

# Developing Laboratory Performance Models for Thin Asphalt Overlay Mixtures

Mousa Zeki

Shakir Al-Busaltan

*Department of Civil Engineering, University of Kerbala, Karbala, Iraq*

[mousazekitz@gmail.com](mailto:mousazekitz@gmail.com)

[shakerfa2003@yahoo.com](mailto:shakerfa2003@yahoo.com)

**Submission date:- 17/2/2019**

**Acceptance date:- 13/3/2019**

**Publication date:-7/4/2019**

## Abstract

Statistical modeling is utilized effectively to development relation/s between the dependent variables and independent variables. In other words, it describes how one or more random variables are related to one more other variables. Building verified models can help in predicting performance characteristics, and saving time and money. This study aims to present a statistical models which help to understand the significance of the different parameters in characterizing the performance of the Thin Asphalt Overlay (TAO). The experimental program included: design the thin asphalt overlay mixtures using one gradation type (9.5 Nominal Maximum Aggregate Size NMAS), three filler types (conventional mineral filler, Ordinary Portland Cement, and Quick lime), and five percentages of asphalt content to identify the optimum asphalt content. Then, Styrene Butadiene Styrene (SBS) modified polymer binder was introduced for performance enhancement. Performance tests were used to evaluate TAO mixture in term of some main namely, volumetric, mechanical, and durability properties are (bulk density, indirect tensile strength and tensile strength ratio). Statistical Product and Service Solutions (SPSS) software (Version 24) was used as a tool for models building. To find the most accurate statistical models, linear and nonlinear regression was achieved. This study demonstrates that the using statistical modeling is achievable and offer a vital tool to describe the characteristics and performance of the TAO mixture in term volumetric, mechanical and durability properties.

**Keywords:** Statistical model; Thin asphalt overlay; Polymer modified asphalt; Indirect tensile strength; Bulk density; Tensile strength ratio; Quicklime.

## 1. Introduction

Thin asphalt overlay (TAO) is a bituminous surface treatment layer that apply to enhances the current properties of pavement structure as far as it is strengthening pavement and eliminating the deformability [1]. TAO is generally the highest level of preventive maintenance treatment, which can perform on asphalt-surfaced pavements. The thickness of TAO is typically 38.1 mm or less, and TAO contained of finer aggregates with nominal maximum aggregate size of 12.5 mm or fewer. TAO provide for roads that need improvements for smoothness and safety an economical resurfacing and renewal paving solution [2]. Moreover, TAO is not only provided a new pavement surface for a fraction costly rebuilding roadway, but it is also the only preventive maintenance technique that simultaneously improves the structural value and extends the pavement's service life. Principally, this technique has been performed by many transportation agencies with varying success.

Volumetric, mechanical and durability properties are the important indexes for characterizing the TAO properties, which then use extensively to describe the variation produced TAOs. Standardized and non-Standardized testing methods, also empirical, simulative, and fundamental test methods, are all nominated to determine TAQs properties. Determining the asphalt mixtures resistance to the main paving distresses including low temperature cracking, fatigue cracking and rutting is the important role played by the properties of the TAO. Also this properties impact on asphalt mixture durability in term of aging and stripping [3], [4].

One of The main elements in the design of asphalt mixtures is the volumetric characteristics. In most cases, asphalt mixtures are considered in terms of weight proportion of bitumen and/or aggregate. However, for the design of asphalt mixtures, it is very important to consider the three main components in asphalt mixtures, namely bitumen, aggregate and air. Understanding the behavior of asphalt mixtures, whether in

laboratory or in service, depends on the complex interaction between the three mentioned components. The asphalt mixture composition can be stated in terms of volume or weight. Since the air does not have a mass, if three components are taken into consideration, the asphalt mixture composition are expressed in terms of volume. For example, an asphalt mixture consists of 95% aggregate and 5% of bitumen by the total weight, will change when the asphalt mixture composition is take into account to be volumetrically. Probably the most important factor that has a significant impact on performance of asphalt pavement is the amount of voids in the mixture. Study was made by The National Cooperative Highway Research Program and state that the asphalt pavement resistance to rutting decrease with increase the voids in mineral aggregate (VMA) and asphalt content [5]. [6], [7] state that the high values of VMA can be guaranteed good durability however still achieving high value of rutting resistance. Density can be considered as one of the most significant criteria in the formation of asphalt mixtures. The amount of air voids in the asphalt mixture that has been designed is sufficient to prevent the occurrence of rutting and also low enough to prevent water and air permeability. Since density change through asphalt mixture life, therefor the voids should be sufficient to avoid plastic flow and should be low enough to avoid water and air permeability [8].

Asphalt mixes have attracted many researchers and engineers trying to improve their dynamic properties due to the growth in traffic volume, traffic loading and tire pressure, and harsh environments which have ultimately increased stresses on asphalt pavements [9]–[11] Huge traffic loading and harsh environments are two key parameters that affect mechanical and dynamic properties of asphalt mixture pavement. Early signs of cracks and deterioration were shown on the pavement as major consequences of these parameters. As a result of cracking problems, tensile properties are important characteristics of pavement engineers. The utilization of indirect tensile strength test (IDT) is to obtained tensile properties of asphalt mixture that related to the cracking properties of asphalt pavement [12], [13].

The premature failures of Asphalt Concrete Pavement have several reasons. Most of these reasons are related to environment conditions and/or traffic loads. Some of the environmental conditions such as water or moisture, temperature and air have detrimental effects on the pavement performance of asphalt pavement. However, water damage and ageing effect are normally characterized through specified testing to identify the potential of asphalt mixture to resist these long term or durable effects. The most environmental factors influencing the durability of asphalt mixture are the moisture induced damaged and the stripping of its components due to loss bitumen- aggregate adhesion [14]. Moisture damage represents the action of degradation of asphalt mixture strength and their durability due to presence of moisture or water, and may be evaluated by losing of mechanical properties of asphalt mixture. The phenomenon of moisture damage in asphalt mixture can generally be categorized in two mechanisms:(a) adhesion loss between asphalt binder and aggregate due to presence of water at aggregate-binder interface,(b) loss of cohesion of bitumen itself due to the softening action [15]. The amount and types of moisture damage are affected by several factors; some of these factors are associated with components of asphalt mixture such as bitumen and aggregate. Other factors are associated with the processes of design, production and construction of asphalt mixture.

Statistical model is a mathematical equation used to describe the relationship between variables. Statistical model shows how to relate one or more random variables to another variable. Statistical methods are used to improve the experimental methods, in which, instead of selecting one starting mix proportion and then adjusting by trial and error for achieving the optimum solution [16].

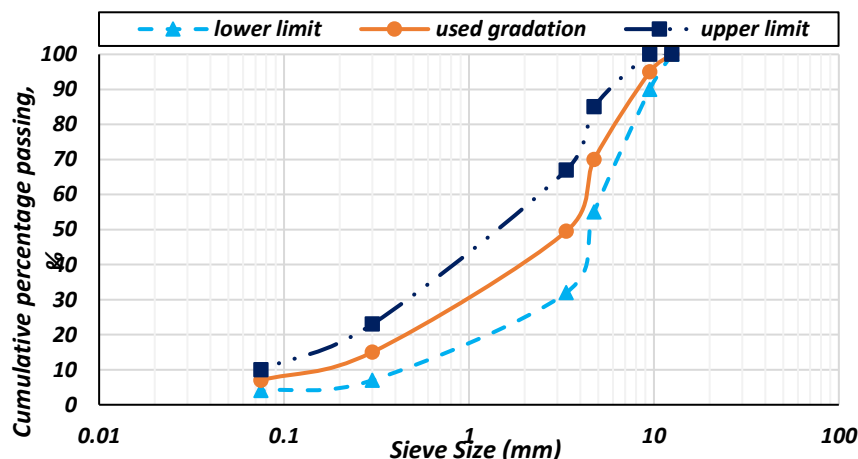
Predictive modeling can be defined as a set of mathematical techniques whose main objective is to establish a mathematical relationship between a dependent variable and different independent or predictive variables, taking into account measuring future values of those predictors and input them into the relationship to predict future values of the goal variable.

The overall aim of this study is to develop a predictive equations correlate the depended variable with independent variable where selected from mechanical, volumetric and durability properties (namely, IDT, TSR and bulk density) act as depended variables, whereas filler types like conventional mineral filler, ordinary Portland cement , quicklime and percent of SBS represent as independent variables. These models will help in understanding the characteristics of the produced TAO in one hand. While, in the other hand it can used as objective functions in optimization process.

## 2. Materials and methodology

### 2.1 Raw material

The aggregate used in this study were sieved, separated and graded in the lab to meet the specified gradation for surface course type III B (9.5 mm NMA) according to General Specification for Roads and Bridges of Iraq [17]. Figure (1) show particle size distribution of the nominated aggregates gradation. However, the mid-range of the GSRB specification was specified to produce the tested gradation for TAO mixtures.



**Figure 1 Distribute of Particle Size of the Used Gradation for Virgin aggregate (dense graded wearing course)**

In this study, various filler types were used, namely, Quick lime (QL), Ordinary Portland Cement (OPC) and conventional mineral filler (CMF) to explore the potential of these fillers in achieving the mentioned purposes. The portion of crush aggregate and natural sand that passed from sieve NO. 200 was used as CMF filler, normally as it gained in asphalt plant. While the OPC and QL were provided from Karbala Cement Plant, and Karbala Lime Plant, respectively. Table (1) illustrates the physical and chemical properties of the used three type fillers.

**Table 1 the Utilized Fillers Properties**

Physical Properties			
Property	Filler type		
	CMF	OPC	QL
Specific surface area ( $m^2/kg$ )	225	410	3050
Density ( $gm/cm^3$ )	2.61	2.987	3.4
Chemical testing			
SiO <sub>2</sub>	81.89	25.41	2
Al <sub>2</sub> O <sub>3</sub>	3.78	2.324	1.35
Fe <sub>2</sub> O <sub>3</sub>	1.92	1.125	0.76
CaO	7.37	65.148	85.5
MgO	3.45	1.326	0.34
K <sub>2</sub> O	0.73	0.760	0.3
Na <sub>2</sub> O	0.19	1.714	0.12

The asphalt binder that used in this study was supplied from AL-Daurah refinery with a grad of (40-50). The properties of this asphalt were detailed in Table (2), whereas all the tests were carried out in the laboratories of University of Kerbala according to GSRB specification.

**Table 2 Grade Asphalt Cement Properties**

<i>Property</i>	<i>ASTM designation</i>	<i>Test results</i>	<i>GSRB requirements</i>
<i>Penetration, 100 gm., 25° C, 5sec (1/10 mm)</i>	D5 [18]	41	40-50
<i>Specific Gravity, 25° C (gm/cm<sup>3</sup>)</i>	D70 (ASTM, 2009a)	1.03	-
<i>Ductility, 25° C, 5 cm/min (cm)</i>	D113 [19]	135	>100
<i>Flash point, (° C)</i>	D92 [20]	313	>232
<i>Softening point (° C)</i>	D36 [21]	47	-
<i>Solubility in trichloroethylene, (%)</i>	D2042 [22]	99.5	>99
<i>After Thin Film Oven test</i>			
<i>Penetration of Residue (%)</i>	D 1754 [23]	69	>55
<i>Ductility of Residue, (cm)</i>		68.5	>25

The Styrene Butadiene Styrene (SBS) Kraton D1192 E (which is a copolymer consists of styrene and butadiene with 30% bound styrene) was nominated in this study with three percentages (2, 4 and 6%). The properties of the modified SBS polymer and gradation are demonstrated in Tables (3 and 4), while the properties of the modified bitumen presented in Table (5).

**Table 3 Kraton D1192 ESM polymer gradation**

<i>Sieve size (mm)</i>	<i>Passing%</i>
NO.20 (850 µm)	100
NO.30 (600 µm)	93.5
NO.40 (425 µm)	69.5
NO.50 (300 µm)	34.2
NO.60 (250 µm)	15.7
NO.80 (180 µm)	8
NO.100 (150 µm)	3.8
NO.200 (75 µm)	0

**Table 4 used polymer properties**

<i>Property</i>	<i>Test Method</i>	<i>Unit</i>	<i>Tested Value</i>	<i>note</i>
<i>Specific Gravity</i>	SO 2781	-----	0.94	
<i>Melt Flow Rate, 200°C/5kg</i>	ISO 1133	g/10min.	<1	
<i>Bulk Density</i>	ASTM D 1895 method B	kg/dm <sup>3</sup>	0.4	
<i>Hardness, Shore A (15 sec)</i>	ASTM D 2240	Hardness, Shore A (15 sec)	70	a
<i>Apparent Molecular Mass of Triblock</i>	KM 01	kg/mol.	150	
<i>Polystyrene Content</i>	KM 03	%m	30.5	
<i>Vinyl Content</i>	KM 03	%	35	
<i>Triblock Content</i>	KM 01	%	90	
<i>Total Extractable</i>	KM 05	%m	1.0	
<i>Volatile Matter</i>	KM 04	%m	0.3	
<i>Antioxidant Content</i>	KM 08	%m	0.16	
<i>Ash (ES, ET)</i>	ISO 247	%m	0.25	
<i>Ash (ETM)</i>	BAM 908	%w	5	
<i>Ash (ESM)</i>	ISO 247	%m	3.75	

*a Measured-on compression molded slabs*

**Table 5 neat and modified bitumen properties**

<i>Properties</i>	<i>Standard (ASTM)</i>	<i>0sbs</i>	<i>2sbs</i>	<i>4sbs</i>	<i>6sbs</i>
<i>Penetration at 25 °C (0.1 mm)</i>	D5-73	40.7	27.2	23.5	22
<i>Softening point (R&amp;B °C)</i>	C36-76	48	59	62	64
<i>Ductility at 25 °C (cm)</i>	D113-79	>100 cm	>100 cm	85	78
<i>Penetration index</i>	D5	-2.1	-0.48	-0.22	-0.03
<i>After thin-film oven test (TFOT)</i>					
<i>Penetration at 25 °C (0.1 mm)</i>	D5-73	32	29	26	25
<i>Softening point °C</i>	C36-76	50	60.5	64	66

## 2.2 Mixture design and analysis

The adopted method for the design of TAO is traditional procedure for the determination of optimum asphalt content (OAC) for wearing course using Marshall Design method. This method was performed as follows:

- Selecting the NMA: 9.5 mm NMA was selected to fulfill the thin asphalt overlay requirements (3 times x 9.5 (NMA) = 28.5 mm < 38.1 mm (the upper limit of TAO thickness)).
- Selecting the gradation: dense graded gradations which based on GSRB (9.5 mm NMA), as mentioned previously, was selected; this gradation is well known in Iraq.
- Determining OAC: five percentages of asphalt content (namely, 4, 4.5, 5, 5.5, and 6, %) were specified to determine the OAC for the conventional mix with neat asphalt binder. To ensure the reliability, at least three compacted specimens for each percentage were prepared according to ASTM D 6926 [24]. Three types of filler were used (CMF, OPC, and QL), therefore, three OAC were determined accordingly. The OACs for the TAO mixtures with CMF, OPC, and QL fillers were found to be 5.4%, 5.37% and 5.3%, respectively.

In this study, only three parameters were selected from mechanical, volumetric and durability properties to develop statistical models. However, the volumetric properties of TAO mixes with various filler types at OAC are determined; main indexes like bulk density, air void, VFB, and VMA were determined and analyzed according to ASTM D3203 [25] and ASTM D2041 [26]. The bulk density (BD) was selected to represent the volumetric properties. The mechanical properties of TAO can be evaluated by many tests; e.g., Indirect Tensile strength, Marshall stability and flow, wheel truck test, indirect tensile stiffness, etc. Indirect tensile strength (IDT) test according to ASTM D6931 [27] was selected as an important test to represent the mechanical properties of the TAO. Similarly, the durability properties were evaluated by tensile strength ratio (TSR) test according to AASHTO T283[28].

Then, SBS modified polymer binder was introduced for performance enhancement. This polymer was utilized in percentages of 2%, 4% and 6% of the bitumen content. Volumetric (e.g., bulk density), mechanical (e.g., indirect tensile strength), and durability (tensile strength ratio) testing methods were performed to identify the variations in thin asphalt mixtures characteristics due to such incorporations. The result of bulk density (as an average of three samples results), IDT (as an average of three samples results) and TSR (as an average of three sets results, each set comprised conditioned and unconditioned samples) are shown in Table

**Table 6 Matrix of results**

<i>Filler type</i>	<i>SBS%</i>	<i>IDT, KPa</i>	<i>TSR, %</i>	<i>Bulk density, gm/cm<sup>3</sup></i>
CMF	0	882.6	57	2.342
CMF	0	956.4	56	2.34
CMF	0	921	58	2.338
CMF	2	1714.3	65	2.368
CMF	2	1783	66	2.368
CMF	2	1817.2	64	2.365

CMF	4	1300	68	2.365
CMF	4	1305.6	68	2.36
CMF	4	1345.1	68	2.361
CMF	6	1264	69	2.357
CMF	6	1296	69.5	2.359
CMF	6	1290.5	68.5	2.358
OPC	0	1142.5	76	2.345
OPC	0	1170.3	81	2.344
OPC	0	1196.3	80	2.346
OPC	2	1842	86	2.388
OPC	2	1835	85	2.388
OPC	2	1852.3	87	2.385
OPC	4	1398	95	2.383
OPC	4	1410	95	2.383
OPC	4	1397	95	2.383
OPC	6	1380	96	2.38
OPC	6	1371	96	2.379
OPC	6	1385.4	96	2.381
OL	0	1294	82	2.363
OL	0	1261.3	82	2.363
OL	0	1283.9	82	2.363
OL	2	1920	85	2.384
OL	2	1896	85	2.384
OL	2	1884	85	2.384
OL	4	1510.4	92	2.382
OL	4	1507.3	92	2.38
OL	4	1522.5	92	2.381
OL	6	1463	93	2.378
OL	6	1453.8	95	2.379
OL	6	1474.6	94	2.377

## 2.3 Statistical Analysis Model

### 2.3.1 Model preparation

Models preparation from the obtained experiments results are the core work in this study. Empirical modeling was achieved using analysis process offer by SPSS software. Variables involved in the empirical modeling are filler types and percent of SBS. The collected results were 36 for each test of IDT, TSR and BD. The results were divided randomly into 28 results to generate the model and the other 8 were used to validate the developed model. The first step to model preparations is the correlation between the variables by using SPSS Pearson's correlation. Many combinations of variables are used starting from only constant to quadratic form of both variables with the incorporation of multiple terms of both variables discussed above.

### 2.3.2 Identification of Variable, coding for empirical modeling and the correlation between variables

The program used in this study (SPSS) requests to define the independent variables and dependent variables of the developed models to meet the requirements to construct the model. These variables and the code adopted for calculation are listed in Table (7). While, Table (8) shows the bivariate Pearson Correlation between variables, however, this table shows

1. The independent variables have very low to absent of correlation between each other, which is good for the accuracy of the model.
2. The correlation between IDT and filler type is good when compared with polymer content
3. The filler type has the most significant correlation to TSR, then polymer content.
4. The correlation between bulk density and both filler type and polymer content are good, but the correlation with filler type is more significant as explained in Table (8)

**Table 7 Dependent and independent variables considered in regression analysis**

Dependent variable				
Abbreviation	Description		Unit	Coded values
IDT	Indirect tensile strength		KPa	
RD	Wheel track test		mm	
TSR	Water sensitivity		%	
BD	Bulk density		gm/cm <sup>3</sup>	
Independent variable				
F	Filler type	CMF		10
		OPC		20
		QL		30
P	Polymer content		%	

**Table 8 correlation between variables**

		<i>F</i>	<i>P</i>	<i>IDT</i>	<i>TSR</i>	<i>BD</i>
<i>F</i>	<i>Pearson Correlation</i>	1	.000	.321	.761**	.534**
	<i>Sig. (2-tailed)</i>		1.000	.056	.000	.001
	<i>N</i>	36	36	36	36	36
<i>P</i>	<i>Pearson Correlation</i>	.000	1	.134	.420*	.474**
	<i>Sig. (2-tailed)</i>	1.000		.437	.011	.003
	<i>N</i>	36	36	36	36	36
<i>IDT</i>	<i>Pearson Correlation</i>	.321	.134	1	.350*	.771**
	<i>Sig. (2-tailed)</i>	.056	.437		.037	.000
	<i>N</i>	36	36	36	36	36
<i>TSR</i>	<i>Pearson Correlation</i>	.761**	.420*	.350*	1	.767**
	<i>Sig. (2-tailed)</i>	.000	.011	.037		.000
	<i>N</i>	36	36	36	36	36
<i>BD</i>	<i>Pearson Correlation</i>	.534**	.474**	.771**	.767**	1
	<i>Sig. (2-tailed)</i>	.001	.003	.000	.000	
	<i>N</i>	36	36	36	36	36
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

### 3. Result and discussion of the prediction model

SPSS software was used to analysis and build predictive models. For the simplification the linear models were tried first, unfortunately all linear models were failed to represent the observations. For many trails it was found that all models were nonlinear, as will see hereafter.

#### 3.1 Building the Indirect tensile strength model

As mentioned previously the IDT was selected to build a model from many mechanical properties. This selection is based on the believe that it is one of the most important parameters, as it represents the cracking phenomenon for the paving materials. Modeling IDT to filler type and polymer content was conducted. Many models were tried (linear, multiple and nonlinear models). It was observed that all linear models were failed to estimate accurate predicted values of IDT. Tables (9) demonstrated samples of the tried models, whereas low values of (R<sup>2</sup>) are the predominant for both regression and model validation. It is worth mentioned that other testing parameters than R<sup>2</sup> were used to test the validity of the models, but the values of R<sup>2</sup> are only presented for simplification and prevent dilatation.

On the other hand, after many trials a nonlinear model was determined with reasonable accuracy. The analysis results of adopted nonlinear model is presented in Tables (10, 11). Table (10) shows the parameter of the developed model and its limitation with Confidence Interval of 95%. Table (11) demonstrates that the MSE is low and sum of residual is lower than sum of regression which is sustained the significant of the model. Moreover, from the same table, the high value of the R-Square (0.893) indicates a reasonable prediction, so we can conclude through these values that the developed model for IDT is acceptable. Figure (2) shows the adequacy of model, this figure indicates that acceptable scatter can recognize between predicted and observed IDT values, furthermore, almost all value within the significant level boundaries.

**Table 9 trial equations to predict the value of IDT**

<i>Types of equations</i>	<i>models</i>	<i>R<sup>2</sup></i>
Linear	$IDT=10.813+1220.583*F$	0.103
Linear	$IDT=1171.215+10.813*F+16.456*P$	0.121
Cubic	$IDT=1163.208+17.698*F-0.172*F^2$	0.104
Compound	$IDT=1192.1*1.008^F$	0.122
Power	$IDT=906.202*F^{0.152}$	0.124
Nonlinear	$IDT=1427.938+0.032*F*P^2$	0.001
Nonlinear	$IDT=1366.963+1.165*F*P$	0.053
Nonlinear	$IDT=1242.663+12.352*F*P-1.953*F*P^2$	0.472
Nonlinear	$IDT=1199.898-6.511*F*P+34.4*F*P^{0.15}$	0.697

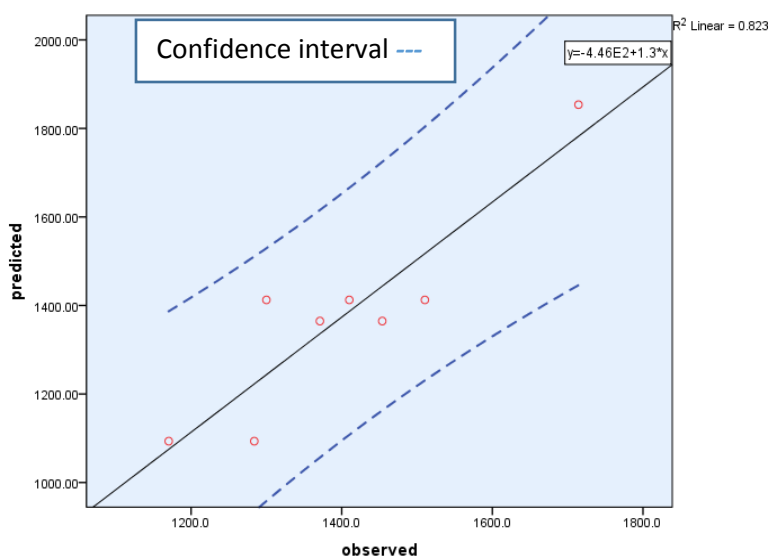
**Table 10 Nonlinear IDT modeling**

<i>Developed model</i>	<i>IDT= C<sub>1</sub>*F<sup>C<sub>2</sub></sup> + C<sub>3</sub>*P – C<sub>4</sub>*P<sup>2</sup> + C<sub>5</sub>*P<sup>3</sup> + C<sub>6</sub></i>			
<i>Parameter Estimates</i>				
<i>Parameters</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>95% Confidence Interval</i>	
			<i>Lower Bound</i>	<i>Upper Bound</i>
<i>C1</i>	8.665	.000	8.665	8.665
<i>C2</i>	-247.702-	78.048	-409.563-	-85.841-
<i>C3</i>	946.235	.000	946.235	946.235
<i>C4</i>	349.501	41.760	262.896	436.105
<i>C4</i>	33.222	3.927	25.078	41.366
<i>C6</i>	1093.443	35.227	1020.387	1166.499

**Table 11 ANOVA for IDT modeling**

<i>Source</i>	<i>Sum of Squares</i>	<i>df</i>	<i>Mean Squares</i>
<i>Regression</i>	60869410.120	6	10144901.690
<i>Residual</i>	268556.843	22	12207.129
<i>Uncorrected Total</i>	61137966.960	28	
<i>Corrected Total</i>	2521154.147	27	
Dependent variable: IDT			
a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .893.			





**Figure 2 comparisons between the experimental and predicted values of the indirect tensile strength**

### 3.2 Building the Tensile strength ratio model

As mentioned previously the TSR was selected to build a model for TAO durability properties. This selection is based on the believe that it is one of the most important parameters beside the aging and abrasion which will initiate by coming research work. Modeling TSR to filler type and polymer content was conducted. Many models were tried (linear, multiple and nonlinear models). It was observed that all linear models were failed to estimate accurate predicted values of TSR. Tables (12) demonstrated samples of the tried models, whereas low values of ( $R^2$ ) are the predominant for both regression and model validation. As mentioned previously in IDT models, that other testing parameters than  $R^2$  were used to test the validity of the models, but the values of  $R^2$  are only presented for simplification and prevent dilatation. Similarly, after many trials a nonlinear model was determined with reasonable accuracy. The analysis results of adopted nonlinear model is shown in Tables (13, 14). Table (14) shows that the MSE is low and sum of residual is lower than sum of regression which mean the significant of the model. From the same table, the high value of the  $R^2$  (0.984) indicates a perfect prediction, so we can conclude through these values that the developed model for TSR is acceptable. Figure (3) presents the adequacy of model and indicates that acceptable scatter can recognize between predicted and observed TSR values, furthermore, almost all value within the significant level boundaries.

**Table 12 trial equations to predict the value of TSR**

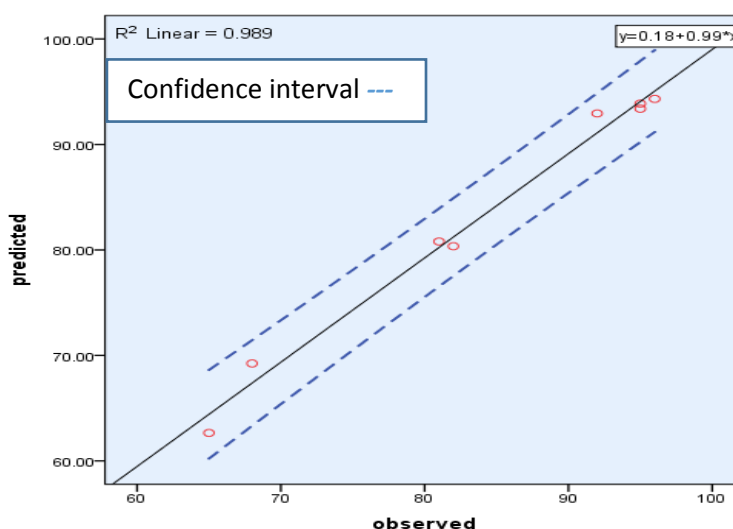
<i>Types of equations</i>	<i>models</i>	<i>R<sup>2</sup></i>
Linear	$TSR = 57.167 + 1.175 * F$	0.579
Linear	$TSR = 73.567 + 2.367 * P$	0.176
Linear	$TSR = 50.067 + 1.175 * F + 2.367 * P$	0.755
Logarithmic	$TSR = 14.392 + 22.855 * \ln(F)$	0.676
Inverse	$TSR = 104.077 - 383.077 / F$	0.741
Power	$TSR = 33.178 + F^{0.302}$	0.691
Quadric	$TSR = 15.5 + 6.175 * F - 0.125 * F^2$	0.797
Cubic	$TSR = 72.667 + 2.028 * P + 0.708 * P^2 - 0.111 * P^3$	0.187
Nonlinear	$TSR = 70.951 + 0.162 * F * P$	0.484
Nonlinear	$TSR = 73.567 + 0.255 * F * P - 2.74 * P$	0.559
Nonlinear	$TSR = 65.521 + 0.113 * F * P + 0.018 * F$	0.66

**Table 13 Nonlinear TSR modeling**

Developed model	$TSR= C_1 + C_2*F - C_3*F^2 + C_4*P + C_5*P^2 - C_6*P^3$			
Parameter Estimates				
Parameters	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
C1	7.902	2.641	2.426	13.378
C2	6.105	.299	5.485	6.725
C3	.123	.007	.108	.139
C4	1.815	1.299	-.879-	4.508
C4	.853	.585	-.360-	2.065
C6	.130	.065	-.005-	.265

**Table 14 ANOVA for TSR modeling**

Source	Sum of Squares	df	Mean Squares
Regression	182043.027	6	30340.504
Residual	73.473	22	3.340
Uncorrected Total	182116.500	28	
Corrected Total	4512.929	27	
Dependent variable: TSR			
a. $R \text{ squared} = 1 - (\text{Residual Sum of Squares}) / (\text{Corrected Sum of Squares}) = .984$ .			

**Figure 3 comparisons between the experimental and predicted values of the tensile strength ratio**

### 3.3 Building the Bulk density model

As mentioned previously the bulk density was selected to build a model from many others volumetric parameters. This selection is based on the believe that almost volumetric properties showed same trend with significant correlation. Modeling bulk density to filler type and polymer content was conducted. Many models were tried (linear, multiple and nonlinear models). It was observed that all linear models were failed to estimate accurate predicted values of BD. Tables (15) demonstrated samples of the tried models, whereas low values of (R<sup>2</sup>) are the predominant for both regression and model validation. As mentioned previously in IDT and TSR models, that other testing parameters than R<sup>2</sup> were used to test the validity of the models, but the values of R<sup>2</sup> are only presented for simplification and prevent dilatation. Similarly, after many trials

a nonlinear model was determined with reasonable accuracy. The analysis results of adopted nonlinear model are shown in Tables (16, 17). The analysis of the models includes the analysis of variance and goodness fitting between observed and predicted values. Figure (4) demonstrates the adequacy of model. The following can be recognized from the analysis process:

- Table (16) shows the parameter of the developed model and its limitation with Confidence Interval of 95%
- Table (17) states that the  $MS_E$  is zero, which is preferable for the significance of the model
- Table (17) discloses that the sum of regression is higher than sum of residue which is sustained the significant of the model. While, from the same table, the high value of the  $R^2$  (0.973) indicates a perfect prediction, thus we can conclude through these values that the developed model for bulk density is acceptable.
- Figure (4) indicates that acceptable scatter can recognize between predicted and observed bulk density values, furthermore, almost all value within the boundaries of 95% Confidence Interval.

**Table 15 trial equations to predict the value of BD**

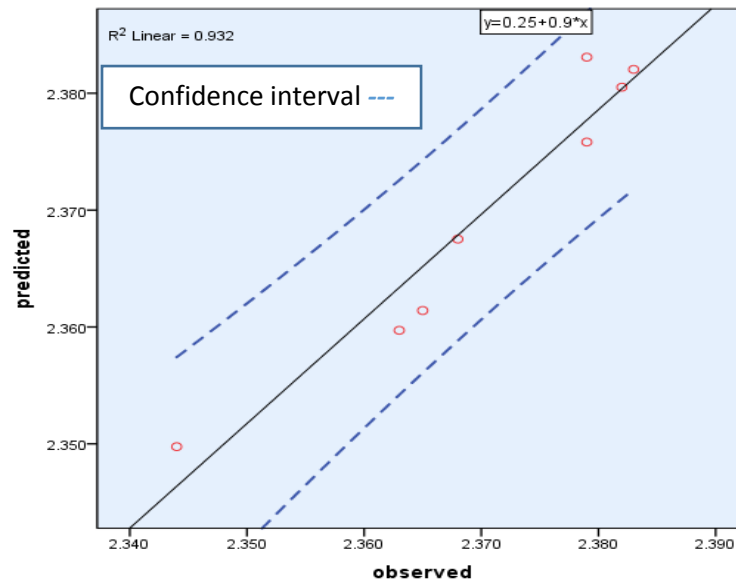
<i>Types of equations</i>	<i>models</i>	<i>R<sup>2</sup></i>
Linear	$BD=2.349+0.001*F$	0.285
Linear	$BD=2.359+0.003*P$	0.225
Linear	$BD=2.34+0.001*F+0.003*P$	0.51
Logarithmic	$BD=2.315+0.019*LN(F)$	0.315
Inverse	$BD=2.388-0.306/F$	0.331
Quadric	$BD=2.326+0.004*F-0.00007125*F^2$	0.335
Quadric	$BD=2.351+0.016*P-0.002*P^2$	0.53
Cubic	$BD=2.349+0.029*P-0.009*P^2+0.001*P^3$	0.596
Nonlinear	$BD=2.326+0.000125*F*P+0.003*F-0.0000712*F^2$	0.521
Nonlinear	$BD=2.307-0.0000175*F*P+0.004*F-0.00007125*F^2+0.016*P-0.002*P^2$	0.865

**Table 16 Nonlinear BD modeling**

Developed model	$BD = C_1 + C_2 * F + C_3 * F^2 + C_4 * P + C_5 * P^2 + C_6 * P^3 + C_7 * (P / F) + C_8 * P * F^3$			
Parameter Estimates				
Parameters	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
C1	2.328	.007	2.314	2.343
C2	.001	.001	-.001-	.003
C3	-2.333E-6	.000	-4.558E-5	4.092E-5
C4	.037	.003	.031	.043
C5	-.009-	.001	-.011-	-.007-
C6	.001	.000	.001	.001
C7	-.082-	.018	-.120-	-.045-
C8	-2.232E-7	.000	-3.244E-7	-1.221E-7

**Table 17 ANOVA for BD modeling**

<i>Source</i>	<i>Sum of Squares</i>	<i>df</i>	<i>Mean Squares</i>
<i>Regression</i>	157.095	8	19.637
<i>Residual</i>	.000	20	.000
<i>Uncorrected Total</i>	157.095	28	
<i>Corrected Total</i>	.007	27	
<i>Dependent variable: BD</i>			
<i>a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .973.</i>			



**Figure 4** comparisons between the experimental and predicted values of the bulk density

#### 4. Conclusion

Within the limitation and the experiment program of this research study, the following can be concluded:

1. General known linear and nonlinear model offered by available software could not represent the resulted values. Where more complicated models are needed
2. The nonlinear equations with some complicated relation are found to be representative to estimate the value of bulk density, IDT and TSR with acceptable reliability, where the results demonstrate that the Mean square of residual for bulk density, IDT and TSR is low and sum of residual is lower than sum of regression which is sustained the significant of the model and the data are close to the fitted regression line which indicates a perfect prediction.
3. Using statistical modeling is achievable and offer a vital tool to describe the characteristics and performance of TAO mixture in term volumetric, mechanical and durability properties. Where these model within the scope of the study proven the significant of the filler type especially for TSR.

#### CONFLICT OF INTERESTS.

- There are no conflicts of interest.

#### References

- [1] J. C. NICHOLLS, I. Carswell, J. T. WILLIAMS, and M. GIBB, "Service lives of thin surfacing systems in the UK," in *PROCEEDINGS OF THE 4TH INTERNATIONAL CONFERENCE BITUMINOUS MIXTURES AND PAVEMENTS, HELD THESSALONIKI, GREECE, APRIL 2007-VOLUME1*, 2007, no. p25-32.
- [2] D. E. Newcomb, "Thin asphalt overlays for pavement preservation," 2009.
- [3] E. Masad, V. K. Jandhyala, N. Dasgupta, N. Somadevan, and N. Shashidhar, "Characterization of air void distribution in asphalt mixes using X-ray computed tomography," *J. Mater. Civ. Eng.*, vol. 14, no. 2, pp. 122–129, 2002.
- [4] Y. F. Qiu and K. M. Lum, "Design and performance of stone mastic asphalt," *J. Transp. Eng.*, vol. 132, no. 12, pp. 956–963, 2006.
- [5] W. Phislop and B. J. Coree, "VMA as a Design Parameter in Hot-Mix Asphalt [R]," *Natl. Coop. Highw. Res. Program, USA*, vol. 5, 2002.

- [6] Y. Wang, K. C. Mahboub, and D. E. Hancher, "Survival analysis of fatigue cracking for flexible pavements based on long-term pavement performance data," *J. Transp. Eng.*, vol. 131, no. 8, pp. 608–616, 2005.
- [7] D. W. Christensen and R. Bonaquist, "Use of strength tests for evaluating the rut resistance of asphalt concrete," *J. Assoc. Asph. Paving Technol.*, vol. 71, 2002.
- [8] E. R. Brown, "Density of asphalt concrete: How much is needed?," National Center for Asphalt Technology, 1990.
- [9] M. Ameri and A. Behnood, "Laboratory studies to investigate the properties of CIR mixes containing steel slag as a substitute for virgin aggregates," *Constr. Build. Mater.*, vol. 26, no. 1, pp. 475–480, 2012.
- [10] S. M. Abtahi, M. Sheikhzadeh, and S. M. Hejazi, "Fiber-reinforced asphalt-concrete—a review," *Constr. Build. Mater.*, vol. 24, no. 6, pp. 871–877, 2010.
- [11] M. Arabani, S. M. Mirabdolazimi, and A. R. Sasani, "The effect of waste tire thread mesh on the dynamic behaviour of asphalt mixtures," *Constr. Build. Mater.*, vol. 24, no. 6, pp. 1060–1068, 2010.
- [12] D. W. Christensen and R. F. Bonaquist, *Evaluation of indirect tensile test (IDT) procedures for low-temperature performance of hot mix asphalt*, no. 530. Transportation Research Board, 2004.
- [13] G. Du, *Implementation of the SuperPave IDT analysis procedure*. 2010.
- [14] C. Gorkem and B. Sengoz, "Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime," *Constr. Build. Mater.*, vol. 23, no. 6, pp. 2227–2236, 2009.
- [15] R. P. Lottman, *Field Evaluation and Correlation of Laboratory Test Method for Predicting Moisture-Induced Damage to Asphalt Concrete*. 2001.
- [16] I. Padmanaban, S. Kandasamy, and S. C. Natesan, "Statistical modeling of high and low volume of fly ash high compressive strength concrete," *Int. J. Appl. Eng. Res.*, vol. 4, no. 7, pp. 1161–1167, 2009.
- [17] GSRB, "General Specification," pp. 1–116, 2003.
- [18] ASTM, "Test method for penetration of bituminous materials," *Dep. Stand. Malaysia*, vol. i, pp. 1–5, 2015.
- [19] ASTM, "Standard Test Method for Ductility of Bituminous Materials 1," vol. i, pp. 1–4, 2007.
- [20] ASTM, "Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester," *Annu. B. ASTM Stand.*, vol. i, pp. 1–10, 2005.
- [21] ASTM, "Standard test method for softening point of bitumen (ring-and-ball apparatus)," 2015.
- [22] ASTM, "Solubility of Asphalt Materials in Trichloroethylene 1," pp. 1–3, 2015.
- [23] D. ASTM, "Standard test method for effects of heat and air on asphaltic materials (thin-film oven test)," *Annu. B. ASTM Stand.*, vol. 4, 2015.
- [24] ASTM, "D6927-15 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. Designation: D6927-15," *Am. Soc. Test. Mater.*, vol. i, pp. 1–7, 2015.
- [25] ASTM, "D3203 Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures," vol. i, no. c, pp. 5–7, 2011.
- [26] ASTM, "D2041/D2041M – 11 Standard Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures," no. January, pp. 8–9, 2015.
- [27] ASTM, "Standard test method for indirect tensile (IDT) strength of bituminous mixtures," 2007.
- [28] AASHTO, "Determining the creep compliance and strength of HMA." p. 16, 2003.

## بناء نماذج أداء مختبرية لخلطات طبقة الأسفلت السطحية الرقيقة

شاكر فالح شاكر

موسى زكي يحيى

قسم الهندسة المدنية، كلية الهندسة، جامعة كربلاء، كربلاء، العراق

shakerfa2003@yahoo.com

mousazekitz@gmail.com

### الخلاصة

تستخدم النمذجة الإحصائية بفعالية لبناء علاقة بين المتغيرات التابعة والمتغيرات المستقلة. وبعبارة أخرى، فهي تصف كيفية ارتباط متغير عشوائي واحد أو أكثر بمتغير آخر. يمكن أن يساعد بناء النماذج الإحصائية التي تم التحقق منها في التنبؤ بأداء الخلطات الاسفلتية وتوفير الوقت والمال. تهدف هذه الدراسة إلى تقديم نماذج إحصائية تساعد على فهم أهمية المؤشرات المختلفة في تحديد خصائص أداء طبقة الاسفلت الرقيقة (TAO) في هذه الدراسة، شمل البرنامج التجريبي: تصميم خلطات طبقة الأسفلت الرقيقة باستخدام نوع واحد من التدرج (9.5 ملم كمقاس اسمي اعظم للركام) و ثلاثة أنواع من المواد المألثة المختلفة (CMF ، OPC ، QL) ، وخمسة نسب من محتوى الاسفلت لتحديد محتوى الأسفلت الأمثل. ثم بعد ذلك، يتم اضافة مادة البوليمر الستايرين البينوتاديين الستايرين (SBS) لتحسين أداء الخلطة. تم اجراء فحوصات مختبرية لتقييم أداء خليط TAO من ناحية الخصائص الحجمية والميكانيكية والديمومة (فحص الكثافة الظاهرية (BD)، فحص قوة الشد غير المباشر (IDT) ونسبة قوة الشد (TSR) ) على التوالي. في هذه الدراسة، تم استخدام برنامج احصائي (SPSS) كأداة لبناء النماذج. لغرض تعيين النماذج الإحصائية الأكثر دقة، تم تحقيق من الانحدار الخطي وغير الخطي. توضح هذه الدراسة أن استخدام النمذجة الإحصائية يمكن تحقيقه ويقدم أداة حيوية لوصف خصائص وأداء خليط (TAO) من ناحية الخصائص الحجمية والميكانيكية والديمومة.

**الكلمات الدالة:** نموذج احصائي، طبقة الاسفلت الرقيقة، الاسفلت المعدل بالبوليمر، قوة الشد الغير مباشرة، الكثافة الظاهرية، نسبة قوة الشد، النورة الحية.