DEVELOPMENT OF STATISTICAL MODEL FOR THE PREDICTION OF PERMANENT DEFORMATION IN PAVING MATERIALS

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ABSTRACT

Permanent deformations (rutting) of asphalt pavements which appear in many roads in Iraq. have caused a major impact on pavement performance by reducing the useful service life of pavement and creating services hazards for highway users. Therefore, it is important to analyze and investigate this type of distress.

The objectives of the present paper include; the analysis of the main contributory factors influencing rutting, and development of statistical model for the prediction of permanent deformation in paving materials.

To achieved these objectives for the requirements of data collection. five types of gradation. (40-50) asphalt cement and different types of filler are used to prepare three hundred sixty asphalt concrete specimens throughout the work using Marshall method and Superpave system. Most of these specimens are tested by applying diametric creep under different temperatures and stress levels.

A statistical model has been developed for the prediction of rut depth in local asphalt paving materials as influencing by the factors of asphalt cement content, mineral filler type, air voids and environmental temperature.

الخلاصة

ان التشوهات الدائمية (التخدد) في التبليط الاسفلتي تظهر في العديد من طرق العراق،وتسبب تأثيرا رئيسيا على اداء التبليط و ذلك عن طريق تقليل العمر الخدمي للتبليط وجعل استخدام هذه الطرق محفوفة بالمخاطر ،لذلك من المهم التحليل والتحري عن هذا النوع من الفشل.

ان اهداف الدراسة الحالية تتضمن تحليل العوامل الاساسية المؤثرة في التخدد،وتطوير نموذج احصائي للتنبؤ به في المواد الاسفلتية.

لتحقيق هذه الاهداف لمتطلبات جمع البيانات فقد تم استخدام خمسة انواع من تدرجات الركام واسفلت نوع(40-50) مع انواع مختلفه من المواد المالئة لتحضير ثلاثمائة وستون نموذج من الاسفلت الكونكريتي خلال فترة الدراسة مستخدمين طريقة مارشال ونظام التبليط الفائق (Superpave) .وقد تم اجراء فحص الزحف على معظم هذه النماذج وضمن درجات الحراره ومستويات الاجهاد المختلفة.

وقد تم بناء نموذج احصائي للتنبؤ بمقدار التخدد في مواد التبليط المحلية والذي يتأثر ببعض العوامل الرئيسية المتمثلة بالفجوات الهوائية ونوعية المادة المالئة وكمية الاسفلت ودرجة الحرارة.

KEY WORDS

Permanent Deformation, Rutting P ediction, Rutting Statistical Model, Flexible Pavement Rutting. Factors Affecting Rutting.

INTRODUCTION

The asphaltic paving mixture is normally subjected to various detrimental types of distresses during its service life .These distresses are caused by load, weather, and construction practices. and /or deficient materials. Some of these serious distresses include rutting (permanent deformation). shoving. stripping, and fatigue (alligator cracking). which finally may lead to complete failure of pavement at the same time. Such distresses will reduce the performance of asphalt pavements, which not only causes inferior ride quality to motorists but also yields higher life-cycle cost. Some of the mentioned distresses are associated with the asphalt cement binder and can be controlled significantly by modifying the material with chemical additives [Ramzi et al. (1998)].

Permanent deformation (rutting) of asphalt pavements has a major impact on pavement performance. Rutting reduces the useful service life of the pavement and, by affecting vehicle handling characteristics, creates serious hazards for highway users. Highway materials engineers have been handicapped in their efforts to provide rutting resistant materials in by the existing methods for testing and evaluating asphalt-aggregate mixes which are empirical and do not give a reliable indication of in-service performance [Huang et al. (1991)].

A variety of materials is currently available for use as modifiers to improve the performance of asphalt concrete pavements. Different efforts and techniques have been carried out to improve the ability of asphalt concrete to resist rutting; for example, many agencies around the United States have adopted specifications to address rutting distress in asphalt concrete pavements [Sousa et al. (1991)]

In Iraq, the severity of rutting has been increased in asphalt pavements possibility due to the increase in truck axle loads, tire pressure, and high pavement temperature in summer [Hussain 1985].

SOURSE OF DATA

The required data for the previously mentioned independent variables are gathered from the results of the experimental tests, while the dependent variable (rutting) is calculated according to the following statistical model, which is reported by Baladi (1988).

$$\textbf{Log(RD)} = -1.6+(0.067)(AV)-(1.5)(\log(TAC))+(0.07)(T)+(0.000434)(KV)+(0.15)(\log(ESAL))-(0.4)(\log(MR_{SUB}))-(0.63)(\log(MR_{B}))+(0.1)(\log(SD))+(0.01)(\log(CS)) \quad (1)$$

where:-

RD = *rut depth (inch),*
TAC = *thickness of AC course (inch),*
SD = *surface deflection (inch),*
AV = *the percent air voids of the AC mix (AV = 1, 2 . . . etc.),*
MR_b = *the resilient modulus of the base material (psi),*
MR_{sub} = *the resilient modulus of the roadbed soil (psi),*
TS = *the tensile strain at the bottom of the AC fiber,*
CS = *the compressive strain at the bottom of the AC layer,*
KV = *kinematic viscosity of the AC binder (centistokes),*
ESAL = *the number of equivalent single axle load at which the rut depth is being calculated, and*
T = average annual air temperature (°C).

STEPWISE REGRESSION PROCEDURE

This procedure begins by computing the simple regression model for each independent variable. It examines all such models to determine which is best and whether the F-statistic of the second variable (with the first variable already in the equation) is greater than F-to-enter. If two independent variables are highly correlated, only one of them will enter the equation. Once the first variable is included, the added explanatory power of the second variable will be minimal and its F-statistic will not be large enough to enter the model.

The procedure continues by deciding whether to add another independent variable at each step. The p-values of all variables are computed (at each step) and compared to the F-to-remove. If a variable F-statistic falls below this standard, it is removed from the equations.

These steps are repeated until no more variables are added or removed. The rutting model derived from the analysis is found to be:

$$RD=2.667283+0.061539*AC+0.001885*Temp.-0.160534*F+0.985539*AV \quad (2)$$

R=0.90..................................R^2=0.813........................SEE=0.32958

where:-

RD= Rut depth in (mm)

AC=Asphalt content (AC from4.0 - 6.0)

Temp. = Temperature in °C

F= Filler type (1=Cement, 2=Hydrated lime and 3=Lime stone dust)

AV= the percent air voids of the AC mix (AV from 2.0 - 5.1)

By using STATISTICA software, the correlation coefficients between all of the variables are calculated and the correlation matrix is setup. This matrix and testing for (R) critical can be seen in **Table (1)**.

Table (1) Correlation Matrix for Rutting Model.

Correlations (New model.sta)					
	ASPHALT	**TEMP_**	**FILLER**	**AIR_VOID**	**RUTTING**
ASPHALT	1	0.1764704	0.128907	-0.3033593	0.2495724
TEMP_	0.1764704	1	0.3228478	-0.2466469	0.2288295
FILLER	0.128907	0.3228478	1	-0.1925076	-0.2912172
AIR_VOID	-0.3033593	-0.2466469	-0.1925076	1	0.8938356
RUTTING	0.2495724	0.2288295	-0.2912172	0.8938356	1

The summary of stepwise regression, regression summary and several possible models can be seen in **Tables (2), (3)**.

Table (2) Regression Summary and Summary of Step Wise Regression for Rutting Model.

Regression Summary for Dependent Variable: RUTTING						
R= .90295077 R^2= .81532009 Adjusted R^2= .81361797						
F(4,434)=479.00 p<0.0000 Std.Error of estimate: .32958						
	BETA	St. Err. **of BETA**	**B**	St. Err. **of B**	**t(434)**	**p-level**
Intercept			2.6672835	0.2366708	11.270015	5.132E-26
ASPHALT	0.0311372	0.0218037	0.0615394	0.0430927	1.4280694	0.153991
TEMP_	0.026925	0.0223344	0.0018855	0.001564	1.2055411	0.2286513
FILLER	-0.133712	0.0219855	-0.160534	0.0263957	-6.0818308	2.609E-09
AIR_VOID	0.8841817	0.0222487	0.9855385	0.0247992	39.740773	0

Table (3) Several Possible Models From the Stepwise Regression Analysis for the Selection of Rutting Model.

Case	Variable	Model	R^2	SEE
1	Av	RD=2.774+0.996Av	0.798	0.342
2	Av,F	RD=3.046+0.969Av-0.148F	0.812	0.330
3	Av,F,Ac	RD=2.708+0.98Av-0.151F+0.066Ac	0.812	0.329
4	Av,F,Ac,Temp	RD=2.667+0.98Av-.160F+0.061As+0.001Temp.	0.813	0.329

TESTING FOR THE MODEL

Testing for Normality

In addition to chi-square test for normality, the following two tests can be used. The first is called the Kolmogorov-smirnov (or K-S test).Whereas, the second is called the Lilliefors test .Both test work similarly by comparing the actual and normal cumulative probabilities. The difference between them is that K-S test assumed that the mean and the standard deviation of the population are known. While Lilliefors test requires to compute the mean and standard deviation from the data [Keller and Warrack (2000)].For this study and according to the available data Lilliefors test is suggested to be used.

Lilliefors Test

H_o =the data are normally distribution.

H1= the data are not normally distribution.

D= max [F(x)-S(x)]

Where

S(x): Sample cumulative distribution function (the proportion of sample value that are less than or equal to x).and,

F(x): Normal cumulative probabilities. (From normal distribution table).

$P(Z \le \frac{x_i - \bar{x}}{S})$

Where,

x_i =value of variable.

$\bar{x}$ =Sample mean.

S=Standard deviation of sample.

Lilliefors test result for the developed model can be seen in the following tables:

D-value for rutting model

Variable	(D) value
Temperature	0.035
Stress	0.042
Asphalt content	0.021
Filler type	0.039
Gradation type	0.035
Compaction methods	0.042
V.M.A.	0.031
Flow	0.015
Stiffness	0.040
Air voids	0.011
Rutting	0.018

For sample size >30 and significant level =0.05,
Then $D_{critical} = 0.886/(n)^{0.5}$

$D_{critical} = 0.0422$ for rutting model .The values of $D_{critical}$ are grater than the above tabulated for rutting model..Thus, D does not fall into the rejection region and there is no reason to reject the null hypothesis.

<u>Checking for $R^{critical}$</u>

Refer to the correlation matrix, most of the coefficients of correlation between each two variables $R_{calculated} > R_{tabulated}$ is equal to 0.095 (n=439, df= n-(1+1) =437).Thus, the null hypothesis that, there is no association between the variables is rejected at 95% confidence level.

The correlation coefficient of the final form of this model =0.90 > $R_{tabulated}$ =0.123, (n=439, df=n-(5+1) =433). Therefore, there is strong correlation between the rutting model and the independent variables in this model.

<u>Goodness of Fit</u>

To checking the goodness of fit for the predicted model. Chi-square test was carried out and the following results are expressed.

1- X^2-test

n=439, df=438, confidence level =95%

Case	variables	X^2-value	X_c^2-value
1	x=observed	91.77	233.99
	y=predicted rutting model		

For case 1 $X^2 < X_c^2$, there is no significant difference between the observed and the predicted values.

RESULTS OF THE ANALYSIS

The stepwise regression using STATISTICA software serves its purpose in drawing attention to dangerous inter-correlation and enables a selection of variables to be made on logical basis. The chosen variables are then entered in a regular multiple regression. The first model developed is shown at the end of the previous section as rutting model Equation (2).

The variables; air voids, filler type, temperature and asphalt content are chosen. The variables used in the model show that the rutting is strongly affected by air voids and asphalt content, while, filler type and temperature reflect lower effect on rutting. The model indicates that rutting increases with the increase in air voids, asphalt content and temperature, while it decreases with the filler type from cement to hydrated lime, which has low value of correlation with the rutting.

It was found that the linear forms of the variables result in best correlation between the independent variables and rutting.

A study of the correlation coefficient matrix and the variables selected for the regression analysis showed several variables correlated reasonably well with the dependent variable, but do not enter because of high order of inter-correlation with a variable already selected for the model. Accordingly, it was decided to reduce the number of variables, leaving as few as possible to describe the pavement.

DISCUSSION OF RESULTS

Regarding the rutting model; four variables are found to be common to the general picture of the model development; these were air voids, filler type, temperature, and asphalt content. The coefficient of determination is found to be 0.813, which means that this model can explain 81.3 percent of the rutting prediction.

There is no multicollinearity between the independent variables that affect the rutting model.

MODEL LIMITATION

As with all regression models, the model is only valid within the ranges of the variables developed .Some additional limitations can be mentioned, as in the follows;

1. Mix stiffness could be estimated by Heukelom method, and
2. The ranges of data for rutting model can be seen in Table (4).

Table (4) Range of Data in Rutting Model

Variables	Mean	Minimum	Maximum
ASPHALT CONTENT (%)	4.659	4.0	6.0
STRESS LEVEL (Mpa)	0.088	0.025	0.1
TEMPERATURE (°C)	31.93	20.0	60
COMPACTION TYPE (1and 2)	1.191	1.0	2.0
GRADATION TYPE (1,2,3,4and5)	3.387	1.0	5.0
FILLER TYPE (1,2,and 3)	1.293	1.0	3.0
STIFFNESS (Kg/cm^3)	4.479	3.0	101
FLOW (mm)	2.921	2.0	5.1
V.M.A (%)	12.54	8.79	100
AIR VOID (%)	2.997	2.0	5.1
RUTTING (mm)	5.760	3.866	8.420

VALIDATION OF THE DEVELOPTED MODEL

Introduction

The final step in the model building process is the validation of the developed models. The objective is to assess the ability of rutting prediction model to accurately predict the amount of rutting in the field using data not already used in developing the model.

Literature Review

A review of the statistical literature [Neter et al., 1990 and Snee 1977] suggests the following methods for validating a regression model:

- Check on Model Predictions and Coefficients
- Collection of New Data
- Comparison with Previously Developed Models
- Data Splitting
- Prediction Sum of Squares (PRESS)

Selection of Validation Methods

The literature suggests that all available methods of validation could be used. However, in this case, it is not possible to use all the methods of validation. Therefore, the applicability of each method in terms of the validation of the rutting model will be discussed and the most appropriate methods of validation will be selected.

The first method (Check on Model Predictions and Coefficients) attempts to make sure that the selected model agrees with the physical theory. This essentially has been already checked during the development process.

The second method (Collection of New Data) suggests that a new data set should be collected. Unfortunately, the collection of the new data is not possible due to time constraints.

The third method (Comparison with previously developed models) compares the results of a newly developed model with a previously developed model or with a theoretical model.

The fourth method (data splitting) has recommended that one may not consider data splitting unless $N > 2P+25$, where N is the sample size and P is number of estimated parameters.

The last method (Prediction Sum of Squares) is a form of data splitting and it is not feasible because of the available large sample size.

For the above mentioned discussion, because of the nature of the available data and minimization of the error of mean for the accuracy requirements, the third method (Comparison with previously developed models) is selected to assess the predictive ability of the rutting model.

COMPARISION WITH PREVIOUSLY DEVELOPTED MODELS

Shell design method (Manually calculated), shell pavement design software SPDM 3.0 and new rutting model have been applied to show the effect of variable variations on the permanent deformation values of asphalt concrete surface layer .The following default values are used in this process;

1-80 mm asphalt concrete mixture as surface layer with stiffness modulus varying according to the type of mixture

2- The above mentioned layer is supported by 200 mm asphalt concrete base layer with stiffness modulus of 1×10^{9} N/m^{2}

3- Silty clay subgrade with a resilience modulus of 2.5×10^{5} N/m^{2} modulus

4- The MMAT (Mean Monthly Air Temperature), are (18.3, 21.4, 25.3, 31.8, 39.1, 42.7, 44.5, 46, 40.4, 34.9, 24.3, and18) [Iraqi Meteorological Organization, 2002].

5- Design life =15 year

6-The total number of axles per lane per day is equal to 2000, and it is anticipated that traffic will increase at the rate of 2 percent

Table (5) shows the rut depth calculation by using shell method (manual calculation). SPDM 3.0 software, and new rutting model for each mix variable.

Table (5) Rut Depth Calculation by Using Shell and New Developed Model

Mix No.	i	h_i (mm)	$T_{\bar{y}}$	η_y E+4	q	W E+6	$S_{bit,visc}$ N/m^2	S_{mix} N/m^2 E+6	Z_i	C_m	Δh_i (mm)	Shell method: Manually By charts (mm)	Shell method: SPDM Software (mm)	Developed rutting model
1	1	40	39	2	0.379	3.79	0.79	6.5	0.6	1.2	2.65	4.98	6.02	6.84
	2	40	36	4	0.382	3.76	1.59	7.4	0.6	1.2	2.33			
2	1	40	39	2	0.381	3.80	0.78	6.6	0.6	1.2	2.61	5.15	4.74	5.58
	2	40	36	4	0.381	3.80	1.57	6.8	0.6	1.2	2.54			
3	1	40	39	2	0.279	3.85	0.77	7.6	0.6	1.2	2.27	4.4	4.67	5.5
	2	40	36	4	0.381	3.8	1.57	8.1	0.6	1.2	2.13			
4	1	40	39	2	0.380	3.79	0.79	5.3	0.6	1.2	3.26	5.87	4.66	5.51
	2	40	36	4	0.380	3.79	1.58	6.6	0.6	1.2	2.61			
5	1	40	39	2	0.382	3.76	0.79	5.92	0.6	1.2	2.91	5.42	4.50	5.35
	2	40	36	4	0.382	3.76	1.59	6.87	0.6	1.2	2.51			
6	1	40	39	2	0.371	3.90	0.76	5.21	0.6	1.2	3.31	6.06	8.64	9.43
	2	40	36	4	0.371	3.90	1.53	6.27	0.6	1.2	2.75			
7	1	40	39	2	0.378	3.80	0.78	5.02	0.6	1.2	3.44	6.61	4.51	5.36
	2	40	36	4	0.378	3.80	1.57	5.44	0.6	1.2	3.17			
8	1	40	39	2	0.372	3.89	0.77	7.9	0.6	1.2	2.18	4.11	4.18	5.03
	2	40	36	4	0.372	3.89	1.54	8.95	0.6	1.2	1.93			
9	1	40	39	2	0.410	3.75	0.80	7.42	0.6	1.2	2.32	4.34	4.33	5.16
	2	40	36	4	0.410	3.75	1.60	8.52	0.6	1.2	2.02			
10	1	40	39	2	0.379	3.79	0.79	5.7	0.6	1.2	3.03	5.67	4.19	5.01
	2	40	36	4	0.379	3.79	1.58	6.54	0.6	1.2	2.64			
11	1	40	39	2	0.371	3.9	0.76	6.5	0.6	1.2	2.65	5.15	4.88	5.72
	2	40	36	4	0.371	3.9	1.53	6.9	0.6	1.2	2.50			
12	1	40	39	2	0.384	3.77	0.79	5.82	0.6	1.2	2.96	5.54	4.81	5.66
	2	40	36	4	0.384	3.77	1.59	6.68	0.6	1.2	2.58			
13	1	40	39	2	0.380	3.79	0.79	6.9	0.6	1.2	2.50	4.83	4.68	5.53
	2	40	36	4	0.380	3.79	1.58	7.4	0.6	1.2	2.33			
14	1	40	39	2	0.381	3.80	0.78	1.9	0.6	1.2	9.09	6.5	4.32	5.17
	2	40	36	4	0.381	3.80	1.57	2.33	0.6	1.2	7.41			
15	1	40	39	2	0.379	3.79	0.79	3.88	0.6	1.2	4.45	8.29	4.75	5.6
	2	40	36	4	0.379	3.79	1.58	4.5	0.6	1.2	3.84			
16	1	40	39	2	0.279	3.79	0.79	8.73	0.6	1.2	1.97	3.69	4.63	5.48
	2	40	36	4	0.279	3.79	1.58	10.02	0.6	1.2	1.72			
17	1	40	39	2	0.371	3.90	0.76	8.83	0.6	1.2	1.95	3.64	4.67	5.52
	2	40	36	4	0.371	3.90	1.53	10.22	0.6	1.2	1.69			
18	1	40	39	2	0.380	3.79	0.79	6.4	0.6	1.2	2.7	5.13	4.88	5.72
	2	40	36	4	0.380	3.79	1.58	7.1	0.6	1.2	2.43			
19	1	40	39	2	0.371	3.90	0.76	5.9	0.6	1.2	2.92	5.57	4.47	5.32
	2	40	36	4	0.371	3.90	1.53	6.5	0.6	1.2	2.65			
20	1	40	39	2	0.279	3.79	0.79	5.31	0.6	1.2	3.25	6.32	4.43	6.28
	2	40	36	4	0.279	3.79	1.58	5.62	0.6	1.2	3.07			
21	1	40	39	2	0.372	3.89	0.77	7.83	0.6	1.2	2.20	4.13	5.48	6.32
	2	40	36	4	0.372	3.89	1.54	8.92	0.6	1.2	1.93			

VALIDATION RESULTS

The rutting values resulted from SPDM software are plotted against those estimated by the new rutting model. This relation is shown in **Fig. (1)**.

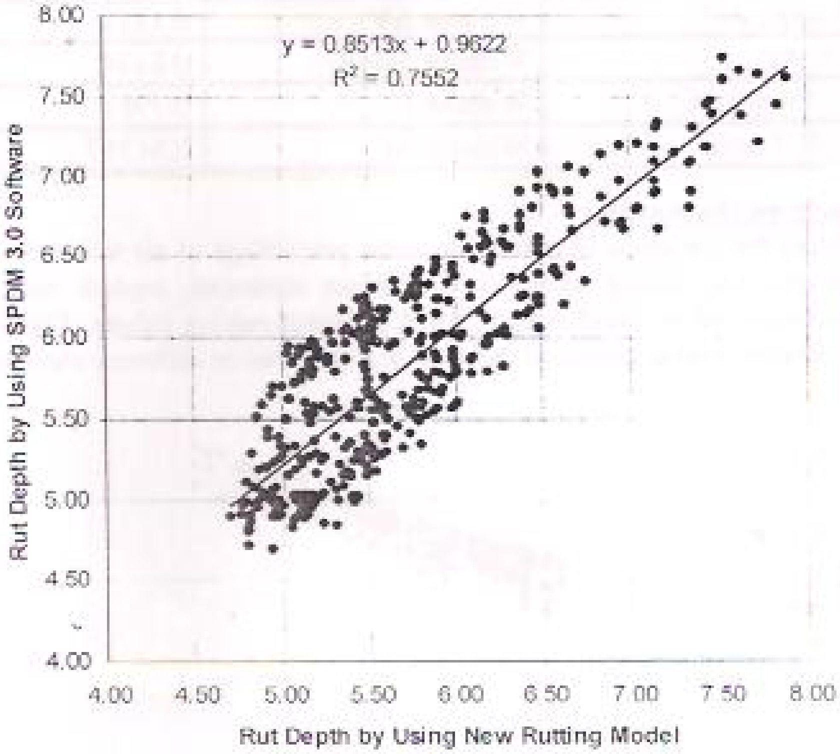

Fig. (1). SPDM 3.0 Software versus New Rutting Model Rut Depth

The best fit of the relation between the rutting value of SPDM 3.0 software and new rutting model can be found in the following form;

$$RD(SPDM\ 3.0\ Software) = 0.8513 * RD(New\ Rutting\ Model) + 0.962 \quad (3)$$
$$R^2 = 0.7552$$

where:-

RD (SPDM 3.0 Software) = *Rut Depth Calculated Using SPDM 3.0 Software*

RD (New Rutting Model) = *Rut Depth Calculated Using New Rutting Model*

These findings seem to have good agreement with the relation y = x.

Thus and for the local materials characteristics and environmental condition, the developed model can be recognized for the prediction of the rutting in Iraq within the mentioned limitations of this model.

SENSITIVITY ANALYSIS

Sensitivity analysis has been made to illustrate the effect of various parameters on rutting prediction model. Analysis is conducted to evaluate the effect of air void, filler type, asphalt content, and temperature on the rutting model of asphalt mixtures.

A parametric study is performed to select the suitable variables in the presented model. **Table (6)** shows the results of the parametric study. Based on the highest coefficient of determination (R^2), rut depth (*RD*), temperature (Temp.), filler type (F), and the air void (AV) are selected for the prediction model.

Table (6) Selection of Model Parameters

Model Parameter	Condition	R^2
RD, AV, F, Temp. ,AC	With all Parameter	0.8136
RD, F, Temp., AC	Without AV	0.1373
RD,AV,F, AC	Without Temp.	0.8134
RD, AV, Temp., AC	Without F	0.7981
RD, AV, F, Temp.	Without AC	0.81317

Effects of Air Voids on the Rutting

Fig. (2) Presents the variation of rutting with the percentage of air voids. In general, as the air void content increases the rutting increases. In certain instances, asphalt mixtures with similar gradation characteristics and air void content yield different rutting values. This difference may be attributed to the different arrangements of the void distributions in different samples.

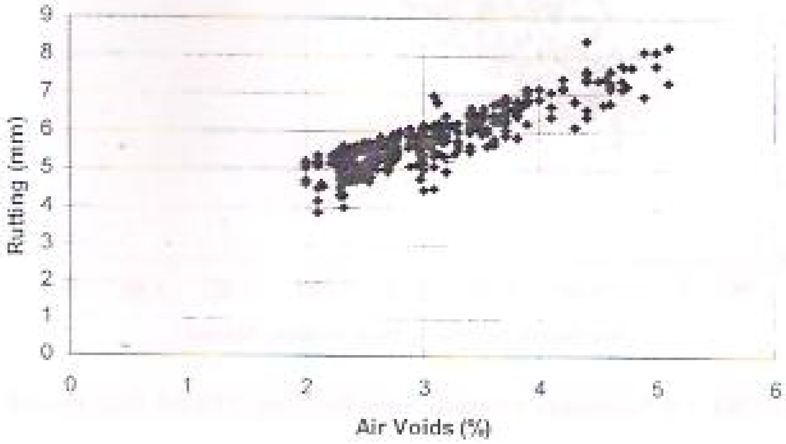

Fig. (2) Variation of Rutting with Air Voids

Effects of Asphalt Content on the Rutting

Fig. (3) Presents the variation of the rutting with the asphalt content. In general, as the asphalt content increases the rutting increases.

In certain instances, asphalt mixtures with similar gradation characteristics and asphalt content yield different rutting values. This difference may be attributed to the different asphalt distributions in different samples.

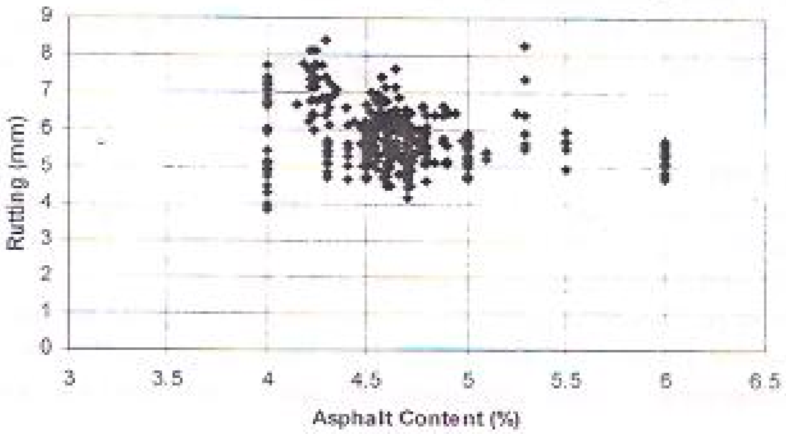

Fig. (3) Variation of Rutting with Asphalt Content

Effects of Filler Type on the Rutting

Fig. (4) Shows the effects of the variation of filler type on the rutting of HMA mixtures. No conclusions could be drawn since the filler type does not varies significantly in the considered mixtures.

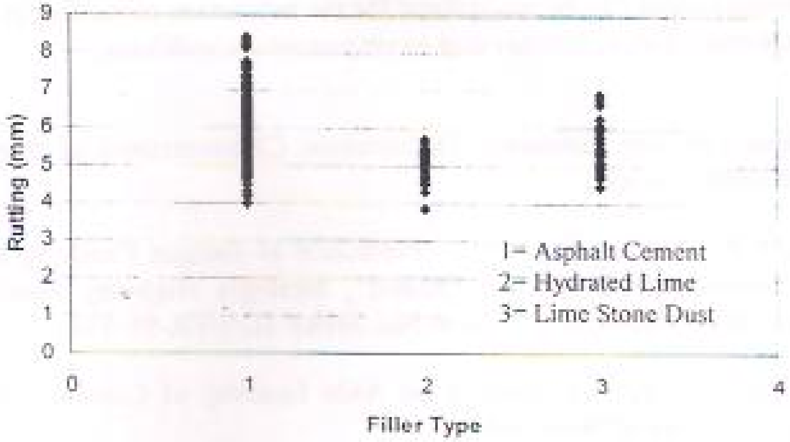

Fig. (4) Variation of Rutting with Filler Type

Effects of Temperature on the Rutting

Fig. (5) Shows the effects of the variation of temperature on the rutting of HMA mixtures. No conclusions could be drawn since the temperature does not varies significantly in the considered mixtures.

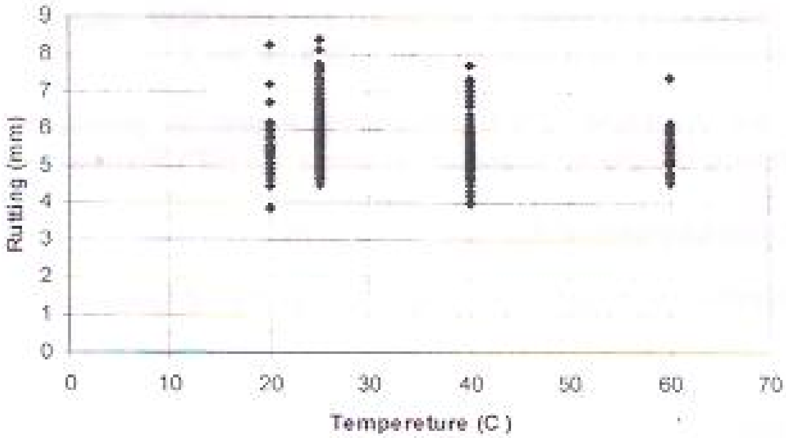

Fig. (5) Variation of Rutting with Temperature

CONCLUSIONS

1- As a result of the statistical analysis, the following model is developed to predict rutting in asphalt concrete mixture;

$$RD=2.667283+0.061539*AC+0.001885*Temp.-0.160534*F+0.985539*AV$$

where:-

RD= Rut depth in (mm)

AC=Asphalt content (AC from4.0 - 6.0%)

Temp. = Temperature in °C

F= Filler type (1=Cement, 2=Hydrated lime and 3=Lime stone dust)

AV= the percent air voids of the AC mix (AV from 2.0 - 5.1%)

2- As compared with the sensitivity analysis results, the air voids and asphalt content have a pivot role to influence the mixture ability to resist permanent deformation. While .lower influence on the permanent deformation appear by other variables.

RECOMMENDATIONS

The developed rutting model can be recognized for the prediction of rutting in Iraq within its limitation and local materials characteristics and environmental conditions.

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NOMENELATURE

RD = Rut depth in (mm)
AC =Asphalt content (AC from4.0 - 6.0%)
Temp. = Temperature in °C
F = Filler type (1=Cement, 2=Hydrated lime and 3=Lime stone dust)
AV = Air Voids of the AC mix (AV from 2.0 - 5.1%)
PRESS= Prediction Sum of Squares.
R = Coefficient of Correlation.
R^2 = Coefficient of Determination.
R_C = Critical Coefficient of Correlation
χ^2 = Chi-square.
χ_c^2 = Critical Chi-square.