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Research Article

Predication Model for Rut Depth of Superpave Asphaltic Concrete Mixtures from Wheel Track Test

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Abstract

In Iraq as similar in other countries, rutting is one of major distresses in asphalt concrete pavement as a result of increased in axle loads, and hot summer temperature. This type of distress lead to decreasing the level of serviceability during the pavement design life and creates serious hazards for highway users. Accordingly, evaluating the asphalt concrete rut depth is one of the major aim objective of this study. To investigate the rut depth in asphalt concrete under repeated loadings, Wheel-Tracking device has been used in a factorial testing program according to study parameters. Based on wheel-tracking test results, when temperature duplicated from 30 to 60 °C the rut depth increases 7 folds. Also, the rut depth is increased about 35 percent when the asphalt content changes from 4.25 to 4.75 percent, whereas it increased about 45 percent when the asphalt content increased from 4.75 to 5.25 percent. Finally, SPSS version 22 software was applied to develop model with R^2 = 0.96 to correlate the criterion variable of wheel track rut depth with the predicated variables considered in this study.

Keywords: *Rutting, Wheel track test, Flexible pavement distresses, HMA, Superpave, Permanent deformation*

1. Introduction

Flexible pavement is usually subjected to numerous detrimental types of distresses throughout its service life. These distresses of a pavement system are affected by many factors that are either traffic associated or non-traffic associated. Such factors include loads, stress, environmental conditions, deficient materials, construction methods and maintenance. Huang, (2004) stated that three major traffic associated failure modes are permanent deformation, fatigue cracking and thermal cracking.

Permanent deformation (Rutting) is a longitudinal surface depression in the wheel path accompanied by small upheavals to the each sides (FHWA, 2003)as shown in Figure1. It is gradually develops with increasing numbers of load applications (Sousa et al, 1991).

Rutting has become the dominant mode of failure in flexible pavements because of the increase in tire pressures and axle loads in the recent years. This distress is caused by the accumulation of permanent deformation in all or some layers in the pavement structure as a result of:

- Densification or one-dimensional Compression and consolidation
- Lateral movements or plastic flow of materials (HMA, aggregate base, and subgrade soils) from wheel loads.

National Cooperative Highway Research Program (NCHRP, 2002) classified rutting into three categories, as follows:

1) Wear rutting, which is due to the progressive loss of coated aggregate particles from the pavement surface and caused by combined environmental and traffic influences.
2) Structural rutting, which is due to the permanent vertical deformation of the pavement structure under repeated traffic loads and it is essentially a reflection of the permanent deformation within the subgrade.
3) Instability rutting, which is due to the densification (decrease in volume and, hence, increase in density) and lateral displacement (shear deformation) of material within the pavement asphaltic concrete layers.

The accumulations of permanent deformation in the surfacing layer are now recognized to be the major component of rutting in flexible pavements. Permanent deformation was selected as the most serious problem for highways and runways among all the distresses in asphalt pavements according to the National Cooperative Highway Research Program (NCHRP, 2002).

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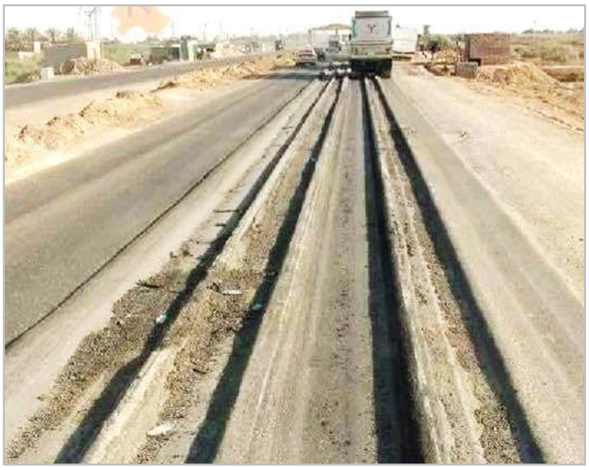


Figure 1: Rutting in Flexible Pavement near the Checkpoint

When a wheel load is applied to an element of asphaltic material in the pavement, it causes some deformation in the material. The magnitude of the deformation depends on the material properties, load level, temperature and loading time. After removing the load, part of the deformation will be recovered, and some permanent deformation will remain in the material. The recovered deformation is related to the elastic and delayed elastic properties, and the permanent deformation is related to the plastic and viscous properties of the material (Taherkhani, 2006).

To minimize rutting in asphalt concrete mixtures, it is necessary to pay more attention to material selection and mixture design. Furthermore, measuring rutting resistance of asphalt mixtures, selecting parameters to use as a measure of resistance, and achieving suitable technique to model and predict the development of permanent deformation need to be addressed.

Recent studies indicated that most of the rutting occurs in the upper part of the asphalt surfacing layer. Brown and Cross (1992) also stated that the majority of rutting occurred in the top of the asphalt concrete layers. They found that the rutting in the subgrade was generally very small. Thus, it was decided that this study has to focus on evaluating rutting of wearing course layer.

2. Experimental work

To achieve the objectives of this study, the Hot Mix Asphalt (HMA) mixture were designed and tested with wheel track test, in order to simulate the flexible pavement materials behavior, and rutting phenomena, when subjected to traffic wheel loads and environmental conditions during the pavement service life.

2.1 Hot Mix Asphalt design

The asphalt concrete mixture were design using SUPERPAVE design method. Selected aggregate gradation was according to FHWA and Iraqi specification (R9) for wearing course with nominal maximum aggregate size of 12.5 mm. Figure 2 represents the selected optimum aggregate blend .The final optimum asphalt content was 4.75 percentage by weight of total mix at 4% air void. The HMA evaluated against water damage and the tensile strength ratio was 91 percent. Table 1 presents the design mixture properties.

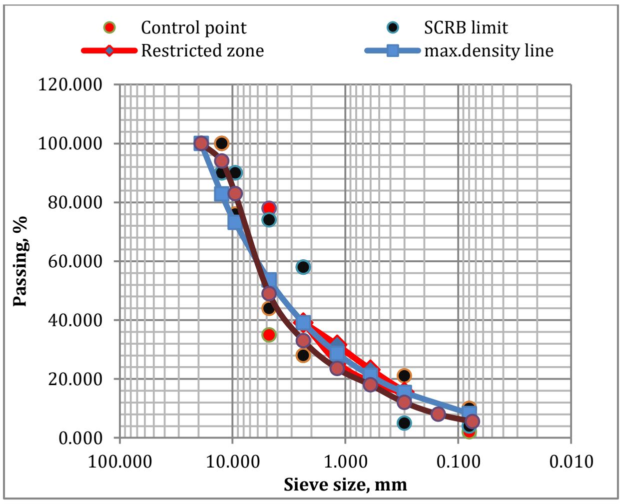


Figure 2: Selected Superpave Aggregate Gradation chart

Table 1: The design mixture properties

Mix. Properties	Result	Criteria
Air Void, %	4.0	4.0
VMA, %	16.45	14.0 Min.
VFA, %	75	65-75
Dust Proportion	1.2	0.6-1.2
%Gmm @ Nini = 8	86.16	Less than 89

2.2 Wheel Tracking Test

The Pavement Wheel Tracker is a device for testing the wearability of asphalt mixes by simulating roadway conditions. The test provides information about the rate of permanent deformation from a moving, concentrated load. It uses a Linear Value Displacement Transducer (LVDT's) to measure the deformation of the specimen. A wheel rubber tire with loading (780 N) moved backwards and forwards on the surface of specimen with a total distance of travel of (290±10) mm and a constant loading frequency of (22) load cycles per 60 seconds. Figure 3 shows the wheel tracking device. The wheel tracking test is a full factorial with; three asphalt contents, three temperatures, two filler types, as illustrated in Table 2, resulting in a nominal total of 18 test.

In this study, compacted asphaltic slabs are prepared at air voids equal to (4%) using Rolling Wheel Compactor (RWC). The dimensions of the compacted slabs used in this work are (12 inch) in length and (12 inch) in width and (2 inch) in height. The aggregate and asphalt are mixed in the special mixer for three minutes until asphalt had sufficiently coated the surface of the aggregates or until a homogeneous mixture is achieved as shown in Figure 4a.

Figure 3: The Wheel Tracking Device

Table 2: Variables for Wheel Track Test

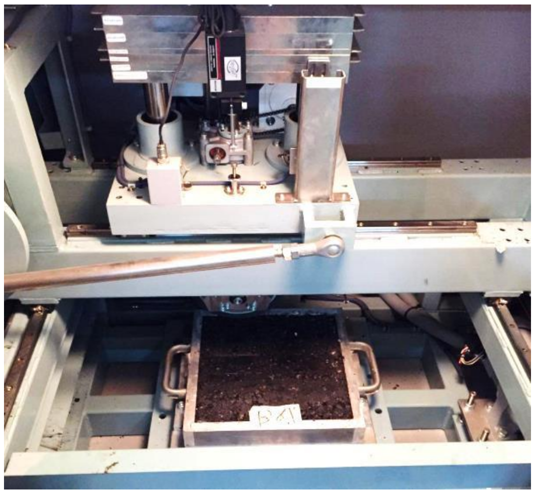
Variable	Description		
Temperature	30°C	45°C	60°C
Asphalt content	Optimum	Optimum + 0.5%	Optimum – 0.5%
Filler type	Lime stone dust	Portland cement	....

Compaction is then performed using the Rolling Wheel Compactor as presented in Figure 4b. The mold and the plates are heated in the oven at the specified compaction temperature to ensure that the mix temperature is not reduced. The compacted slab samples were left at ambient room temperature for 24 hours to let it cooling and prepare it to testing as illustrated in Figure 4c. After preparing slabs, it will be tested at a desire temperature as shown in Figure 4d.

(a)

(b)

(c)



(d)

Figure 4: Wheel Track Test Procedure: (a) Mixing by special mixer (b)Rolling wheel compactor (c) Compacted slabs (d) Slab during the test

Table3: Mean Value of Rut Depth for Each Sort Variable

Variables	Temperature, °C			Asphalt Content,%			Filler Type	
	30	45	60	Opt.-0.5	Opt.	Opt.+0.5	Cement	Limestone
Rut Depth(mm)	2.234	4.678	23.13	6.617	8.951	12.982	9.122	10.906

3. Results and Discussion

In univariate analysis, one of the first steps is often a graphical study of the characteristics of the data sample (Leahy, 1989). The analysis is accomplished by sorting the entire data file by each of the sort variables to assess the individual effects of test parameters on rut depth. For example, to clearly show the effect of temperature the entire data is sorted by test temperatures and the mean value of rut depth is calculated and presented in Table 3.

3.1 Effect of Temperature

Figure (5) shows the effect of temperature on rut depth. These effects are substantially influenced by temperature. It can be observed that the permanent displacement (rut depth) increase by factor of 2.09 and 4.94 when the temperature is increases from 30 to 45 ºC and from 45 to 60 °C respectively.

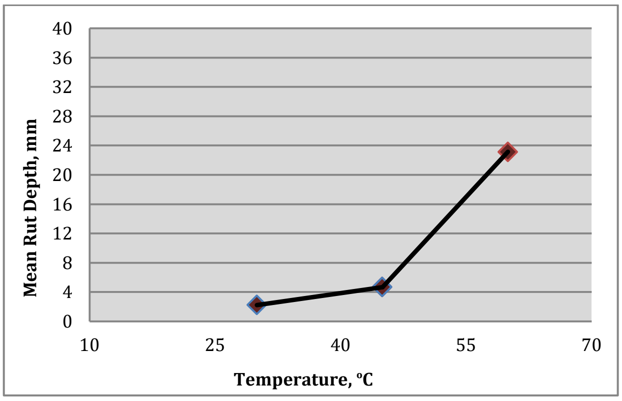


Figure 5: Effect of Temperature on Rut Depth

3.2 Effect of Asphalt Content

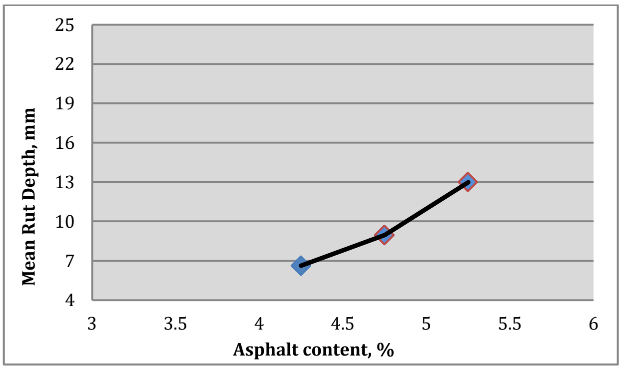


Figure 6: Effect of Asphalt Contents on Rut Depth

Based on the data shown in Table 2 and Figure 6, it appears that the examined asphalt content has influence on the plastic response of the material. It can be found that the rut depth is increased about 35 percent with the increases in asphalt content from 4.25 to 4.75 percent, while it increased about 45 percent when asphalt content increased from 4.75 to 5.25 percent.

3.3 Effect of Filler Type

The change in filler type of the mixtures can be effected on the permanent deformation as depicted in Figure 7 The analyzing of results shows that the rut depth (RD) decrease about 16 percent when using cement instead of limestone dust.

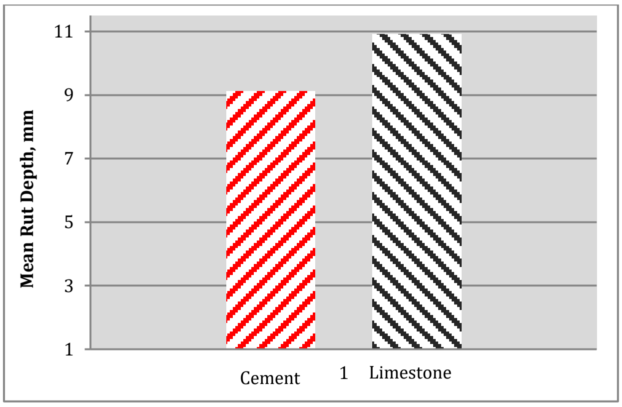


Figure 7: Effect of Filler Type on Rut Depth

Figures from 8 through 10 shows the effect of test variables on rut depth versus number of repetition on log-log scale.

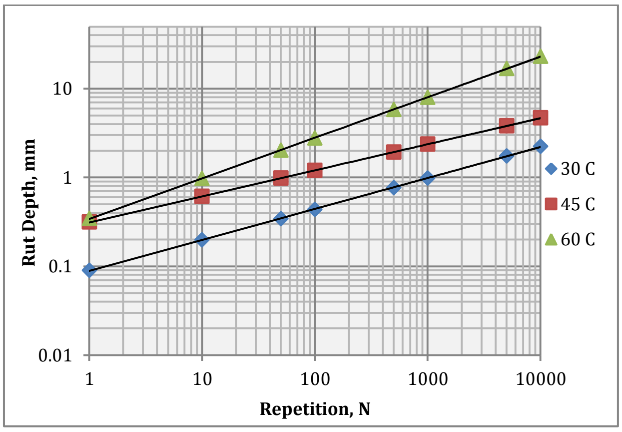


Figure 8: Effect of Temperature on Rut Depth versus Number of Repetition

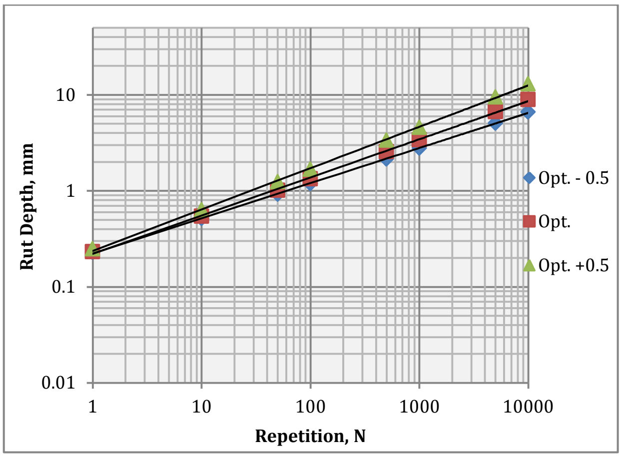


Figure 9: Effect of Asphalt Contents on Rut Depth versus Number of Repetition

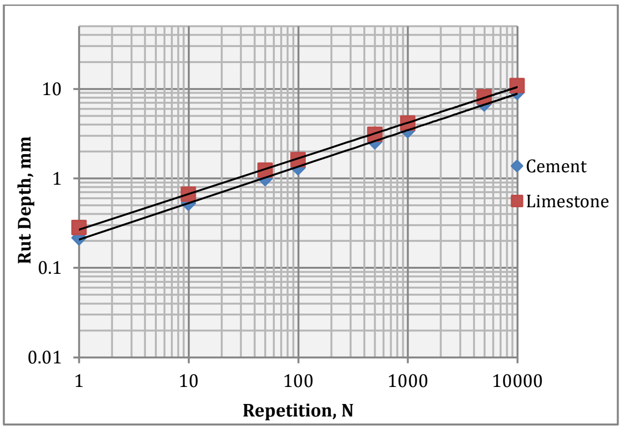


Figure 10: Effect of Filler Type on Rut Depth versus Number of Repetition

4. Rut Depth Predication Model

Pavement permanent deformation models are important inputs for the efficient management of pavement systems, the allocation of cost responsibilities to various vehicle classes for their use of the highway system, and the design of pavement structures.

SPSS software (Statistical Package for the Social Sciences) Version 22 applied to predict permanent deformation (Rut Depth) model in asphalt concrete pavement. In statistical modeling the overall objective is to develop a predictive equation correlate the permanent deformation from wheel track test in the form with the independent test variables. These variables include number of repetition, testing temperature, asphalt content and filler type, the identification of these variables can be described as follows:

- RD = Wheel track rut depth, mm
- N = Number of repetition loads, cycles
- AC = Asphalt content, percentage
- T = Test temperature, °C
- FT = Type of filler (1 for cement and 0 for limestone).

4.1 Regression Analysis Approach

Regression analysis is a statistical technique that attempts to explore and model the relationship between two or more variables. Equation (1) represents the dependent variable, y_i , as a linear function of one independent variable, x_i , subject to a random 'disturbance' or 'error', u_i :

$$\boldsymbol{y_i = \beta_0 + \beta_1 x_i + u_i} \qquad (1)$$

where:

y_i = the dependent variable, β_0 = constant, β_1= the slope, and, x_i= the independent variable.
The error term u_i is assumed to have a mean value of zero, a constant variance, and it will be uncorrelated with itself across observations.

Also, as a type of linear regression modeling there is linear transformed regression , with the aids of theoretical arguments existed in literature or examining the plots of the relation between each independent variables with the dependent variable the form of the relation for each variable can be determined, then in terms of transformed variables that can be substituted in the linear regression analysis, the final model can be obtained, this type of models also known as intrinsically linear model.

4.1.1 Regression Results

Rut depth is estimated according to the results of wheel track test after considering the predicated variables (i.e ; temperature, asphalt cement content , filler type and number of load repetition). Investigating the relationships between the criterion variable of rut depth and the independent variables illustrated previously in this study, The relationship between the rut depth and number of load repetition seems to be linear when plotted in logarithmic scale. While, the predicator variables could be represented in linear form. The summary of statistical analysis for rut depth model is shown in Table (4). The coefficients of the predicative model as presented in Table (5).

Table 4: Statistical Summary for Rut Depth Model

Model	R	R square	Adjusted R square	Std. Error of the Estimate
1	0.980	0.960	0.958	0.2829

Table 5: Coefficients of Rut Depth Model

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-6.592	.293		22.522	.000
Log N	.840	.019	.771	45.248	.000
T	.066	.002	.580	34.042	.000
AC	.462	.058	.136	7.996	.000
FT	-.281	.047	-.101	-5.956	.000

Dependent Variable: LnRD

The general form of the model is as follows:

$$\boldsymbol{LnRD = C_o + C_1 LogN + C_2 AC + C_3 T + C_4 FT} \qquad (2)$$

Conclusions

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

1) A statistical model was developed to estimate rut depth of asphalt concrete wearing course in terms of test condition (temperature and load repetition) and mix properties (asphalt cement content and filler type) with the following:

$$\boldsymbol{LnRD = -6.592 + 0.84 LogN + 0.066T 0.462AC - 0.281FT}$$

Where:

RD=Rut depth (mm)
N= Number of repetitions
T= Temperature (Celsius)
AC= Asphalt content (percentage by weigh of total mix)
FT= Type of filler (1 for cement and 0 for limestone).

For N=10000, T=30°C, AC= 4.75 % and FT=1,
RD= 1.937 mm.

2) From the conducted wheel track test results, when temperature duplicated from 30 to 60°C , the rut depth increases 7 folds.
3) The rut depth is increased about 35 percent when the asphalt content changes from 4.25 to 4.75 percent, whereas it increased about 45 percent when the asphalt content increased from 4.75 to 5.25 percent.
4) More resistance provided against rutting type of failure using cement as a filler type instead of limestone dust, this point obviously detected in wheel track test, cement provides 16 more rut resistance than that provided by limestone dust.

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