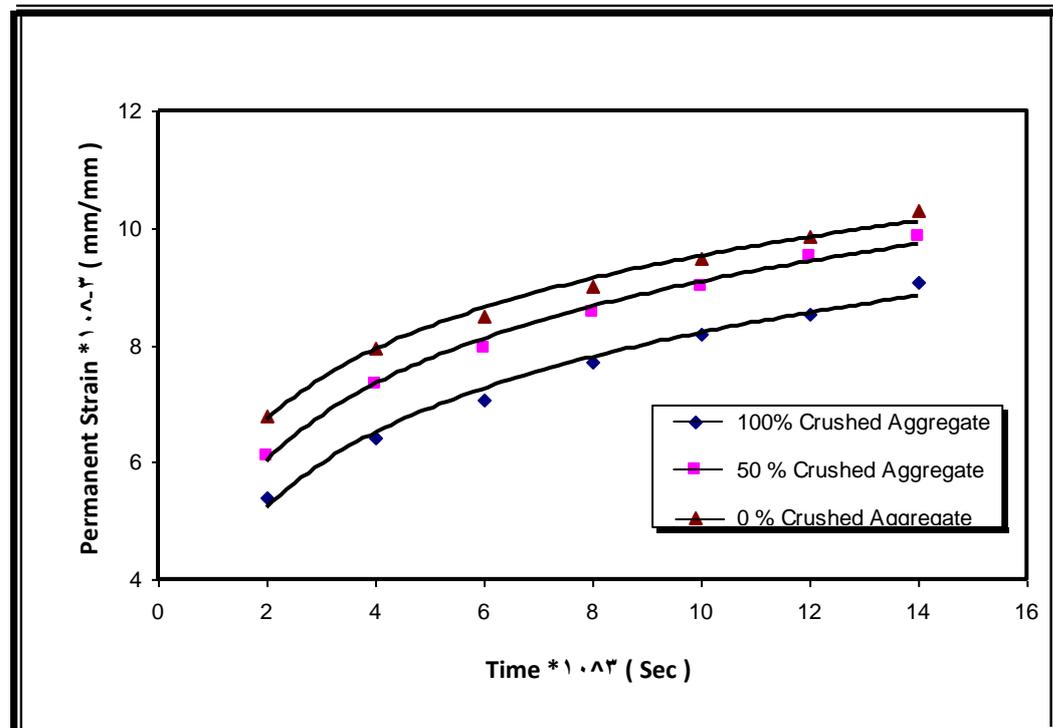
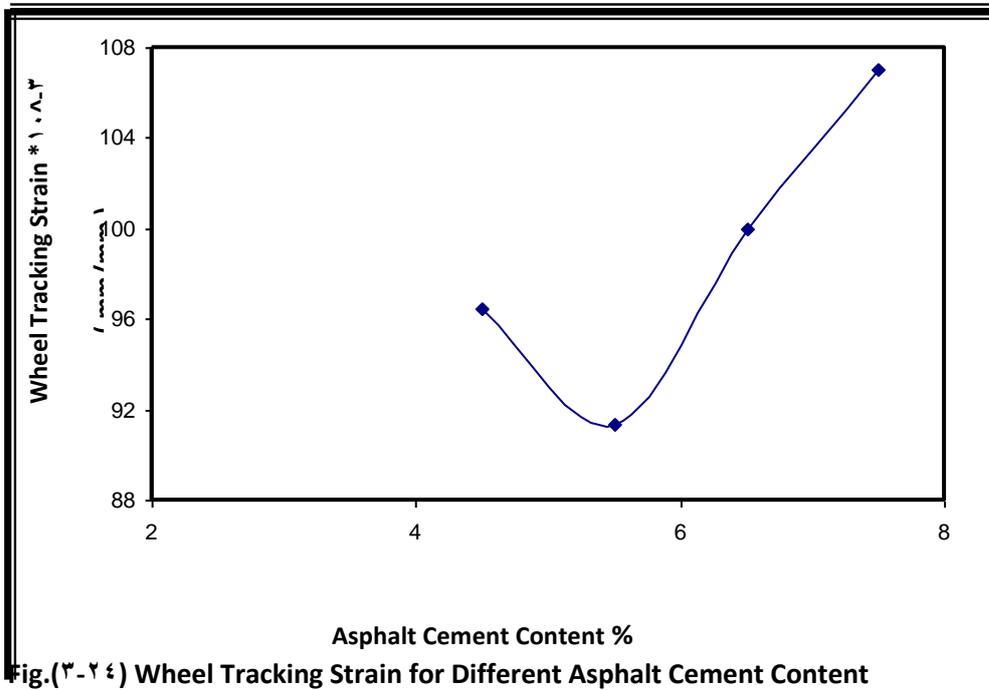
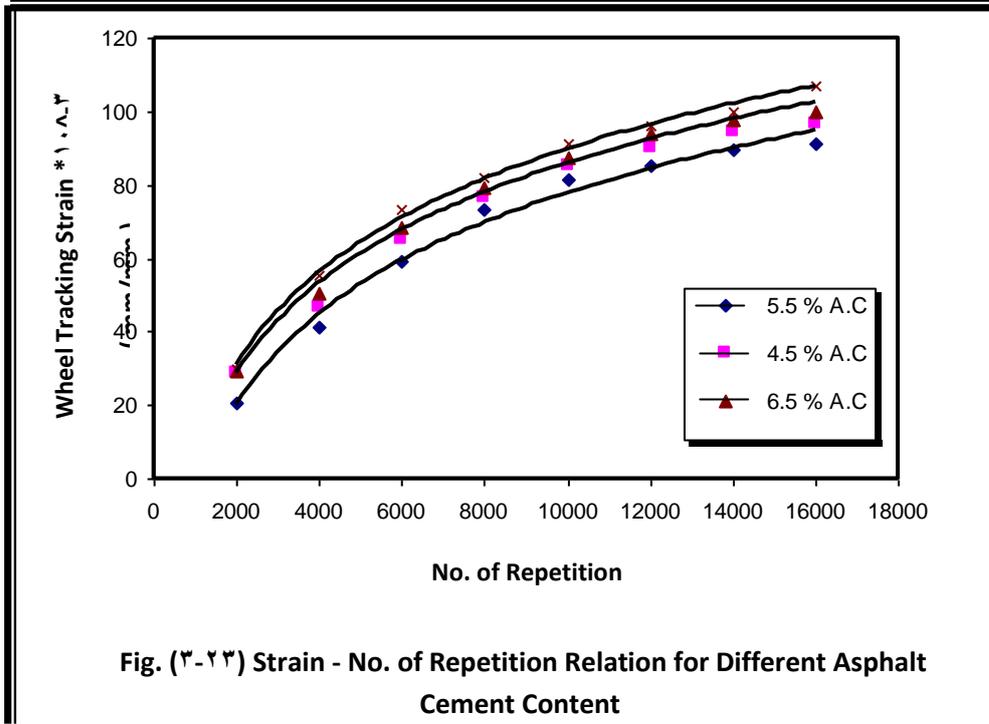


Fig. (3-19) Strain -Time Relation for Different Compaction Effort



CHAPTER 3 *Materials and Testing*





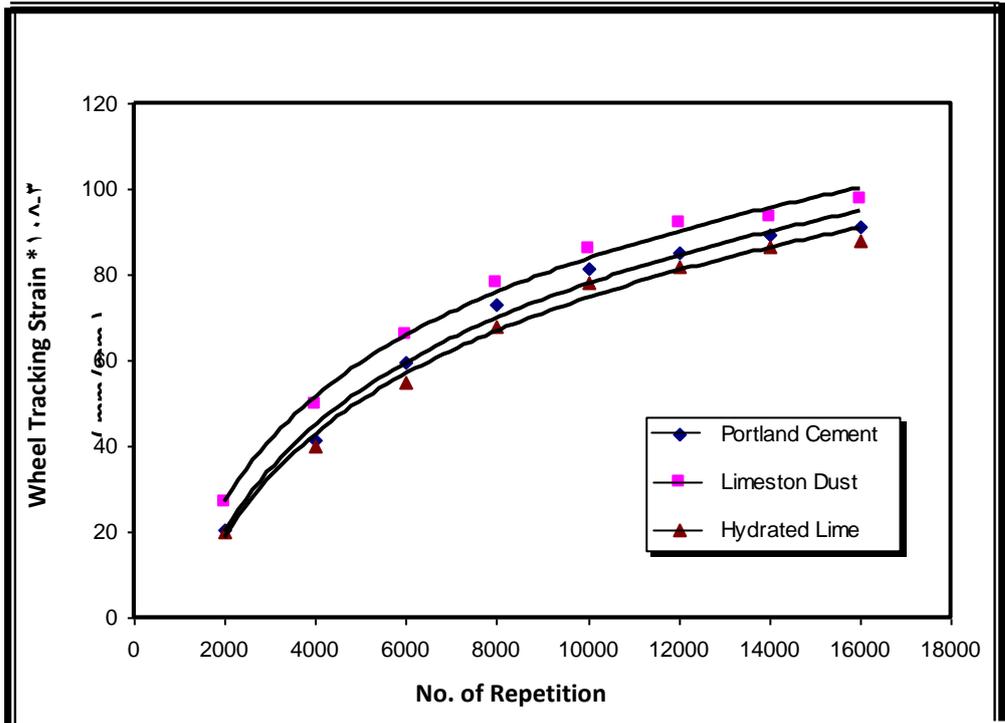


Fig. (۳-۲۵) Strain - No. of Repetition Relation for Different Filler Type

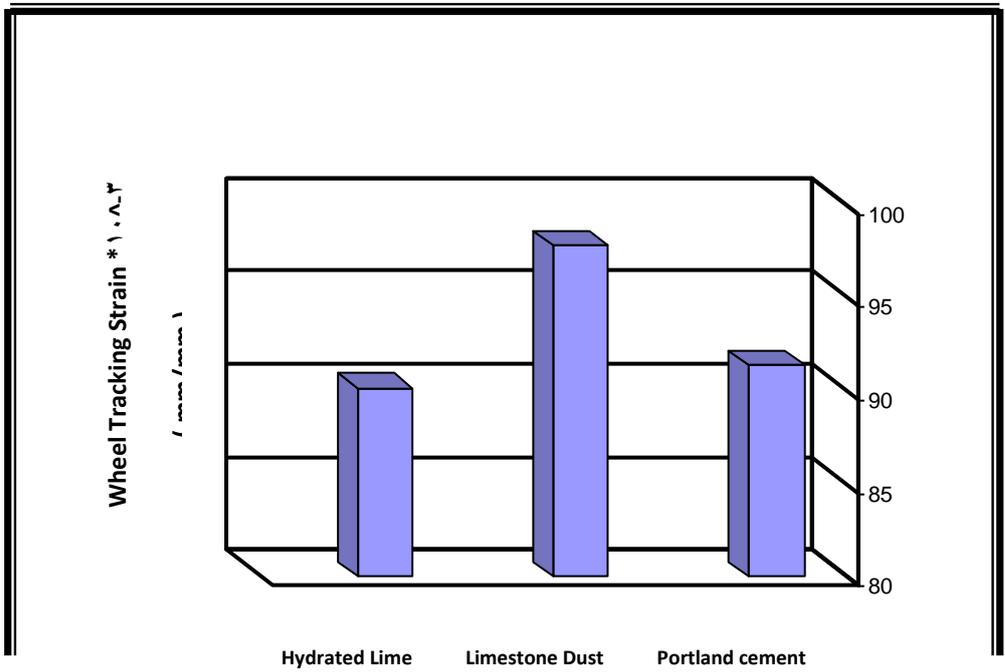


Fig. (۳-۲۶) Wheel Tracking Strain for Different Filler Type

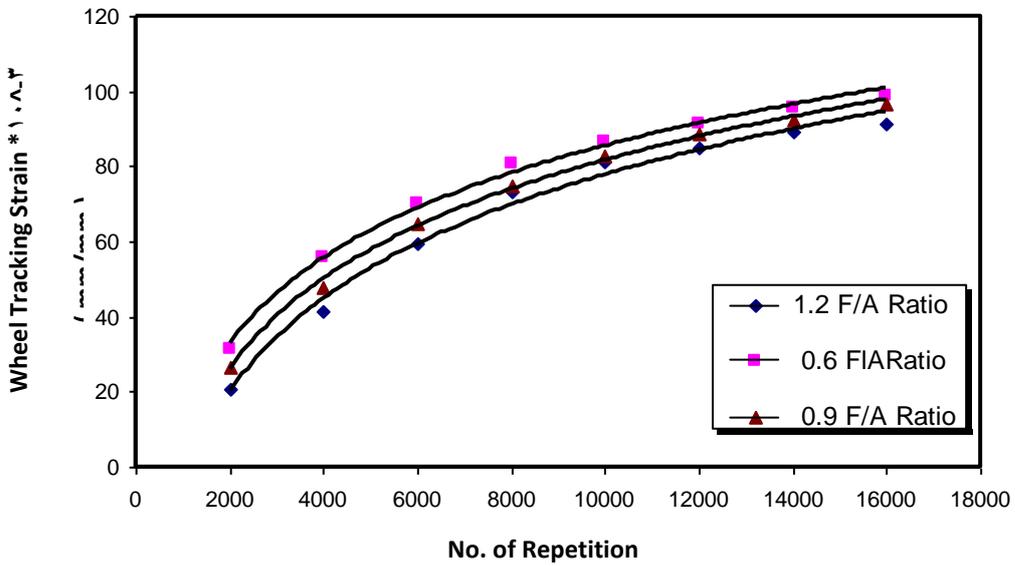


Fig. (3-27) Strain - No. of Repetition Relation for Different F/A Ratio

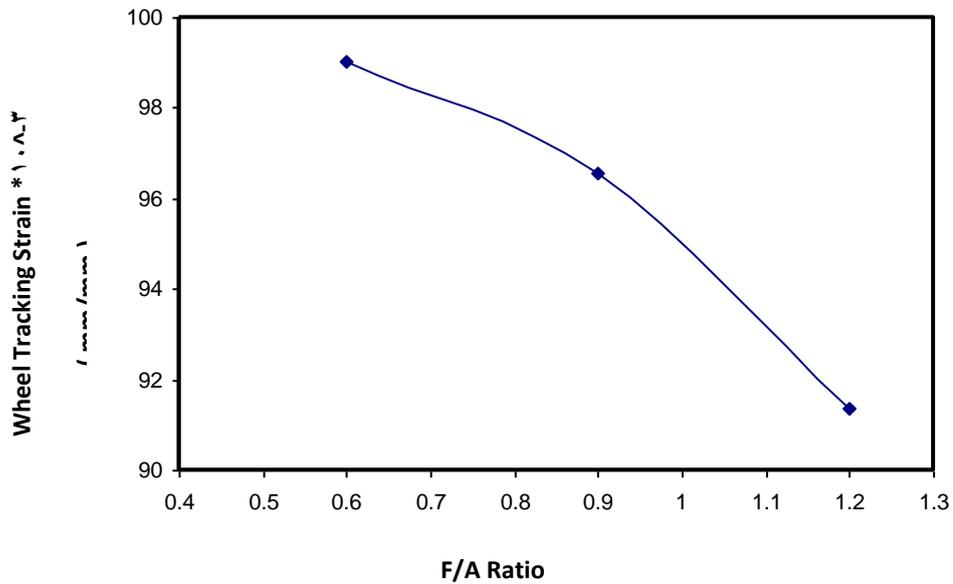


Fig. (3-28) Wheel Tracking Strain for Different F/A Ratio

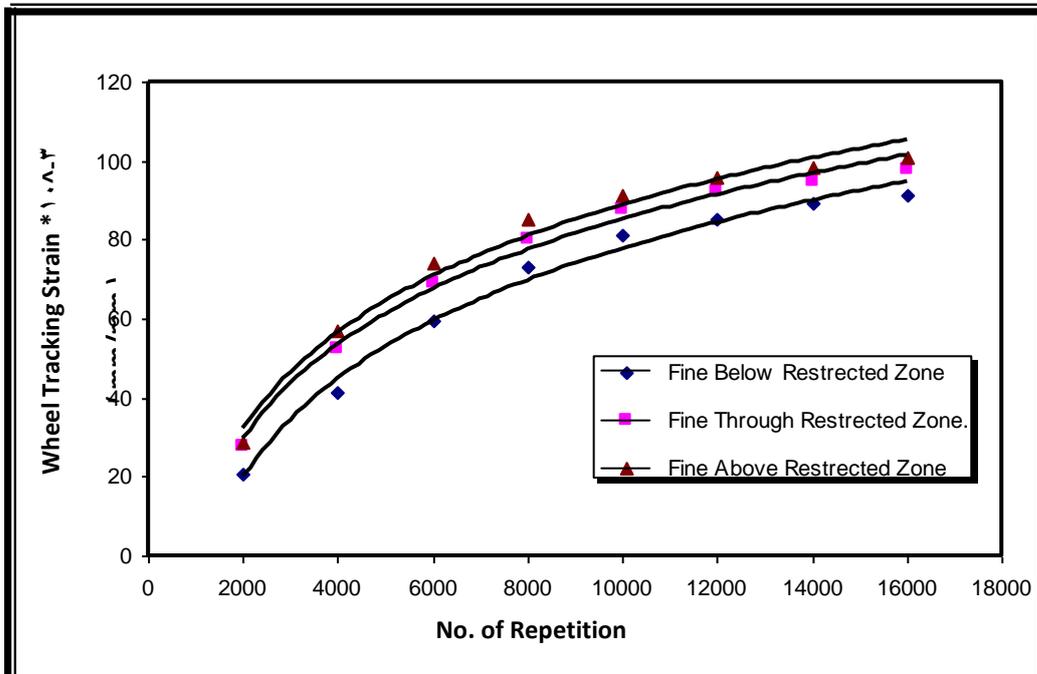


Fig. (3-29) Strain - No. of Repetition Relation for Different Restricted Zone

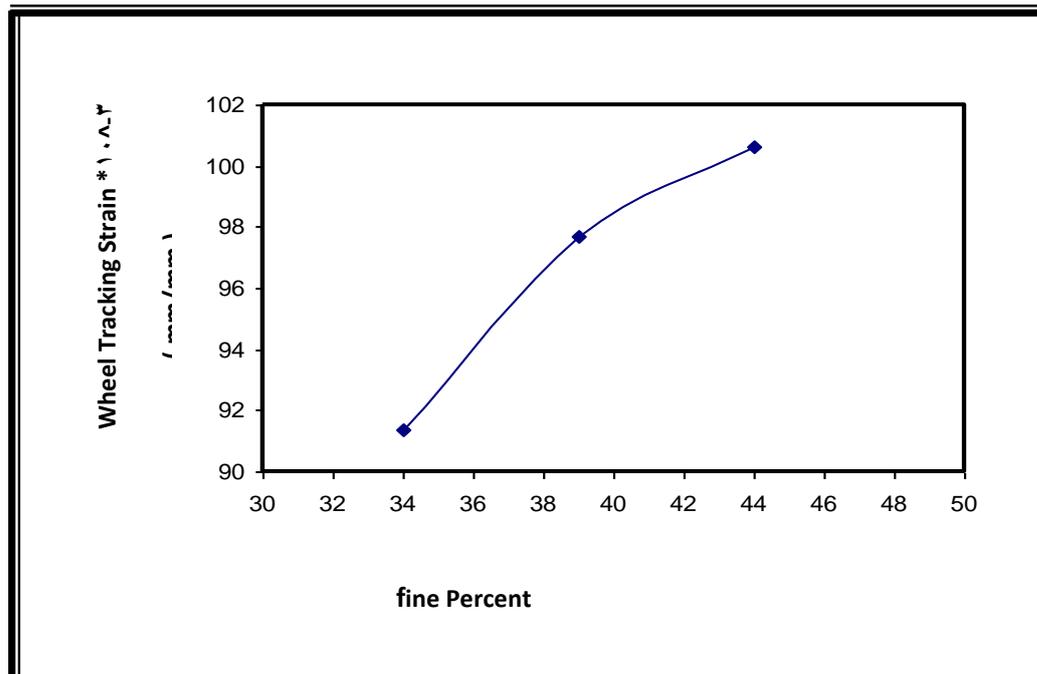


Fig. (3-30) Wheel Tracking Strain for Different Restricted Zone

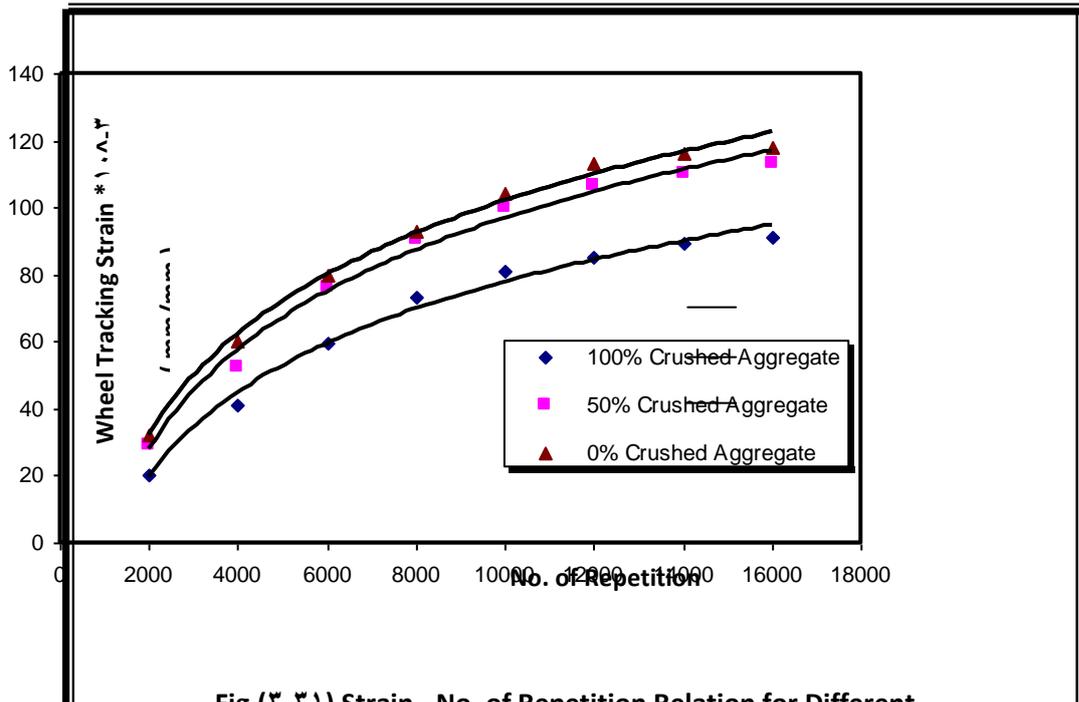


Fig.(3-31) Strain - No. of Repetition Relation for Different Crusher Percent

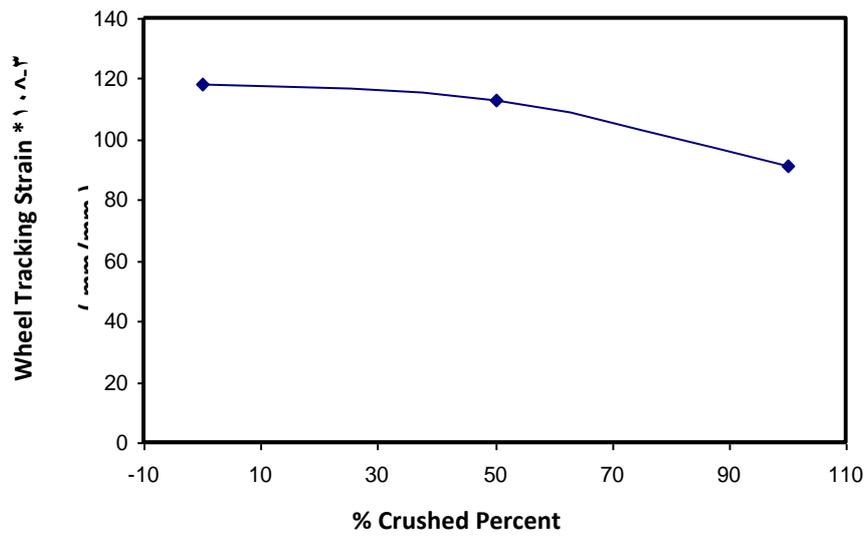


Fig. (٣-٣٢) Wheel Tracking Strain for Different Crushed Percent

Thus, as final conclusions from the experimental work, the following points could be drawn:

۱. Marshall stiffness is increased when using crushed aggregate , hydrated lime according to the type of filler and decreased for asphalt cement higher than the optimum value.
۲. Using the superpave suggested gradation below the restricted zone gives a good resistance of the asphalt mixtures to permanent deformation.
۳. Using hydrated lime gives less amount of permanent deformation as compared with other types of filler.

Thus, from a total of ۹۲ samples prepared and tested for this work, the lower permanent deformation and higher Marshall stiffness mixture could be within ۵.۵ % asphalt cement content, ۱.۲ F/A ratio, fines below restricted zone and ۱۰۰ % crushed aggregates could be treated as a standard mix and used to prepare the samples for repeated cyclic creep and recovery test to formulate the predicted model.

CHAPTER FOUR
MODELING OF RUTTING IN LOCAL
ASPHALT PAVEMENT

4. 1: Introduction

Permanent deformation in bituminous pavements is treated as a visco-elastic flow phenomenon or visco-plastic or combination of them. It is shown that for a linear visco-elastic system, permanent deformation is independent of the elastic parameters of the materials, but may be deduced from a linear elastic model supplied with viscose parameters. In visco-plastic, permanent deformation is a function of time, level of stress state, number of cycles and material parameters. The focus of the work is limited to predict permanent strain at intermediate and high temperatures. The visco-plastic material parameters could be evaluated from repeated cyclic creep and recovery test for a representative asphalt concrete mixture.

The model considers permanent strain of asphalt concrete behavior over range of temperatures, number of load repetitions and levels stress pavement. It is designed to use in predicting permanent deformation in flexible pavements.

4.2: Modeling of Permanent Strain

Two approaches exist to predict rutting as a result of densification and plastic flow. The first approach is mostly used in pavement design procedures and limits deformation to be below a specified failure limit ; these models are not useful for performance modeling because of the need to predict not to limit, but the trend for rutting is during the live of the pavement (Paterson, 1987). The second approach predicts the trend of rutting during the live of pavement, and identifies the response of pavement to action of traffic, environment and maintenance. As such, the second approach is useful for pavement performance predictions.

A constitutive model was based on an extended form of the (David and Deen, 1980) and developed to be used for intermediate and high temperatures. This is conducted by using repeated cyclic creep and recovery testes in order to characterize the local asphalt concrete. The specimens underwent for seven loading cycles, each cycle consisted of 1000 second of creep under constant stress followed by 1000 second of creep recovery. The test was performed at three stress levels, each of them was applied under three degrees of temperature in order to evaluate the visco-plastic material parameters.

4.2.1: Mixture Building and Testing

The mixture consisted of crushed gravel aggregate and 6.0 percent asphalt cement content with grade 40-50 (AC - 20). The selected gradation of fine aggregate is below the restricted zone with air void content equal to 4.08 percent and 1.5 F/A ratio (used portland cement as filler). This mixture which

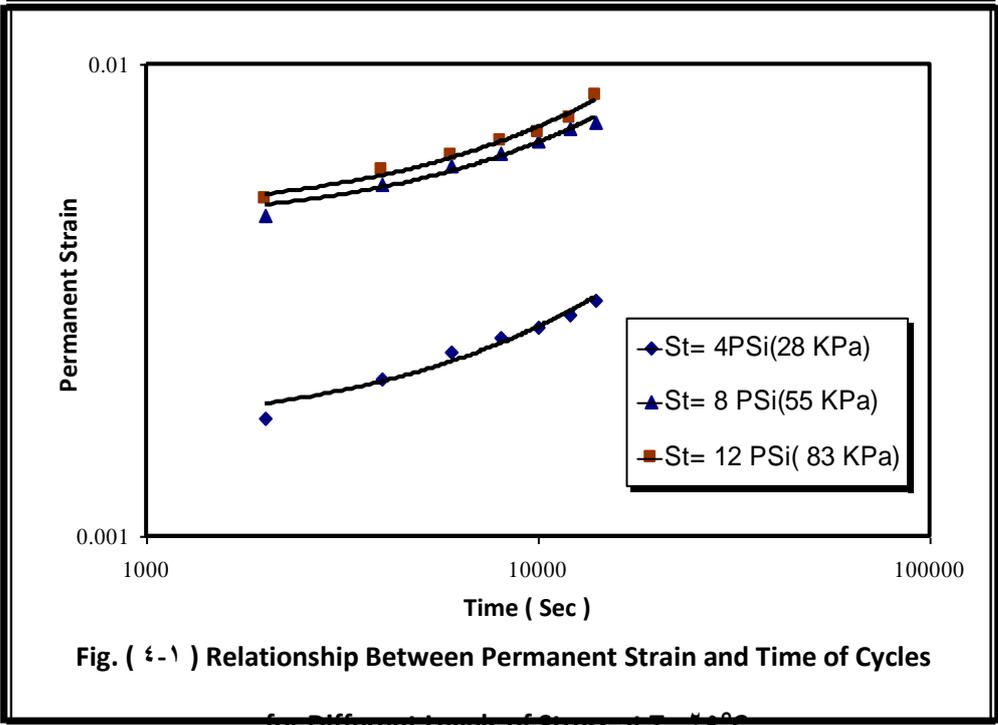
was used to prepare the samples was used for testing . Three levels of stress state were selected under three degrees of temperature.

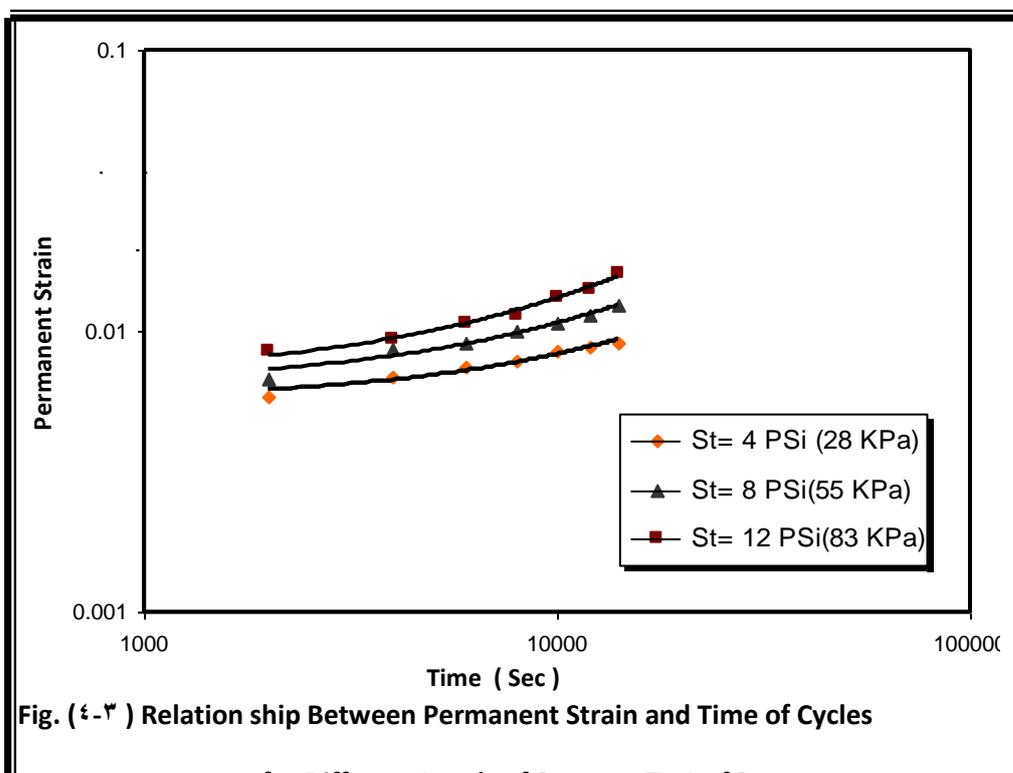
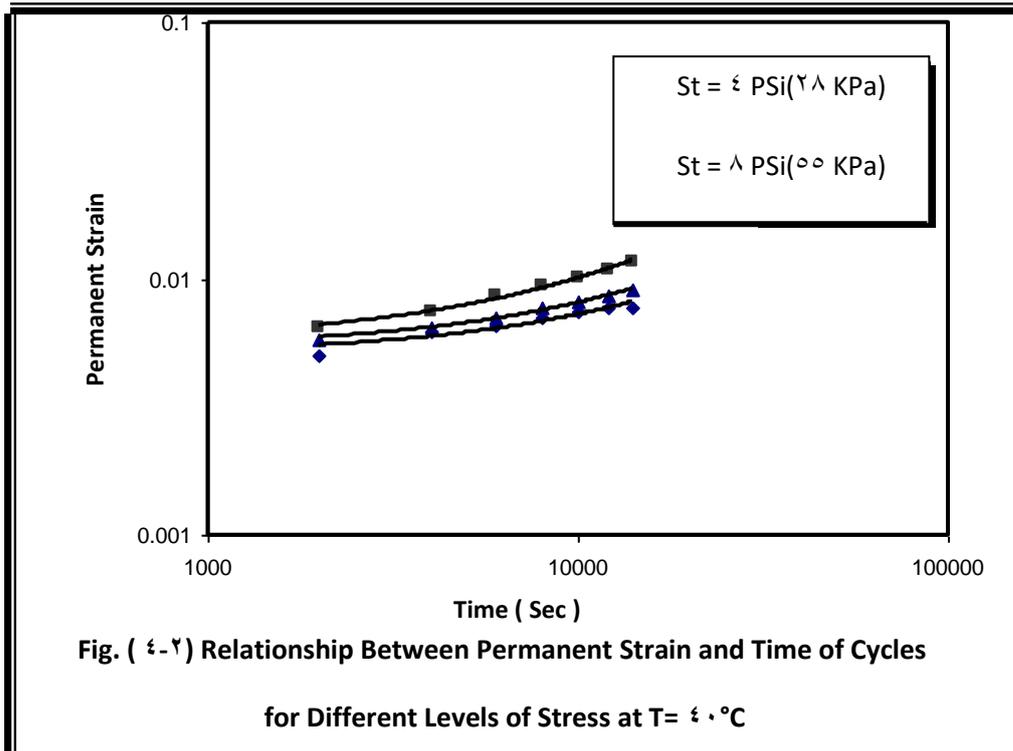
To build the proposed permanent strain model, a repeated cyclic creep and recovery test was conducted in order to characterize the asphalt concrete mixture. The obtained results were taken as an average of two samples as shown in appendix A. Because of the most relaxation occurred at the initial loading, the first reading is taken after (10 sec loading, 10 sec rest) as showed in

CHAPTER 4	Modeling of Rutting
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The procedure of this test is repeated for each of the selected three level of stress under each of the selected degrees of temperature in order to cover all the conditions concerned with stress state. The model could be applied to predict material behavior at other temperatures. The maximum degree of temperature was selected as (60 °C) due to the fast rate of failed samples in laboratory with temperature higher than this value.

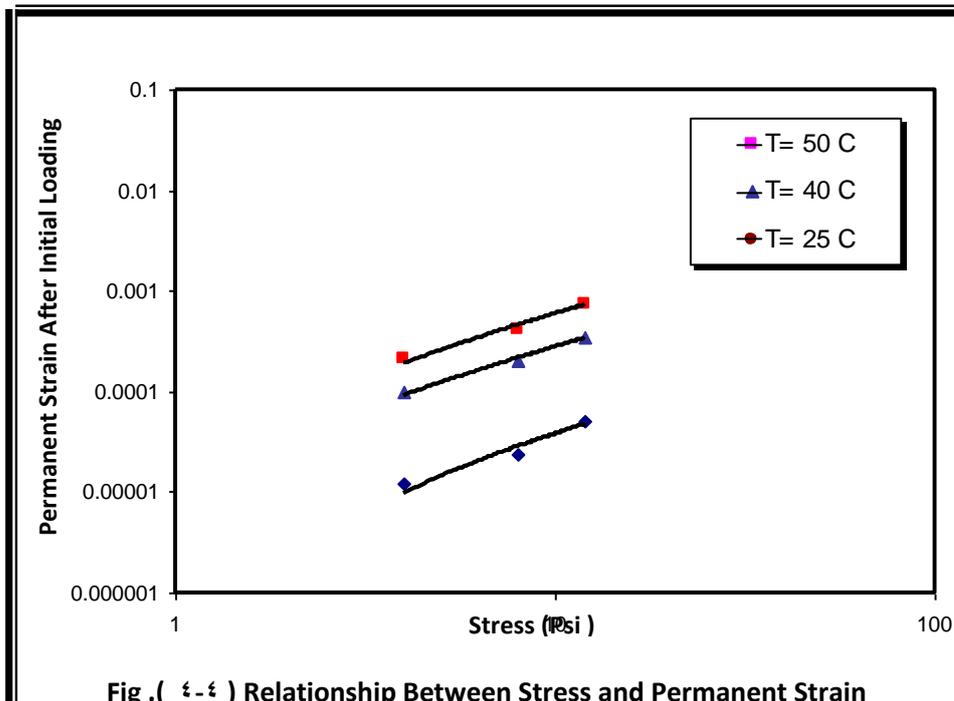
The permanent strain for each selected temperature under each of the three stress levels were plotted on log-log scale as shown in Figures (4-1 to 4-3) as a function of accumulative time of cycles.





4.2.2: Theoretical Formulation

Depending on the obtained data from the repeated cyclic creep and recovery test as showed in appendix a, the permanent strains after initial loading were plotted on log-log scale as a function of temperature and stress state as shown in Figure (4-4).



To determine the form of this interdependency from each test was plotted in Figure ($\xi-\xi$), the relationship between stress and permanent strain appeared to be linear. Therefore, the logarithmic slopes of the lines in Figure ($\xi-\xi$) were plotted as a function of temperature as illustrated in Figure ($\xi-\circ$). A linear regression analysis of the data plotted in Figure($\xi-\circ$) yielded the

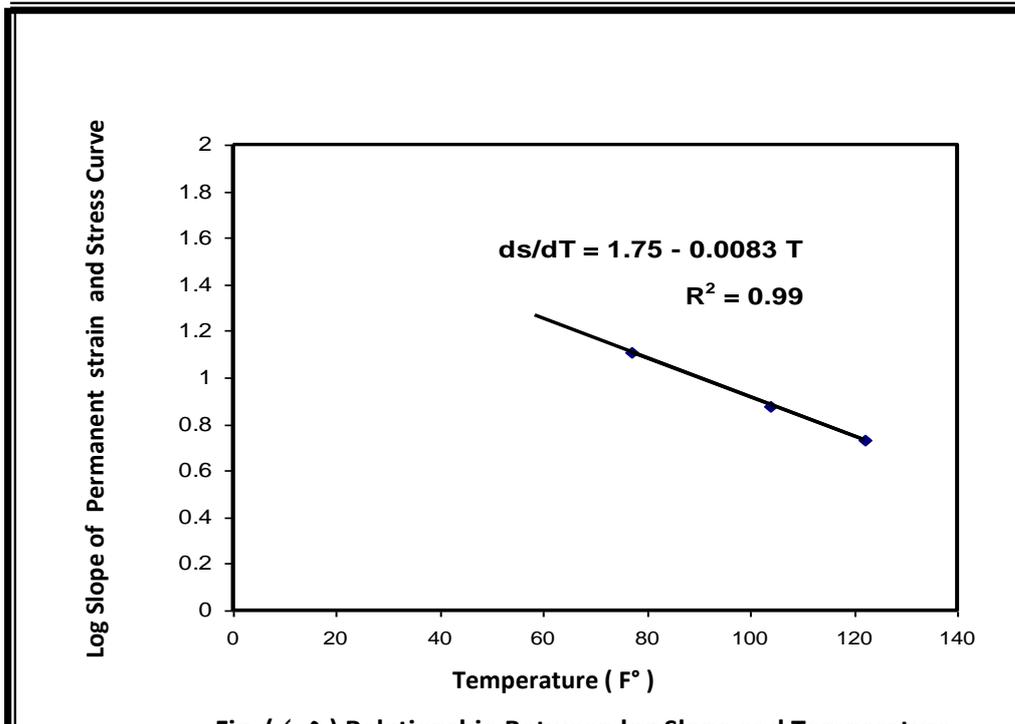


Fig. (4-5) Relationship Between log Slope and Temperature

$$ds/dT = 1.75 - 0.0083T \dots\dots\dots 4-5$$

in which

ds/dT= logarithmic slope of permanent strain versus stress curves and

T= temperature (F).

Also, the curves in Figure (4-4) could be extrapolated to a stress of (1) psi and those intersected values (b) with Y-axis in which, it is represented by the permanent strain are plotted as a function of temperature, as shown in Figure (4-6). A non-linear regression analysis performed on these data indicated that logarithm of the intersection values varied with temperature according to the following equation:

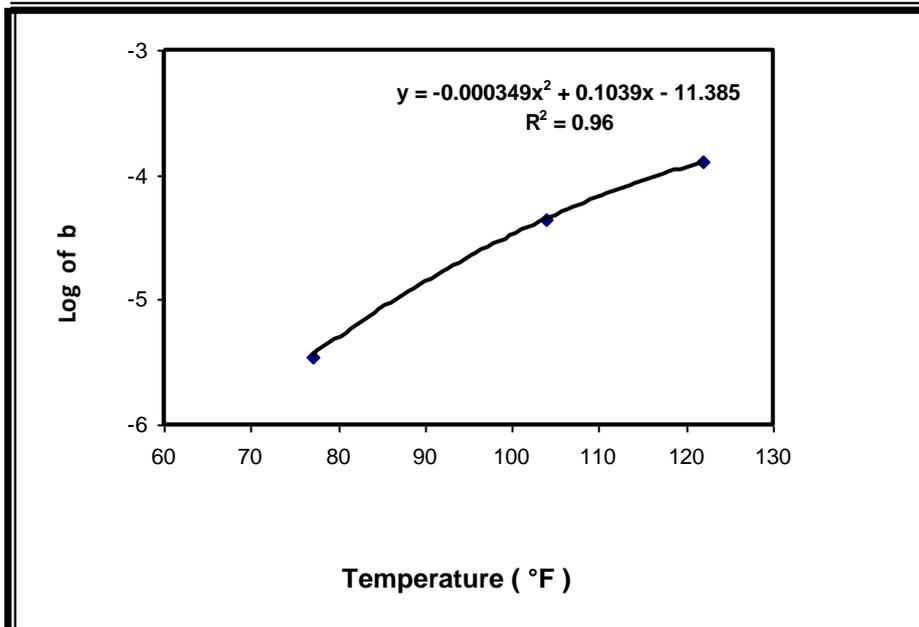


Fig. (4-1) Relationship between log of b and temperature

$$db/dT = -0.000349 T^2 + 0.1039 T - 11.385 \dots\dots\dots 4-2$$

In which:

db/dT = log of the intersection values with permanent strain axis (b),

T = temperature (F).

If equations (4-1) and (4-2) are combined, the form of C can be determined

:

$$C = db/dT + [(ds/dT) \log \sigma] \text{ (David and Deen, 1980) } \dots\dots\dots 4-3$$

in which:

σ = stress (psi), or

Equation (2-3) can be rearranged and becomes

CHAPTER 4	Modeling of Rutting
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$$C = (-0.000349 T^2 + 0.1039 T - 11.380) + [(1.70 - 0.0083 T) \log \sigma] \dots \dots \dots \epsilon - \epsilon$$

The permanent deformation characteristics of asphalt concrete under repeated creep and recovery test could be represented by using a linear relation between the plastic strain and the number of repetition on a log – log scale (Nahla, 2005). Therefore the term represents the relation between the plastic strain and the number of repetition in David model can be replaced by a linear relation (S log N) thus, the general form of the modified model is:

$$\log \epsilon_p = C + S \log N \dots \dots \dots \epsilon - \epsilon$$

In which:

ϵ_p = Permanent Strain (mm/mm).

C = Function of Temperature , Stress state and mixture properties.

S = log slope of permanent deformation and time curve.

N = Number of load repetitions.

Equation (4-0) describes the permanent strain of the mixture as a function of stress state, temperature, mixture properties and number of stress repetitions.

CHAPTER 4	Modeling of Rutting
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4.2.3: Pavement Structure and Loading

The pavement structure used in this work consisted of five layers, each layer material was defined by elastic modulus and poisson's ratio as shown in Table (4-1). The analysis of loading is conducted for tandem axle with dual tires and with contact pressure equal to (90 Psi). For example, the cross section of pavement structure is presented in Figure (4-7).

Table (4-1) Characteristics of Pavement Structure.

Name of Layers	Number of Layers	Thickness of Layers (in)	Elastic Modulus (Psi)	Poisson's Ratio
Surface	1	2	41000	0.30
Binder	2	2.8	33800	0.30
Base	3	4	24200	0.30
Subbase	4	16	10000	0.30
Subgrade	5	∞	7000	0.40

4.1" Radius

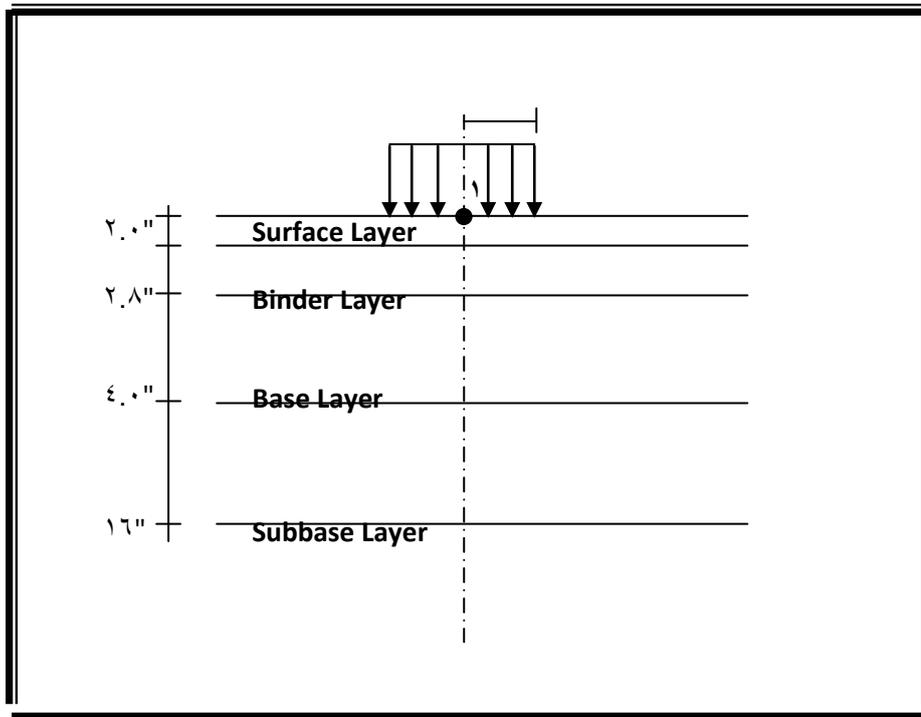


Figure (4-1) Cross section in pavement Structure.

4.2.4 : Pavement Temperature

The air temperature data are used to account for the effect of temperature on moduli of asphalt mixtures. The relationship between the mean pavement temperature M_p and mean monthly air temperature M_a is based on the depth below pavement surface (Yang, 1993), equation represent this relation is:

$$M_p = M_a \left(1 + \frac{0.0015Z}{1 + 0.0015Z} \right) \dots \dots \dots \quad (4-6)$$

In which:

Z = the depth below surface in inches.

M_p = the mean pavement temperature (°F).

M_a = the mean monthly air temperature (°F).

The monthly air temperatures are presented in table (4-1), The mean annual air temperatures (MAAT) is computed as average for three seasons, then converted it to mean pavement temperature by equation (4- 6) for surface layer ($z = 0$).

Month	MMAT °C	MMAT °F
January	10.0	59.9
February	19	66.2
March	24	75.2
April	33	91.4
May	38	100.4
June	42	107.6
July	47	116.6
August	48	118.4
September	40	104
October	32	89.6
November	24	75.2
December	17	62.6
MAAT = 37.44 °C (98 °F)		
*Mean pavement temperature = 48.8 °C (120 °F)		
*[Computed by using equation (4-6)] 1.2		

Table (4-2)
MAAT
T
Determination (IMO).

4.3: Application of the Proposed Model

The final form of the modified model is:

$$\log \epsilon_p = C + S \log N$$

where:

ϵ_p = Permanent Strain (mm/mm).

C = Function of Temperature, Stress state and mixture properties.

S = log slope of permanent deformation and time curve.

N = Number of load repetitions.

As mentioned perviously, this model applied to structure pavement consisting of five layers. The magnitude of the vertical stress at the selected point, such as point (1) on the centre line of the loaded area can be obtained using KENLAYER software as shown in appendix C. The temperature slected represents the mean annual air temperature which is 36.44 °C and converted to mean pavement temperature which equal 44.4 °C . All information about pavement structure, axle load and run of KENLAYER software are presented in appendix C. The accumulative permanent deformations along vertical line under one wheel of the dual wheel are presented in table (4-3) by using equation (4-5) as a function of a number of load repetitions.

Table (4-3) The accumulative permanent strain.

$C = -2.441$ $S = 0.220$	
Load Repetitions	ϵ_p (N)
1	$3.62 * 10^{-3}$
10	$6.9 * 10^{-3}$
100	$1.2 * 10^{-2}$
1000	$1.71 * 10^{-2}$
10000	$3.0 * 10^{-2}$
100000	$4.8 * 10^{-2}$
1000000	$8.9 * 10^{-2}$
10000000	$13.6 * 10^{-2}$

To calculate rut depth, the magnitude of permanent strain is multiplied by the thickness of layer, thus, the predicted value of rut depth in one year for the (100) mm wearing surface layer under 1×10^6 load repetitions is equal to 13.6 mm.

* C :Computed from equation (4-4) and equal to:

$$C = (-0.000349 T^2 + 0.139 T - 11.380) + [(1.70 - 0.0083 T) \log \sigma]$$

By substituted $T \approx 00^\circ \text{C}$ (122 °F) and $\sigma = 96.17 \text{ PSI}$ (KENLAYER)

$$C = -2.441$$

6.1: Conclusions

According to the materials used in this work and within the limitation of the testing program, the following results are concluded:

1. The general form of the modified del is to be:

$$\log \epsilon_p = C + S \log N$$

and

$$db/dT = [-0.000349 T^2 + 0.1039 T - 11.380] \text{ and}$$

$$ds/dT = 1.70 - 0.0083T$$

This model appeared to provide an estimation of permanent deformation depending on asphalt concrete properties, state of stress, load repetitions and degree of temperature.

2. As for the same asphalt mixture, the slope (db/dT) of the modified model is proportional with the degree of temperature. The magnitude of the slope is equal to (- 0.403), (-4.304) and (-3.903) for degrees of temperature (20) °C, (40) °C and (60) °C respectively.
3. The modified model for predicting permanent deformation in flexible paving mixtures will provide a suitable mean for predicting rutting distress required in the process of design and construction of asphalt pavements. The form of rut depth equals to:

$$RD = \sum p_i \cdot h_i$$

Where:

RD = Rut depth (mm).

$\sum p_i$ = Permanent strain (mm/mm).

h_i = Thickness of layer (mm).

- ξ. The temperature has a significant effect on the permanent deformation. Approximately, the permanent deformation at (ϕ °C) will be increased to (η) times the permanent deformation at (ψ °C).
- ο. In flexible pavements, permanent deformation (rutting) is increased when using an asphalt with higher binder content, less stability and greater thickness.

ο. ψ: Recommendations for Further Work

On the basis of this study, it is recommended that:

1. The states of stresses under which permanent deformation characteristics of materials are obtained in the laboratory could be extended to duplicate the states of stress that are encountered within the entire rutting zone, in particular where the shear stress is relatively greater than the normal stresses.
2. Evaluation of the effect of some additives on the performance of the flexible pavements to rutting using the proposed model can be investigated.

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APPENDEX A

A₁

Results of Repeated Creep Test for Mix No. 1

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
0	0.2970	1.9780	2.3417	2.0793	2.7872	2.9207	2.7433
100	1.0890	2.1900	2.7387	2.9109	3.1437	3.3217	3.4207
200	1.0840	2.3330	2.7981	2.9901	3.2030	3.4009	3.4791
300	1.8810	2.4410	2.7050	3.0040	3.2427	3.4703	3.0083
400	2.0490	2.4710	2.8179	3.0941	3.2020	3.4900	3.0781
500	2.1070	2.0207	2.8774	3.1238	3.2723	3.0390	3.0979
Unloading							
0	2.0080	2.4007	2.7773	3.0347	3.1831	3.4400	3.4989
100	1.7600	2.0227	2.0299	2.7872	2.9801	3.1039	3.2713
200	1.8200	2.1933	2.0001	2.7674	2.8871	3.0440	3.2118
300	1.8000	2.1730	2.4700	2.7477	2.8079	3.0247	3.1821
400	1.7908	2.1737	2.4700	2.7981	2.7871	2.9801	3.1723
500	1.7809	2.1037	2.4700	2.7487	2.7673	2.9703	3.1723
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
0	1.0760	7.1777	8.4844	9.3402	10.0980	10.7003	11.1020
100	3.9407	7.9028	9.0700	10.0748	11.3898	12.0301	12.3938
200	0.7391	8.4028	9.7707	10.8018	11.7000	12.3221	12.7004
300	7.8102	8.8442	9.9909	11.0770	11.7480	12.0373	12.8923
400	7.4239	8.9028	10.2071	11.2100	11.7844	12.7449	12.9741
500	7.8102	9.1327	10.3800	11.3181	11.8071	12.8242	13.0308
Unloading							
0	7.4070	8.8793	10.0727	10.9902	11.0329	12.4700	12.7771
100	7.7391	8.1719	9.1773	10.0980	10.8100	11.2470	11.8173
200	7.0942	7.9477	9.0083	10.0278	10.4078	11.0307	11.7379
300	7.0398	7.8700	8.9148	9.9000	10.1799	10.9090	11.0293
400	7.4884	7.8391	8.9148	9.7707	10.0981	10.8100	11.4077
500	7.4020	7.8032	8.9148	9.0973	10.0274	10.7438	11.4077

Results of Repeated Creep Test for Mix No. 1

Accum. Strain ϵ^c (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							

Loading	۲.۰۲۰۰	۴.۹۴۹۲	۰.۶۹۶۶	۶.۱۹۱۰	۶.۰۹۰۰	۷.۰۲۷۹	۷.۴۳۲۰
۱۰۰	۳.۱۷۱۰	۰.۶۹۶۷	۶.۴۴۴۱	۶.۹۱۸۳	۷.۳۱۲۲	۷.۶۰۴۲	۸.۰۹۸۲
۲۰۰	۴.۳۶۳۴	۰.۸۰۸۳	۶.۰۴۰۱	۷.۰۱۹۳	۷.۴۰۳۱	۷.۷۱۴۸	۸.۱۰۹۳
۳۰۰	۴.۹۴۹۴	۰.۹۹۹۷	۶.۶۳۶۰	۷.۱۰۰۱	۷.۴۶۳۷	۷.۷۰۰۲	۸.۱۹۹۷
۴۰۰	۰.۳۲۲۹	۶.۰۹۰۶	۶.۶۹۶۶	۷.۱۷۰۸	۷.۰۰۴۱	۷.۷۸۰۰	۸.۲۱۹۹
۱۰۰۰	۰.۴۷۴۴	۶.۱۶۱۳	۶.۷۷۶۹	۷.۲۰۱۱	۷.۰۴۳۰	۷.۸۰۰۷	۸.۲۴۰۱
Unloading							
Accum. Strain * ۱۰^{-۳} (mm/mm)							
۰۰۰	۴.۸۴۸۲	۰.۶۱۰۸	۶.۱۴۰۶	۶.۰۳۴۰	۶.۹۱۶۸	۷.۳۰۱۲	۷.۰۷۳۰
۷۰۰	۴.۷۸۷۶	۰.۰۹۰۶	۶.۱۰۰۶	۶.۴۹۴۱	۶.۸۷۶۴	۷.۳۴۱۱	۷.۰۰۳۰
۱۰۰۰	۴.۷۷۷۰	۰.۰۸۰۰	۶.۰۸۰۰	۶.۴۸۹۰	۶.۸۶۶۳	۷.۷۳۳۱	۷.۰۴۳۲
Creep Compliance * ۱۰^{-۵} (۱/Kpa)							
Loading	۳.۶۰۹۴	۸.۹۶۰۹	۱۰.۳۱۹۹	۱۱.۲۱۰۰	۱۱.۹۴۷۴	۱۲.۷۳۱۷	۱۳.۴۶۳۷
۱۰۰	۰.۷۰۹۶	۱۰.۳۲۰۱	۱۱.۶۷۴۰	۱۲.۰۳۳۱	۱۳.۲۴۶۷	۱۳.۸۶۶۳	۱۴.۶۷۰۶
۲۰۰	۷.۹۰۴۷	۱۰.۶۱۲۸	۱۱.۸۰۷۰	۱۲.۷۱۶۱	۱۳.۴۱۱۴	۱۳.۹۷۶۰	۱۴.۷۸۱۳
۳۰۰	۸.۹۶۶۳	۱۰.۸۶۹۰	۱۲.۰۲۱۷	۱۲.۸۶۲۰	۱۳.۰۲۱۱	۱۴.۰۴۹۲	۱۴.۸۰۴۰
۴۰۰	۹.۶۴۲۹	۱۱.۰۳۳۶	۱۲.۱۳۱۰	۱۲.۹۹۰۰	۱۳.۰۹۴۳	۱۴.۱۰۴۱	۱۴.۸۹۱۱
۱۰۰۰	۹.۹۱۷۳	۱۱.۱۶۱۷	۱۲.۲۷۶۹	۱۳.۰۴۰۴	۱۳.۶۶۴۸	۱۴.۱۴۰۷	۱۴.۹۲۷۷
Unloading	۹.۰۱۴۸	۱۰.۹۷۸۸	۱۲.۱۳۰۶	۱۲.۸۶۲۰	۱۳.۴۴۰۲	۱۳.۹۰۲۸	۱۴.۷۴۴۷
۱۰۰	۸.۹۶۰۹	۱۰.۴۶۶۴	۱۱.۳۴۳۸	۱۲.۰۳۹۱	۱۲.۶۴۰۹	۱۳.۴۶۳۷	۱۳.۹۰۳۰
۲۰۰	۸.۸۰۰۰	۱۰.۳۳۸۴	۱۱.۲۱۰۷	۱۱.۹۱۱۱	۱۲.۰۴۸۷	۱۳.۳۹۰۰	۱۳.۷۰۶۷
۳۰۰	۸.۷۸۲۹	۱۰.۱۷۳۰	۱۱.۱۲۴۲	۱۱.۸۳۷۸	۱۲.۰۳۰۴	۱۳.۳۱۷۳	۱۳.۷۲۰۱
۴۰۰	۸.۶۷۳۱	۱۰.۱۳۶۹	۱۱.۰۰۱۸	۱۱.۷۶۴۶	۱۲.۴۰۷۲	۱۳.۲۹۹۰	۱۳.۶۸۳۸
۱۰۰۰	۸.۶۰۴۸	۱۰.۱۱۸۶	۱۱.۰۲۳۰	۱۱.۷۰۰۴	۱۲.۴۳۸۷	۱۳.۲۸۰۷	۱۳.۶۶۰۲

APPENDIX A

Ar

Results of Repeated Creep Test for Mix No. ۱

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	2.000	0.400	7.0790	7.0090	7.9090	7.2990	7.7890
100	4.400	7.000	7.7090	7.2090	7.7790	8.1890	8.2890
200	4.900	7.180	7.8990	7.3890	7.7090	8.2790	8.0890
300	0.380	7.380	7.0390	7.4890	7.8090	8.3090	8.7790
400	0.720	7.000	7.1490	7.0790	7.9290	8.4190	8.7290
1000	0.840	7.700	7.1990	7.7290	7.9790	8.4790	8.7690
Unloading							
.	0.700	7.440	7.0090	7.0390	7.9190	8.3990	8.7890
100	0.380	7.100	7.7790	7.1290	7.4390	7.8990	8.7480
200	0.300	7.090	7.0790	7.9990	7.3390	7.8190	8.7290
300	0.230	7.030	7.0090	7.9190	7.2790	7.7090	8.7181
400	0.200	0.990	7.4090	7.8840	7.2290	7.7090	8.7003
1000	0.180	0.9790	7.4390	7.8090	7.2090	7.7890	8.0997
Creep Compliance *10⁻⁶ (1/Kpa)							
Loading							
.	3.0193	7.0217	7.3424	7.9221	8.4001	8.8108	9.4076
100	0.3140	7.2473	8.1737	8.7770	9.2727	9.8907	10.1322
200	0.9178	7.4737	8.3327	8.9240	9.3713	9.9873	10.3737
300	7.4970	7.7003	8.0018	9.4002	9.4921	10.0970	10.4824
400	7.7874	7.8002	8.7347	9.1039	9.0777	10.1784	10.0428
1000	7.0031	7.9710	8.7900	9.2143	9.7370	10.2409	10.0911
Unloading							
.	7.8840	7.7777	8.0209	9.1007	9.0747	10.1443	10.4940
100	7.4970	7.3771	8.0770	8.7100	8.9849	9.0404	10.4404
200	7.4009	7.3000	7.9472	8.4030	8.8741	9.4438	10.4221
300	7.3174	7.2827	7.8717	8.3078	8.7790	9.3109	10.4092
400	7.2801	7.2403	7.8013	8.3147	8.7312	9.3109	10.3878
1000	7.2060	7.2217	7.7773	8.2844	8.7071	9.2878	10.3871

APPENDIX A

A₄

Results of Repeated Creep Test for Mix No. 1

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading	3.1783	5.3071	7.3908	9.4314	11.5276	13.6794	15.8879
100	4.2277	6.3971	8.5127	10.5842	12.7124	14.8988	17.1478
200	5.0940	7.2131	9.1117	11.1472	13.2781	15.4574	17.7003
300	5.8820	7.9002	9.6700	11.6902	13.8204	16.1177	18.2701
400	6.1300	8.0938	9.7690	11.7047	13.8400	16.2374	18.3048
500	6.4373	8.2137	9.7680	11.7042	13.8394	16.2376	18.3340
Unloading	0.2204	7.3072	7.9700	9.4402	11.0008	12.1374	13.1370
100	0.1178	7.2374	7.9727	9.2274	10.7023	11.9394	12.9781
200	0.0932	7.2176	7.7730	9.1680	10.7028	11.8702	12.9187
300	0.0801	7.1978	7.7330	9.1284	10.6732	11.8207	12.8791
400	0.0701	7.1780	7.6938	9.1087	10.6223	11.7414	12.8290
500	0.0531	7.1600	7.6042	9.0880	10.5038	11.6919	12.7899
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading	11.4793	19.2287	23.1731	24.7014	26.3980	27.7898	28.2278
100	10.3177	21.3773	24.3213	25.8992	27.7898	28.9811	29.4800
200	17.4700	22.0112	24.7697	27.7177	28.1920	29.4833	29.9100
300	17.7887	23.3884	25.2037	27.9703	28.4072	29.7278	29.9822
400	18.7000	23.8900	25.7123	27.1900	28.0007	29.8420	30.0898
500	19.7003	23.9723	25.9710	27.3340	28.7709	29.9800	30.1974
Unloading	18.9327	23.0297	25.2037	27.9703	28.2737	29.4833	29.4782
100	18.0427	22.0992	24.3210	27.1872	27.7207	28.7709	28.9071
200	18.4037	22.0270	24.1770	25.9710	27.0463	28.4789	28.7909
300	18.4071	22.4007	24.0327	25.8270	27.4028	28.3300	28.0474
400	18.3018	22.3840	23.8900	25.7007	27.2047	28.0480	28.3777
500	18.3083	22.3188	23.7471	25.7811	27.1877	27.8792	28.2242

Results of Repeated Creep Test for Mix No. 1

Accum. Strain * 10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							

Loading	3.4000	7.2000	7.1000	7.3812	8.3760	8.0110	8.7310
100	4.4000	7.7000	7.4700	8.0201	8.0900	8.9110	8.9607
200	0.0800	7.9200	7.0700	8.2278	8.7376	8.9710	9.2231
500	7.1000	7.0800	7.7900	8.3713	8.7976	9.0310	9.4211
700	7.4000	7.1700	7.7300	8.4200	8.8376	9.0810	9.0802
1000	7.7000	7.3000	7.8000	8.4700	8.8070	9.1210	9.9312
Accum. Strain *10⁻³ (mm/mm)							
500	0.9000	7.0800	7.1230	7.7700	8.2130	8.7270	9.1033
700	0.8700	7.4800	7.0810	7.7200	8.1700	8.0770	9.0921
1000	0.8300	7.4200	7.0711	7.7100	8.1710	8.0401	9.0700
Creep Compliance *10⁻⁶ (1/Kpa)							
Loading	7.1094	11.2318	12.8723	13.3717	14.0079	10.4184	10.8170
100	7.9710	12.1377	13.0144	14.0382	10.0710	17.1431	17.2422
200	10.1087	12.0372	13.7907	14.9004	10.8270	17.2018	17.7083
500	11.0007	12.8270	13.9311	10.1472	10.9347	17.3700	17.0772
700	11.0942	12.9710	14.0037	10.2037	17.0072	17.4010	17.3004
1000	12.1377	13.2247	14.1304	10.3270	17.0402	17.0230	17.9913
Unloading	11.2318	12.7898	13.7907	14.8913	10.7103	17.2337	17.4807
100	10.8790	12.2473	13.2247	14.2391	10.0289	10.8714	17.1201
200	10.7708	12.0702	13.0797	14.1777	14.9070	10.7920	17.7092
500	10.7884	11.9202	12.9048	14.0079	14.8787	10.7287	17.0820
700	10.7109	11.7391	12.8278	13.9800	14.8097	10.0372	17.4711
1000	10.0710	11.7304	12.7918	13.9774	14.8020	10.4711	17.4402

APPENDIX A

A:

Results of Repeated Creep Test for Mix No. 1

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	4.7700	7.8467	7.83.2	8.9892	9.8389	10.1929	11.2071
100	0.7938	7.7.18	8.0118	9.0.00	10.2879	10.9.47	11.77.4
200	7.01.1	7.8.38	8.9087	9.7789	10.4.01	11.4210	11.9.07
300	7.9183	8.1.30	9.2.37	9.8.11	10.0723	11.8.01	12.1.04
400	7.4.67	8.1937	9.3.07	9.9847	10.7723	12.0003	12.2008
1000	7.1834	8.20.2	9.0.97	10.24.0	10.8.01	12.109.0	12.3272
Unloading							
.	7.9181	8.2.00	9.3.78	10.0077	10.7414	11.937	12.0394
100	7.00.8	7.8477	8.8704	9.7844	10.2837	11.4018	11.8093
200	7.4792	7.7132	8.7039	9.7.31	10.1777	11.10.0	11.8.31
300	7.4498	7.0991	8.7733	9.0210	10.1.74	11.0.419	11.7778
400	7.4277	7.0032	8.7.77	9.47.07	10.0.407	10.9783	11.7497
1000	7.4198	7.4931	8.0723	9.4.99	10.0.102	10.9.0.1	11.7221
Creep Compliance *1.0^-0 (1/Kpa)							
Loading							
.	0.7770	8.2789	9.4077	10.8070	11.8827	12.31.2	13.0943
100	7.8770	9.18.9	10.2799	11.48.0	12.4237	13.1798	14.0827
200	7.8724	9.4248	10.8197	11.7894	12.0770	13.794.0	14.3811
300	8.3003	9.7878	11.1104	11.837.0	12.7784	14.2073	14.72.0
400	8.0.31	9.8907	11.2387	12.0088	12.8771	14.0090	14.8.17
1000	8.7707	9.974.0	11.480.0	12.3771	13.0.497	14.7847	14.8879
Unloading							
.	8.3001	9.7870	11.24.0	12.1407	12.8019	14.4177	14.04.3
100	7.9110	9.4770	10.7.07.0	11.7971	12.4199	13.83.7	14.3228
200	9.8129	9.3104	10.0723	11.0979	12.2917	13.4777	14.200.0
300	7.7897	9.1777	10.470.0	11.4993	12.2.07	13.3307	14.2231
400	7.7729	9.1222	10.3907	11.4209	12.1323	13.2088	14.19.4
1000	7.7033	9.0497	10.303.0	11.3747	12.0.907	13.1743	14.1071

APPENDEX A	A_v
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Results of Repeated Creep Test for Mix No. 1

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.4000	7.2000	10.3200	13.7131	17.2090	20.8400	24.6300
100	0.7400	7.0000	13.3098	19.9021	27.4000	35.0000	42.6000
200	7.0000	7.7000	10.0000	17.1000	24.7371	32.5000	40.2300
300	7.1800	7.8800	10.7000	18.2038	26.8097	34.2411	41.3300
400	7.4000	10.3200	13.7200	18.3079	26.8870	35.7600	42.9900
1000	7.0000	11.0090	18.8031	27.0211	36.9030	47.2001	58.4900
Unloading							
.	7.3900	7.9403	10.7007	17.2197	24.8411	32.7000	40.3100
100	7.2000	7.8131	10.0301	17.0837	24.7200	32.9121	40.2100
200	7.1188	7.7083	10.4820	17.9831	27.6091	36.8031	45.1700
300	7.0194	7.7243	10.4403	17.9321	27.0900	36.8111	45.1000
400	0.9301	7.7003	10.4278	17.9020	27.0087	36.7000	45.1440
1000	0.8830	7.7902	10.4123	17.8900	27.0421	36.7110	45.1220
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
.	12.3188	22.7449	20.4782	27.9467	29.7427	32.0289	31.9927
100	20.7971	23.7318	27.4847	28.8119	30.7109	32.7173	33.1021
200	21.7391	24.4070	27.1739	29.0289	31.2938	33.1021	33.4420
300	22.3913	24.9270	27.7173	29.9000	31.9192	33.4822	33.8043
400	23.1884	20.4782	27.9710	30.1010	32.1377	33.9130	34.0217
1000	23.7318	20.7467	28.2721	30.2712	32.4402	34.1489	34.3840
Unloading							
.	23.1021	20.1741	27.7184	29.7810	32.0329	32.8270	33.7318
100	22.7449	24.7801	27.3010	29.2887	31.0942	32.2902	33.3790
200	22.1790	24.4870	27.1100	28.9242	31.3730	32.0774	33.2247
300	21.8101	24.3734	27.9707	28.7394	31.1231	31.9239	33.1021
400	21.0039	24.2940	27.9123	28.7322	31.0094	31.7028	33.1304
1000	21.3102	24.2398	27.8071	28.0879	30.9497	31.0710	33.0077

Results of Repeated Creep Test for Mix No. 1

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
·	3.8000	7.8700	7.9700	8.8007	9.0700	10.3399	11.2099
100	0.3210	7.7000	8.7707	9.0607	10.2700	11.0990	11.3087
200	0.9200	7.8900	8.9807	9.7207	10.4300	11.2399	11.4697
300	7.0400	8.2300	9.2007	9.9807	10.7100	11.4990	11.0299
400	7.1200	8.3900	9.2807	10.0707	10.8000	11.7090	11.7001
1000	7.4000	8.4000	9.3007	10.1007	10.8400	11.7287	11.7620
Unloading							
·	7.1200	8.2700	9.0907	9.8400	10.0999	11.4290	11.0831
100	7.7400	7.8200	8.8077	9.4800	10.2199	11.0097	11.4793
200	7.7800	7.7800	8.7607	9.4400	10.1799	10.9880	11.4383
300	7.7200	7.7400	8.7007	9.3700	10.1199	10.9073	11.4197
400	7.0800	7.7100	8.7407	9.3200	10.0799	10.8799	11.3980
1000	7.0400	7.7900	8.7007	9.2700	10.0399	10.8287	11.3832
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
·	8.8840	12.4407	14.4384	10.9431	17.3379	18.7317	20.3077
100	9.7394	14.0398	10.8887	17.3199	18.7000	20.1078	20.0573
200	10.7247	14.2934	17.2792	17.7097	18.8949	20.3721	20.7603
300	11.4878	14.9094	17.7677	18.0807	19.4021	20.8310	20.8870
400	12.8980	10.1992	17.8127	18.2438	19.0702	21.0317	21.0237
1000	13.4007	10.3079	17.8489	18.2981	19.7377	21.0774	21.1277
Unloading							
·	12.8980	14.9818	17.4684	17.8270	19.2027	20.7007	20.9838
100	12.2101	14.1770	10.9039	17.1739	18.0143	19.9401	20.7908
200	12.1014	14.0942	10.8707	17.1014	18.4418	19.9077	20.7210
300	11.9927	14.0217	10.77191	17.9747	18.3331	19.7097	20.7878
400	11.9202	13.9773	10.7032	17.8931	18.2607	19.7099	20.7494
1000	11.8478	13.9311	10.0807	17.7934	18.1882	19.7172	20.7217

APPENDIX A	A₁
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Results of Repeated Creep Test for Mix No. 1

Accum. Strain ϵ_{cr} (mm/mm)

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	4.00	7.7601	8.8300	10.0300	10.8010	11.0890	12.7900
100	7.0021	8.7092	9.7301	10.7000	11.4320	12.0200	12.8900
200	7.7031	8.8370	10.0230	10.8010	11.7071	12.4000	13.0000
300	7.0011	8.9001	10.4320	11.1021	11.7991	12.7800	14.0100
400	7.4210	8.9701	10.0400	11.2810	11.8731	12.7700	14.3300
1000	7.7021	9.1030	10.7200	11.3000	11.9301	13.1000	14.0700
Accum. Strain *10⁻³ (mm/mm)							
500	7.3873	8.4899	9.7800	10.0200	11.3992	12.2800	14.2180
700	7.3098	8.4023	9.7200	10.4800	11.3387	12.2300	14.1980
1000	7.3210	8.4201	9.7900	10.4400	11.2804	12.2100	14.1780
Creep Compliance *10⁻⁶ (1/Kpa							
Loading							
.	0.4340	9.3781	10.7642	12.1130	13.1000	13.9964	10.3270
100	7.2489	10.4079	11.7370	12.8723	13.8077	14.0179	10.0777
200	8.1009	10.7733	12.1000	13.1000	14.0182	14.9708	10.7708
300	8.4773	10.7049	12.0990	13.4787	14.1293	10.3140	17.9202
400	8.9720	10.8213	12.7294	13.7200	14.3274	10.4107	17.3077
1000	9.3724	10.9940	12.8270	13.7077	14.4143	10.8212	17.0977
Unloading							
.	9.1281	10.7700	12.0710	13.2917	14.1909	10.0797	17.3792
100	9.0083	10.4177	11.9807	12.9780	13.9129	10.0000	17.3400
200	8.9714	10.2937	11.9202	12.7997	13.8287	14.9270	17.2439
300	8.9218	10.2030	11.8110	12.7004	13.7671	14.8309	17.1714
400	8.8880	10.2080	11.7391	12.7007	13.7940	14.7700	17.1473
1000	8.8417	10.1792	11.7028	12.7080	13.7297	14.7473	17.1231

APPENDIX A	A₁
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Results of Repeated Creep Test for Mix No. 2

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.0431	7.0294	7.2938	7.8399	8.2811	8.7301	8.9001
100	4.0881	7.0980	7.7881	8.1303	8.4700	8.8003	9.1000
200	0.7923	7.3176	7.9030	8.3097	8.7178	8.9822	9.2498
300	7.2011	7.4794	8.0039	8.0911	8.7201	9.1001	9.3398
400	7.0700	7.0700	8.1173	8.7887	8.8199	9.1099	9.4311
1000	7.9214	7.7100	8.1408	8.7241	8.8770	9.2240	9.0422
Accum. Strain *10⁻³ (mm/mm)							
500	7.1489	7.8439	7.0021	8.0770	8.0003	8.7997	9.2701
700	7.1131	7.8021	7.0309	8.0230	8.4099	8.7732	9.2700
1000	7.0993	7.7987	7.0131	7.9921	8.4231	8.7404	9.2687
Creep Compliance *10⁻⁶ (1/Kpa)							
Loading							
.	7.4187	11.8284	13.2134	14.2027	10.0019	10.7432	17.2230
100	8.3117	12.8097	13.9277	14.7378	10.3270	17.0422	17.0570
200	10.3121	13.2070	14.3179	10.1443	10.7119	17.2721	17.7078
300	11.3244	13.0497	14.4998	10.0730	10.8073	17.4807	17.9199
400	11.9021	13.7907	14.7002	10.7403	10.9780	17.0940	17.0803
1000	12.0387	13.7872	14.7078	10.8040	17.0743	17.7101	17.2870
Unloading							
.	11.7080	13.3981	14.2809	10.4707	10.8002	17.4271	17.0273
100	11.3184	12.8209	13.9001	10.1911	10.7048	17.2017	17.8017
200	11.2012	12.0971	13.8279	14.7822	10.0774	17.0099	17.8201
300	11.1393	12.3983	13.7813	14.7141	10.3990	10.9414	17.8027
400	11.0744	12.3227	13.7019	14.0303	10.3209	10.8703	17.7934
1000	11.0490	12.3174	13.7107	14.4787	10.2092	10.8431	17.7911

APPENDIX A

A₁₁

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.7021	7.088.	7.3110	7.8439	8.0791	8.7920	9.2001
100	4.7701	7.1101	7.7000	8.1000	8.7399	8.9232	9.3990
200	0.8301	7.3088	7.9238	8.0978	8.9000	9.1207	9.0109
300	7.3378	7.0032	8.1198	8.7931	8.9932	9.2320	9.7321
400	7.7342	7.7033	8.1303	8.8213	9.0877	9.3001	9.7029
500	7.9788	7.7090	8.1701	8.9002	9.1230	9.4299	9.7220
Unloading							
.	7.4802	7.4399	7.9021	8.7200	8.9701	9.2098	9.7000
100	7.2877	7.2278	7.7200	8.0398	8.8192	9.1321	9.0093
200	7.2030	7.0787	7.7738	8.4472	8.7301	9.0432	9.0110
300	7.1800	7.0031	7.0937	8.4193	8.7421	9.0097	9.4921
400	7.1700	7.9777	7.0822	8.3992	8.7000	8.9801	9.4802
500	7.1798	7.9211	7.0873	8.3801	8.0932	8.9708	9.4799
Creep Compliance *10⁻⁵ (1/Kpa)							
Loading							
.	7.7171	11.9347	13.2404	14.2099	10.0237	10.9284	17.7778
100	8.7414	12.8890	13.9001	14.7730	10.8331	17.1702	17.0280
200	10.0708	13.3311	14.3047	10.0739	17.1240	17.0318	17.2298
300	11.4810	13.7833	14.7097	10.9290	17.2920	17.7200	17.4494
400	12.0184	13.7740	14.7378	10.9807	17.4630	17.9477	17.0777
500	12.7247	13.8700	14.7918	17.2231	17.0280	17.0831	17.7123
Unloading							
.	11.7480	13.4780	14.3103	10.8071	17.2001	17.7700	17.4003
100	11.3907	13.0938	13.9874	10.4707	10.9778	17.0437	17.3170
200	11.2382	12.8230	13.8837	10.3010	10.8244	17.3827	17.2300
300	11.2047	12.7877	13.7077	10.2023	10.7009	17.3219	17.1908
400	11.1784	12.7227	13.7308	10.2109	10.0887	17.2773	17.1833
500	11.1771	12.0382	13.7401	10.1813	10.0773	17.2423	17.1737

Results of Repeated Creep Test for Mix No. 3

APPENDIX A	A ₁₂
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Results of Repeated Creep Test for Mix No. 4

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.7191	7.7002	7.0400	7.9020	8.7023	8.8012	9.2037
100	4.7998	7.3290	7.7301	8.2997	8.8801	8.9987	9.4020
200	5.8931	7.0270	7.8211	8.4921	8.9929	9.1301	9.4987
300	7.4200	7.7400	7.9020	8.7300	9.0771	9.2209	9.0720
400	7.7731	7.7298	7.9821	8.7021	9.1130	9.37012	9.7099
1000	7.0021	7.7420	8.0730	8.9281	9.1021	9.4087	9.7177
Unloading							
.	7.0027	7.0310	7.9201	8.7901	8.9930	9.3230	9.7220
100	7.3428	7.3999	7.8110	8.7000	8.8098	9.2077	9.0727
200	7.2777	7.3100	7.7990	8.7030	8.7931	9.1921	9.0499
300	7.2231	7.2821	7.7601	8.7021	8.7021	9.1730	9.0389
400	7.2198	7.2799	7.7499	8.0899	8.7199	9.1437	9.0211
1000	7.2099	7.2031	7.7100	8.0713	8.7002	9.1399	9.0200
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
.	7.7831	12.0474	13.7094	14.3171	15.7600	17.0347	17.7739
100	8.7902	13.2771	14.0038	15.0307	17.0871	17.3019	17.0330
200	10.7709	13.7308	14.1787	15.3842	17.2914	17.0400	17.2077
300	11.7313	13.8400	14.3171	15.7340	17.4240	17.7130	17.3414
400	12.0889	14.0032	14.4703	15.8002	17.0099	17.9748	17.4998
1000	12.7849	14.0203	14.7200	17.1740	17.0798	17.1301	17.7020
Unloading							
.	11.8708	13.7431	14.3070	15.9331	17.2920	17.8894	17.4320
100	11.4900	13.4007	14.1003	15.7717	17.0003	17.7793	17.3237
200	11.3040	13.2427	14.1287	15.7777	15.9290	17.7023	17.3000
300	11.2737	13.1922	14.0097	15.0830	15.8002	17.7000	17.2807
400	11.2777	13.1701	14.0397	15.0714	15.7979	17.0747	17.2483
1000	11.2498	13.1397	13.9782	15.0097	15.7712	17.0077	17.2473

Accum. Strain ϵ_c (mm/mm)

Results of Repeated Creep Test for Mix No. 6

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.021.0	7.2900	7.921	7.0987	8.1801	8.7211	8.8971
100	4.7299	7.7371	7.430.	7.8831	8.3771	8.770.1	8.9720
200	0.1121	7.9000	7.7210	8.0490	8.0910	8.9077	9.0911
300	0.7077	7.1230	7.7112	8.1400	8.7004	8.9831	9.1722
400	7.1213	7.2011	7.7781	8.2011	8.7070	9.0070	9.2038
1000	7.7830	7.3271	7.8230	8.2071	8.7800	9.1183	9.3321
Unloading							
.	7.4921	7.0889	7.7378	8.1077	8.7411	8.9081	9.2131
100	7.2870	7.9401	7.0138	8.0099	8.0002	8.8430	9.1700
200	7.2071	7.8770	7.4788	8.0200	8.4900	8.7831	9.1327
300	7.1437	7.7792	7.4300	8.0010	8.4710	8.7300	9.1198
400	7.1000	7.7200	7.4299	7.9987	8.4099	8.7198	9.1004
1000	7.0021	7.7007	7.4013	7.9811	8.4409	8.7001	9.1000
Creep Compliance *10⁻⁵ (1/Kpa)							
Loading							
.	7.3787	11.4048	12.8480	13.7607	14.8280	10.7179	17.1179
100	8.3870	12.2048	13.4792	14.2809	10.1077	10.8878	17.2037
200	9.4009	12.0997	13.8071	14.0824	10.0743	17.1371	17.4793
300	10.1088	12.9048	13.9790	14.7472	10.7710	17.2737	17.0981
400	11.0893	13.0404	14.0907	14.8070	10.8741	17.4077	17.7741
1000	12.1077	13.2737	14.1730	14.9080	10.9007	17.0187	17.9009
Unloading							
.	11.7710	12.8422	13.8370	14.7878	10.7041	17.2284	17.7903
100	11.3903	12.0727	13.7119	14.7012	10.4894	17.0208	17.7132
200	11.2447	12.4393	13.0304	14.0289	10.3804	10.9114	17.0470
300	11.1298	12.2811	13.4792	14.4940	10.3479	10.8102	17.0213
400	11.0017	12.1838	13.4099	14.4903	10.3209	10.7977	17.4872
1000	10.8733	12.1389	13.4081	14.4080	10.2914	10.7710	17.4807

APPENDIX A	A1ε
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Results of Repeated Creep Test for Mix No. 6

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No. Time(sec)	1	2	3	4	5	6	7
Loading							
. 100	3.2010	0.3126	7.2900	7.8100	7.1631	7.4721	7.7000
200	4.003	0.7791	7.7013	7.9920	7.3400	7.7301	7.8401
300	4.7900	0.9901	7.8010	7.1493	7.4900	7.7729	7.9131
400	0.0431	7.2200	7.9920	7.2420	7.7201	7.8091	7.9629
500	0.3498	7.4980	7.1631	7.3292	7.7100	7.9420	8.0231
1000	0.7439	7.7631	7.2000	7.3700	7.7621	7.9801	8.0700
Unloading							
. 100	0.3178	7.4131	7.0098	7.2701	7.0900	7.8831	7.9621
200	0.1187	7.2773	7.8701	7.1020	7.4421	7.7921	7.8200
300	0.0030	7.2031	7.7309	7.0210	7.3709	7.7109	7.7000
400	4.9620	7.1730	7.7831	7.9970	7.2932	7.7700	7.7031
500	4.9230	7.1400	7.7292	7.9621	7.2730	7.7301	7.7982
1000	4.9000	7.1329	7.7013	7.9400	7.2713	7.7201	7.7921
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
. 100	0.7989	9.7242	11.0769	12.3378	12.9766	13.0374	14.0398
200	7.2000	10.2882	12.0494	12.7670	13.2971	13.8226	14.2030
300	8.4963	10.8016	12.3210	12.9016	13.0697	14.0813	14.3303
400	9.1360	11.2690	12.7666	13.1204	13.8040	14.2370	14.4200
500	9.7916	11.7717	12.9766	13.2770	13.9764	14.3876	14.0346
1000	10.2244	12.0708	13.0443	13.3342	14.0717	14.4067	14.7023
Unloading							
. 100	9.7336	11.7178	12.7989	13.1790	13.7009	14.2809	14.4240
200	9.2728	11.3719	12.4277	12.8678	13.4820	14.1161	14.1666
300	9.0734	11.2370	12.19361	12.7192	13.3349	13.9690	14.0407
400	8.9891	11.1838	12.1000	12.7666	13.2123	13.8777	13.9048
500	8.9193	11.1231	12.0094	12.7120	13.1766	13.8317	13.9460
1000	8.8777	11.1103	11.9088	12.0733	13.1040	13.8040	13.9349

Results of Repeated Creep Test for Mix No. V

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No. Time(sec)	1	2	3	4	5	6	7
Loading	3.4801	7.0721	7.0271	7.8002	8.2701	8.7211	9.0090
100	4.0931	7.9910	7.7492	8.0037	8.0393	8.9031	9.2131
200	0.7700	7.2321	7.9221	8.2021	8.7021	9.0321	9.4092
300	7.3700	7.4320	8.0821	8.3911	8.8309	9.1307	9.0100
400	7.7971	7.0017	8.2300	8.0079	8.9829	9.2101	9.0771
500	7.9992	7.7729	8.2729	8.0821	8.9327	9.2731	9.7002
Unloading	7.0917	7.3800	8.0327	8.3221	8.8700	9.1109	9.0091
100	7.4109	7.1931	7.7991	8.2739	8.7031	9.0003	9.4431
200	7.3270	7.0701	7.7301	8.2229	8.7801	8.9237	9.4199
300	7.2831	7.0239	7.0778	8.2021	8.7331	8.8701	9.3990
400	7.2772	7.9821	7.0371	8.1800	8.7099	8.8431	9.3871
500	7.2037	7.9037	7.0123	8.1731	8.0937	8.8399	9.3820
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading	7.3040	11.9009	13.7379	14.1307	10.0001	10.7990	17.3210
100	8.3208	12.7707	14.0384	14.0900	10.4790	17.1288	17.7903
200	10.2727	13.1017	14.3017	14.9494	10.8002	17.3720	17.0407
300	11.0398	13.4747	14.7414	10.2012	10.9980	17.0411	17.2282
400	12.1324	13.7804	14.9103	10.4128	17.1284	17.7849	17.3317
500	12.7797	13.9001	14.9887	10.0472	17.1824	17.7809	17.3917
Unloading	11.9414	13.3790	14.0019	10.0772	17.0788	17.0002	17.2277
100	11.7230	13.0309	14.1288	14.9708	10.8070	17.3097	17.1070
200	11.4728	12.8172	13.8227	14.8970	10.7248	17.1771	17.0700
300	11.3824	12.7244	13.7097	14.8088	10.7397	17.0790	17.0820
400	11.3037	12.7487	13.7041	14.8188	10.0977	17.0201	17.0007
500	11.3291	12.0913	13.7092	14.8073	10.0782	17.0143	17.9973

Results of Repeated Creep Test for Mix No. ^

Accum. Strain ϵ_c (mm/mm)

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.4099	7.2997	7.2331	7.0223	8.1296	8.0401	8.8910
100	4.0031	7.7700	7.0098	7.8291	8.3099	8.7344	9.3447
200	0.7178	7.9821	7.7030	8.1398	8.0621	8.9928	9.2031
300	7.2379	7.1492	7.9000	8.2001	8.0733	9.1007	9.3099
400	7.0997	7.2030	8.0007	8.3779	8.8422	9.1031	9.0307
1000	7.8731	7.332	8.0799	8.4121	8.9088	9.1833	9.7021
Unloading							
.	7.3901	7.1037	7.8720	8.2109	8.7377	9.0029	9.4819
100	7.1017	7.9721	7.7011	8.0800	8.7021	8.9087	9.3491
200	7.0878	7.8821	7.2399	7.9231	8.0299	8.8234	9.2897
300	7.0478	7.8091	7.1000	7.8700	8.4377	8.7721	9.2433
400	7.0210	7.7720	7.0021	7.8327	8.3920	8.7200	9.2302
1000	7.0103	7.7437	7.2700	7.8299	8.3711	8.7097	9.2110
Creep Compliance *10⁻⁵ (1/Kpa)							
Loading							
.	7.2779	11.4076	13.1034	13.7273	14.7270	10.4711	17.1088
100	8.2483	12.2744	13.7902	14.1831	10.1447	10.8231	17.3770
200	10.3078	12.7487	14.0471	14.7470	10.0110	17.2914	17.7722
300	11.3000	12.9001	14.3120	14.9408	10.8074	17.4870	17.9073
400	11.9009	13.1403	14.0030	10.1071	17.0184	17.0817	17.2707
1000	12.4012	13.2827	14.7193	10.2393	17.1391	17.7374	17.3901
Unloading							
.	11.0803	12.9087	14.2437	14.8748	10.8291	17.3081	17.1773
100	11.1443	12.7307	13.7701	14.7377	10.7740	17.1389	17.9377
200	9.2170	12.4770	13.1107	14.3034	10.4027	10.9844	17.8289
300	10.9071	12.3303	12.9028	14.2400	10.2800	10.8914	17.7401
400	10.9077	12.2009	12.7849	14.1897	10.2028	10.8070	17.7304
1000	10.8938	12.2178	13.1721	14.1847	10.1700	10.7782	17.7870

Results of Repeated Creep Test for Mix No. 9

APPENDIX A		A_{1A}						
Accum. Strain *10⁻³ (mm/mm)								
Cycle No.	1	2	3	4	5	6	7	
Time(sec)								
Loading								
.	3.3970	7.1992	7.1227	7.4310	8.0780	8.0391	9.0000	
100	4.3780	7.7134	7.4904	7.7219	8.3721	8.7619	9.1021	
200	0.0970	7.9400	7.7020	7.7821	8.0311	8.9920	9.2733	
300	7.1297	7.1267	7.7198	7.8799	8.7210	9.1777	9.4210	
400	7.4209	7.1976	7.7631	7.9931	8.8401	9.2031	9.0300	
1000	7.7398	7.2099	7.7920	8.1198	8.8721	9.3329	9.7112	
Unloading								
.	7.2374	7.0921	7.7191	8.0112	8.7096	9.2099	9.0329	
100	7.0491	7.8200	7.4000	7.9000	8.4821	9.1219	9.4011	
200	0.9031	7.7390	7.3829	7.8299	8.3899	9.0131	9.3829	
300	0.9217	7.7199	7.3198	7.7787	8.3310	8.9321	9.3318	
400	0.8772	7.0932	7.2730	7.7011	8.3121	8.8066	9.3121	
1000	0.8074	7.0721	7.2099	7.7098	8.3096	8.8202	9.3090	
Creep Compliance *10⁻⁶ (1/Kpa)								
Loading								
.	7.1039	11.2304	12.9034	13.4619	14.7340	10.4693	17.3134	
100	8.1123	12.1719	13.0791	13.8077	10.1778	10.8730	17.0798	
200	10.1394	12.0824	13.7717	14.0980	10.4048	17.2907	17.7904	
300	11.1040	12.9106	13.9801	14.2701	10.7998	17.7081	17.0770	
400	11.7411	13.0391	14.1178	14.4802	17.0237	17.7628	17.2603	
1000	12.2081	13.1019	14.1178	14.7097	17.0726	17.9074	17.4110	
Unloading								
.	11.2996	12.8480	13.8027	14.0130	10.7876	17.7701	17.2697	
100	10.9080	12.3600	13.4963	14.3110	10.3771	17.0201	17.1210	
200	10.7846	12.2092	13.3748	14.1806	10.1990	17.3280	17.9980	
300	10.7277	11.9920	13.2700	14.0916	10.0923	17.1813	17.9004	
400	10.7293	11.9442	13.1707	14.0099	10.0081	17.0440	17.8797	
1000	10.7112	11.9009	13.1019	14.0076	10.0036	10.9786	17.8600	

Results of Repeated Creep Test for Mix No. 10

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
. .	3.4980	7.2230	7.1009	7.0219	8.1130	8.0621	9.1018
100.	4.0722	7.7321	7.0231	7.7031	8.4122	8.8012	9.2130
200.	0.7321	7.9620	7.7211	7.8130	8.0011	9.0191	9.3299
300.	7.1421	7.1021	7.7399	7.8920	8.7411	9.2017	9.4620
400.	7.0987	7.2201	7.8231	8.0109	8.8031	9.3044	9.0001
1000.	7.8117	7.2789	7.8900	8.1008	8.8819	9.3809	9.7321
Unloading							
. .	7.3371	7.1237	7.7221	8.0144	8.7718	9.2787	9.0082
100.	7.1220	7.9041	7.0237	7.9279	8.0210	9.1021	9.4821
200.	7.0231	7.7004	7.4099	7.8440	8.4399	9.0798	9.4319
300.	0.9631	7.7311	7.3921	7.8019	8.3711	8.9620	9.3718
400.	0.8877	7.7298	7.3764	7.7901	8.3609	8.9219	9.3098
1000.	0.8713	7.7001	7.3421	7.7811	8.3411	8.9130	9.3414
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
. .	7.3378	11.2744	12.8730	13.7277	14.7983	10.0110	17.4887
100.	8.2829	12.1908	13.7288	13.8743	10.2394	10.9442	17.7911
200.	10.2030	12.7132	13.8073	14.1048	10.4911	17.3389	17.9019
300.	11.1279	12.9067	14.0217	14.2980	10.8303	17.7797	17.1422
400.	11.9041	13.0880	14.1722	14.0210	17.0382	17.8007	17.3009
1000.	12.3400	13.1874	14.3034	14.7844	17.0903	17.9943	17.4494
Unloading							
. .	11.4802	12.9000	13.8987	14.0188	10.7097	17.8092	17.3100
100.	11.0914	12.0074	13.7298	14.3721	10.4370	17.0798	17.1777
200.	10.9114	12.2289	13.0143	14.2110	10.2897	17.4489	17.087
300.	10.8027	12.0128	13.3914	14.1338	10.1700	17.2374	17.9778
400.	10.7771	12.0100	13.3449	14.1120	10.1470	17.1728	17.9071
1000.	10.7374	11.9707	13.3009	14.0971	10.1107	17.1477	17.9228

Results of Repeated Creep Test for Mix No. 11
Accum. Strain ϵ_{cr} (mm/mm)

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.7211	7.3429	7.2129	7.4634	8.1932	8.7729	8.8721
100	4.7170	7.8731	7.0848	8.0839	8.7429	8.8072	8.9701
200	0.7717	7.0311	7.7421	8.2098	8.7817	9.0531	9.1499
300	7.0213	7.2239	7.7031	8.4497	8.9130	9.1307	9.2307
400	7.8319	7.3092	7.8398	8.0197	8.9729	9.1821	9.3019
1000	7.9820	7.4722	7.9001	8.0721	9.0231	9.2077	9.3821
Accum. Strain *10⁻³ (mm/mm)							
500	7.2117	7.7220	7.2000	7.9731	8.4427	8.7037	9.1299
700	0.9712	7.7039	7.2031	7.9404	8.4007	8.7039	9.1187
1000	0.9233	7.7821	7.1720	7.9239	8.3821	8.7921	9.1172
Creep Compliance *10⁻⁶ (1/Kpa)							
Loading							
.	7.0090	11.3907	13.0778	13.0207	14.8427	10.7117	17.0727
100	8.0443	12.4331	13.7400	14.7447	10.7074	17.0407	17.2092
200	10.2077	12.7370	13.84438	14.9734	10.9087	17.4000	17.0709
300	11.8139	13.0877	14.0404	10.3072	17.1477	17.0001	17.7317
400	12.3777	13.3318	14.2020	10.4340	17.2371	17.7342	17.9418
1000	12.7494	13.0184	14.3208	10.0291	17.3471	17.7793	17.9970
Unloading							
.	11.7443	13.0490	13.9001	10.1200	10.8309	17.4048	17.7797
100	11.3242	12.7327	13.0872	14.8898	10.7210	17.1217	17.7041
200	11.0110	12.3007	13.2884	14.7379	10.4701	10.9774	17.0747
300	10.9088	12.1770	13.1340	14.4440	10.2940	10.8079	17.0397
400	10.7992	12.1447	13.0490	14.3847	10.2270	10.7779	17.0193
1000	10.7307	12.1002	12.9937	14.3048	10.1849	10.7470	17.0148

APPENDIX A	A_r.
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Results of Repeated Creep Test for Mix No. 12

Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.0921	7.3107	7.1702	7.4502	8.1442	8.7770	8.8410
100	4.7700	7.8227	7.0079	8.0711	8.7310	8.8300	8.9037
200	0.7422	7.9800	7.7112	8.2377	8.7710	9.0104	9.1031
300	7.4099	7.1877	7.7291	8.4009	8.8814	9.1121	9.2201
400	7.7221	7.3210	7.8110	8.4910	8.9013	9.1890	9.3377
1000	7.9044	7.4200	7.9134	8.0017	8.9987	9.2300	9.3707
Unloading							
.	7.3021	7.1702	7.7312	8.3219	8.7114	9.0441	9.2207
100	7.1097	7.9210	7.4522	8.1734	8.0831	8.8713	9.1722
200	7.0021	7.7804	7.3211	8.0301	8.4922	8.7902	9.1398
300	0.9311	7.7812	7.2100	7.9301	8.4010	8.7031	9.1121
400	0.8912	7.7210	7.1709	7.9017	8.3044	8.7032	9.1098
1000	0.8877	7.0877	7.1433	7.8911	8.3392	8.7300	9.1001
Creep Compliance *10⁻⁵ (1/Kpa)							
Loading							
.	7.0074	11.4413	12.9980	13.0009	14.7039	10.7019	17.0172
100	8.4792	12.3097	13.7900	14.7034	10.7377	17.0004	17.2204
200	10.2213	12.7048	13.7880	14.9231	10.8722	17.3322	17.4911
300	11.7027	13.0193	14.0019	10.2280	17.0894	17.0074	17.7121
400	12.1777	13.2727	14.1012	10.3831	17.2171	17.7477	17.9101
1000	12.0980	13.4019	14.3308	10.4922	17.3018	17.7210	17.9849
Unloading							
.	11.0074	12.9804	13.8247	10.0709	10.7810	17.3842	17.7130
100	11.1088	12.0389	13.0003	14.8078	10.0490	17.0711	17.7173
200	10.8733	12.2833	13.2728	4.0073	10.3844	10.9333	17.0077
300	10.7447	12.1037	13.0710	14.3701	10.2201	10.7774	17.0074
400	10.7724	11.9904	12.9998	14.3147	10.1347	10.7770	17.0032
1000	10.7709	11.9401	12.9407	14.2904	10.1072	10.7340	17.4807

APPENDIX A

A_{r1}

Results of Repeated Creep Test for Mix No. 13

APPENDIX A

A₁₁

Accum. Strain *10⁻³ (mm/mm)

Cycle No. Time(sec)	1	2	3	4	5	6	7
Loading	3.7913	7.2884	7.1442	7.4219	8.0931	8.4039	8.7439
100	4.7124	7.7848	7.4789	8.0001	8.4370	8.7821	8.9019
200	5.7370	7.9211	7.5931	8.2009	8.7021	8.8031	8.9924
300	7.2011	7.0847	7.7422	8.3798	8.7399	8.9987	9.0934
400	7.0170	7.1407	7.7099	8.4074	8.8178	9.0931	9.1877
1000	7.8124	7.2720	7.8397	8.4928	8.8497	9.1097	9.2027
Unloading	7.2720	7.0989	7.0974	8.2787	8.7031	8.9734	9.2027
100	7.0847	7.7019	7.3921	8.0778	8.0039	8.8241	9.1737
200	0.9024	7.7772	7.2474	7.9397	8.47478	8.7433	9.1133
300	0.9291	7.0991	7.2002	7.8029	8.4048	8.7800	9.1100
400	0.9201	7.0021	7.1831	7.8031	8.3887	8.7123	9.1030
1000	0.9123	7.0329	7.1702	7.7932	8.3774	8.7010	9.1007

Creep Compliance *10⁻⁶ (1/Kpa)

Loading	7.7871	11.3920	12.9423	13.4404	14.7714	13.3100	10.8403
100	8.0379	12.2913	13.0487	14.0019	10.2827	10.7284	17.1277
200	10.3922	12.0382	13.7007	14.8707	10.0830	17.0382	17.2900
300	11.2338	12.8344	14.0207	10.1807	10.8331	17.3018	17.4730
400	11.8020	12.9401	14.0077	10.3197	10.9742	17.4730	17.7423
1000	12.3413	13.1077	14.2021	10.3800	17.0320	17.0934	17.7739
Unloading	11.3400	12.8703	13.7710	14.9790	10.7774	17.2071	17.7731
100	11.0228	12.2317	13.3914	14.7100	10.4971	10.9807	17.7009
200	10.7823	12.0973	13.1270	14.3830	10.3020	10.8393	17.0097
300	10.7411	11.9048	13.0438	14.2272	10.2270	10.7347	17.4980
400	10.7248	11.8797	13.0028	14.1370	10.1977	10.7019	17.4731
1000	10.7101	11.8349	12.9800	14.1181	10.1747	10.0824	17.4098

Results of Repeated Creep Test for Mix No. 14

Accum. Strain *10 ⁻³ (mm/mm)							
Cycle No.	1	2	3	4	5	6	7
Time(sec)							
Loading							
.	3.7231	7.3101	7.1769	7.4831	8.1392	8.4740	8.7611
100	4.7622	7.8019	7.0138	8.0739	8.4839	8.7996	8.9204
200	0.7632	7.9420	7.7099	8.2399	8.7021	8.8831	9.0239
300	7.3120	7.1130	7.7821	8.3997	8.7744	9.0701	9.1121
400	7.0031	7.1621	7.7939	8.4767	8.8039	9.1298	9.1839
1000	7.8422	7.2831	7.8722	8.0131	8.8919	9.1821	9.2873
Unloading							
.	7.2900	7.1132	7.7398	8.3196	8.4700	8.9962	9.2319
100	7.1266	7.7821	7.4460	8.1198	8.0921	8.8029	9.1896
200	0.9833	7.7340	7.2987	7.9904	8.0166	8.7619	9.1621
300	0.9467	7.7429	7.2431	7.8931	8.4629	8.7206	9.1499
400	0.9233	7.0946	7.2206	7.8619	8.4302	8.7099	9.1321
1000	0.9200	7.0798	7.2039	7.8439	8.4169	8.7933	9.1298
Creep Compliance *10 ⁻⁶ (1/Kpa)							
Loading							
.	7.7447	11.4313	13.0016	13.0063	14.7449	10.3000	10.8710
100	8.7271	12.3222	13.7119	14.7080	13.3693	10.7601	17.1692
200	10.4400	12.0570	13.8766	14.9273	10.7641	17.0920	17.3476
300	11.4306	12.8867	14.0980	10.2168	10.8906	17.4132	17.0074
400	11.8710	12.9748	14.1193	10.3062	17.0396	17.0390	17.7370
1000	12.3902	13.1940	14.2612	10.4223	17.1080	17.7342	17.8248
Unloading							
.	11.3949	12.8862	13.8402	10.0717	10.8333	17.2970	17.7244
100	11.0989	12.2864	13.4900	14.7097	10.0604	17.0378	17.7478
200	10.8393	12.1992	13.2221	14.4844	10.4286	10.8730	17.0980
300	10.7730	12.0342	13.1210	14.2991	10.3313	10.8072	17.0709
400	10.7306	11.9467	13.0898	14.2420	10.2811	10.7788	17.0436
1000	10.7246	11.9199	13.0000	14.2099	10.2480	10.7487	17.0304

APPENDIX B

The Results of Wheel Tracking Test (Rate of Rutting *١٠٨-٣)

No. of App. Mix No.	٢٠٠٠	٤٠٠٠	٦٠٠٠	٨٠٠٠	١٠٠٠٠	١٢٠٠٠	١٤٠٠٠	١٦٠٠٠
١	٢٠.٥٠	٤١.٣٤	٥٩.٣٤	٧٣.٥٤	٨١.١٨	٨٥.٥٢	٨٩.٣٤	٩١.٣٨
٢	٢٨.٦٥	٤٦.٥٠	٦٥.١٨	٧٦.٤٢	٨٥.١٦	٩٠.١٢	٩٤.٦٢	٩٦.٤٥
٣	٢٩.٤٠	٥٠.٤٢	٦٨.٥٣	٧٩.٤٠	٨٧.٤٢	٩٣.٩٨	٩٧.٨٤	١٠٠
٤	٣٠.٠٠	٥٥.٤٦	٧٣.٥٢	٨١.٩٠	٩١.١٨	٩٦.٢٦	٩٩.٩٢	١٠٠.٧
٥	٢٦.٧٨	٤٩.٩٦	٦٥.٩٤	٧٧.٩٨	٨٥.٩٨	٩١.٩٢	٩٣.٤٠	٩٧.٨٠
٦	٢٠.٠٠	٤٠.٠٠	٥٥.٠٠	٦٨.١٠	٧٨.٠٦	٨٢.٥٢	٨٦.٤٠	٨٨.٠١
٧	٣١.٤٠	٥٥.٧٨	٧٠.٢٤	٨٠.٥١	٨٦.٥٢	٩١.٤٣	٩٥.٤١	٩٩.٥٢
٨	٢٦.٥٨	٤٧.٨٤	٦٥.٥٢	٧٥.٠٦	٨٣.٠٥	٨٨.٦٣	٩٢.٤٢	٩٦.٥٨
٩	٢٧.٩٦	٥٣.٥٨	٦٩.٥٢	٨٠.٤٢	٨٧.٩٧	٩٢.٤٢	٩٥.٥٢	٩٧.٦٩
١٠	٢٨.٥٠	٥٦.٩٨	٧٤.٢٥	٨٥.١٨	٩١.٢٤	٩٥.٦٤	٩٨.٤٢	١٠٠.٦
١٣	٢٨.٩٠.٤	٥٢.٦٢	٧٦.٢٣	٩٠.٣٢	١٠٠.٠٣	١٠٦.٥٨	١١٠.٢٤	١١٣
١٤	٣٢.٤٢	٦٠.٤٢	٨٠.٥٢	٩٣.١٩	١٠٤.٣٤	١١٣.٤٤	١١٦.٣٨	١١٨.٠٠

