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PREDICTION OF RESILIENT MODULUS MODEL FOR WEARING ASPHALT PAVEMENT LAYER

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ABSTRACT

Resilient modulus for pavement layers is a key design parameter for pavement systems and permits for determination of how the pavement system will react to traffic loadings. It can be defined shortly as elastic modulus of a material under repeated loads. Several factors have effects on the elastic modulus of the layers of asphalt pavements. The indirect repeated axial load test was carried out by using the pneumatic repeated load system (PRLS) at Transportation Laboratory at Baghdad University to test seventy two cylindrical specimens prepared by the gyratory device. SPSS program was used to predict the resilient modulus model which contains many factors like asphalt content, asphalt viscosity, air voids, surface area, and temperature. Multiple linear regression is used to build the model of resilient modulus because it is a function of more than independent variables. F statistical significance value from the results of ANOVA table is smaller than 0.05 in the predicted model then the independent variables in the predicted model explain the variation in the resilient modulus variable. The coefficient of determination (R^2) is 0.886 for the predicted model which is referred to a very good relation obtained. The predicted model shows that the modulus of resilience is highly affected by variation of temperature and moderately by viscosity of the asphalt whereas the stress level, types of filler, and the asphalt content have smaller effect on resilient modulus. The predicted model shows that there is a positive relationship among the resilient modulus and the two variables viscosity and the surface area whereas the three variables temperature, asphalt content, and air voids have inverse relationship with resilient modulus. Two asphalt types (40-50) and (60-70) from Dora refinery were used; the average value of resilient modulus corresponding to asphalt grade (40-50) is almost 21.331% times the value for asphalt grade (60-70). Three asphalt contents (optimum asphalt content, optimum asphalt content±0.5) were used; when the content of asphalt was increased from 4% to 4.5%, the average resilient modulus decreased by 2.923% whereas increasing the percent of asphalt content from 4.5 to 5 the average resilient modulus decreased by 1.737%. Two types of mineral fillers (cement and limestone) were used, and when cement was used as mineral filler, the average resilient modulus increased by 4.422% rather than using limestone as filler in the asphalt mixture. Three temperatures for test were used 10, 25, and 40 ^{o}C. The results showed that when temperature was increased from 10 to 25 $^{\circ}$C, the average resilient modulus decreases by 65.738%; whereas when the test temperature was increased from 25 to 40 ^{o}C, the average resilient moduli decreased by 97.715%. The results also showed that the average resilient modulus increased by 9.69% when the stress level increased from 6.5 psi to 13 psi.

KEYWORDS: resilient modulus, pavement, wearing course, asphalt concrete.

1. INTRODUCTION

Resilient modulus is the elasticity modulus of a material under repeated loads and is a measure of the distribution of the loads through pavement layers. Resilient modulus also controls fatigue cracks caused by tensile stresses at the bottom of Asphalt Concrete (AC) layer and permanent deformations throughout the pavement. The resilient modulus under the uniaxial dynamic loading in general is the ratio of the maximum stress to the maximum unit deformation. The review of literature shows that the relationship between the characteristics of bearing of asphalt concrete and the resilient modulus has been studied from many researchers. AASHTO 1986 guide used the resilient modulus in the design of pavements procedure (Little et al., 1992). Thom et al. 1977 stated that the stiffness modulus is a key factor of pavements evaluation. Commonly, most of the materials of pavement are not elastic, and after each load application they sustain some permanent deformation. Test of indirect tensile (ITT) has been identified as practical and economical means of stiffness modulus measuring (Nunn, 1996). The indirect tensile test with repeated load was applied to show the relationship between the optimum contents of asphalt cement and the properties of asphalt mixtures (Gonzales et al., 1975).

Bagui (2013) determined the elastic modulus of aggregate interface layer using FPAVE software. Figures have been developed to determine resilient modulus, varying the CBR value, the thickness of cement treated base, and the thickness of interface layer of aggregates which is useful to determine the pavement thickness for cement treated base.

Misra et al. (2007) analyzed the data of the Falling Weight Deflectometer device (FWD) to obtain the coefficients of structural layer and the resilient modulus of the stabilized road bases.

Fig 1 shows the deformation curve of asphalt mixture sample under the effect of repetitive loads. As it can be seen from the figure, while there is a considerable plastic strain at the beginning of resilient modulus test as the number of repetitions increases, the plastic strain due to each load repetition gradually decreases. Approximately after 100-200 load repetitions, the strain is practically all recoverable as indicated by ε_r in the figure (Huang, 2004 and Sağlik and Gungor, 2012). The test of resilient modulus is a non-destructive test because of small applied load that leads to use the same samples again to do many other tests by applying different load and environmental circumstances (Huang, 2004).

In triaxial confining test, dividing the deviator stress ($\sigma_d = \sigma_1 - \sigma_3$) by the recovery strain (ε_r) is called the resilient modulus (M_R) and calculated with the formula given below:

$$M_R = \frac{\sigma_d}{\varepsilon_r} \qquad 1$$

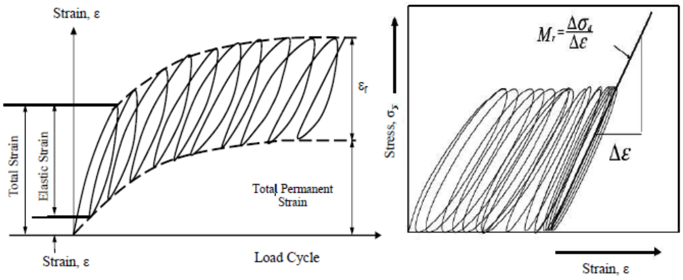

Fig. 1. Behavior of the pavement materials under repetitive loads and the resilient modulus. (Sağlik and Gungor, 2012).

AASHTO design guides in 1986 and 1993 have related the performance of the pavement to a value called resilient modulus for both unbound and bituminous bound pavement layers. Resilient modulus (M_R) can be defined shortly as elastic modulus of a material under repeated loads. Being performed under repetitive loading, the resilient modulus better represents the pavement behavior under traffic loads and three dimensional state of stress. New approach, however, in pavement design is mechanistic – empirical methods in which the response of the pavement defined in terms of stresses and strains, is analyzed using rigorous theories of mechanics and critical response quantities are then related empirically to pavement performance. In this method also, the resilient modulus is vitally important parameter to calculate stresses and strains.

In spite of the fact that resilient modulus of pavement materials has been extensively researched for over 30 years, it is still hard task to determine resilient modulus due to its stress dependent nature. Besides, a laboratory tri-axial test on a small soil sample should be conducted in order to measure the resilient modulus. Because the tri-axial test is complex and its results influenced by many factors, and many highway agencies are hesitated to implement it. Thus, the resilient modulus of pavements is generally estimated from some empirical correlations with their other physical properties.

Results of many different types of tests indicate that the behavior of asphalt mixtures is affected by many factors like temperature and other environmental conditions, loading frequency, mix properties, applied load, and tri-axial stress state, specimen type, and type of test. The reason for the dependency on the various factors is that asphalt concrete often exhibits a combination of elastic, time dependent, and plastic behavior in response to loading at in-service temperatures (Little et al, 1992).

The earliest correlations were simple linear. Some of them are given below:

1. Shell Oil (Heukelom and Foster 1960):

$$M_R = 1500CBR \quad 2$$

2. Transport and Road Research Laboratory (Lister 1987)

$$M_R = 2555CBR^{0.64} \quad 3$$

By ignoring stress factor, these relationships provide very rough estimation, and their usage is generally limited to a very specific range of material properties. For example, equation 1 is generally used for fine grained soils with a soaked CBR between 5% and 10%.

The relationships considering stress factor are complex exponential models. Most commonly used of them are;

3. AASHTO Model:

$$M_R = k_1(\theta)^{k_2} \quad 4$$

4. Uzan (Universal):

$$\frac{M_R}{\sigma_{atm}} = k_1\left(\frac{\theta}{\sigma_{atm}}\right)^{k_2}\left(\frac{\theta_d}{\sigma_{atm}}\right)^{k_3} \quad 5$$

5. Rafael Pezo:

$$M_R = k_1\sigma_d^{k_2}\sigma_3^{k_3} \quad 6$$

6. NCHRP 1-28A:

$$M_R = k_1P_a\left(\frac{\theta}{\sigma_{atm}}\right)^{k_2}\left(\frac{\tau_{oct}}{\sigma_{atm}}+1\right)^{k_3} \quad 7$$

Where:

M_R = Resilient modulus.

$\theta = \sigma_1 + \sigma_2 + \sigma_3$ (Total stress).

k_1, k_2, k_3 = Regression coefficients.

σ_d = Deviator stress.

σ_3 = Confining pressure.

σ_{atm} = Atmospheric pressure.

$\tau_{oct} = (1/3)[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2]$ (Octahedral shear stress).

Al-Jassar et al. (2003) evaluated the relationship and effects of temperatures on the resilient modulus at different frequencies of loading, and the stability/flow ratio values were as follows:

7. $E_{1.0\,Hz} = 1.155\,\frac{stability}{flow} \qquad R^2 = 76\%$ (8)

$$E_{1.5\,Hz} = 1.075\,\frac{stability}{flow} \qquad R^2 = 81\% \tag{9}$$

$$E_{0.33\,Hz} = 1.044\,\frac{stability}{flow} \qquad R^2 = 82\% \tag{10}$$

where

$E_{i\,Hz} = Resilient\ Modulus\ at\ 60\ ℃\ and\ i\ Loading\ Freqency, Mpa.$

STF = Stability/Flow ratio, kg/0.01 in.

R^2 = Coefficient of determination.

8. Fonseca and Witczak (1996) developed an equation, which is adopted by the Asphalt Institute in their design procedure of flexible pavement:

$$M_r = f\,(\eta, f, V_a, V_{beff}, P_{3/4}, P_{3/8}, P_4, P_{200}) \tag{11}$$

Where:

M_r: resilient modulus, η: viscosity of asphalt in 10^6 poise at 20 °C, f: frequency of load in Hz, V_a = percent of air voids by volume in mixture, V_{beff}: %effective asphalt content by volume, $P_{3/4}$: % retained on ¾" sieve, $P_{3/8}$: %retained on 3/8", P_4: % retained on No.4, P_{200}: % passing No.200.

9. Leahy (1989) tested 251 cylindrical asphalt concrete specimens using repeated load tests and presented the following relationship:

$$Log(Mr) = S/(-8.652 + 4.207T + 1.01S - 0.233V + 0.992Eac + 0.476Vol \tag{12}$$

R^2 = 0.82

Where

M_r = Resilient Modulus, S = Log stress in psi, T = Log temperature in °F, V = Log (asphalt viscosity in 10^6 poise), E_{ac} = log effective asphalt content (% by volume), Vol = log % air voids.

2. RESEARCH OBJECTIVE

The main objective of the research is prediction of resilient modulus model for wearing asphalt pavement layer using many factors like asphalt content, asphalt viscosity, air voids, surface area, and temperature in order to use it in the thickness design of surface layer of asphalt pavements.

3. EXPERIMENTAL DESIGN AND MATERIALS

Local available Materials were used in this research, which are used for the pavement construction in Iraq: asphalt binder, aggregate, and mineral filler. Traditional laboratory physical properties tests were carried out to the materials, and the results were in the following paragraphs.

3.1. Asphalt Binder

Two asphalt binder grades were used: (40-50) penetration grade and (60-70) penetration grade from Dora oil refinery. The following Table 1 shows the properties of both types of asphalt.

Table 1. Asphalt binder physical properties

Physical property	ASTM Designation	Asphalt Cement 40-50		Asphalt Cement 60-70	
		Test results	SCRB Specification	Test results	SCRB Specification
Penetration at 25°C, 100gm, 5 sec. (0.1mm)	D5	44	40-50	65	60-70
Softening point, °C	D36	50	----	43	----
Ductility at 25°C, 5cm/min, (cm)	D113	>100	>100	---	>100
Viscosity (pas. sec.)	D4402	0.5	---	0.35	---
Flash point, °C	D92	285	≥232	290	≥232
Specific gravity	D70	1.035	---	1.025	---
Thin film oven test residue	D1754				
- Retained penetration, % of original	D5	57.7	55^{+}	65.3	52^{+}
- ductility, 5cm/min at 25°C, cm	D113	80	25^{+}	100+	50^{+}

3.2. Aggregate

Al-Nibaie quarry was the source of aggregate used in preparing the samples in this research, and it was crushed quartz. This type of aggregate is widely used in Baghdad city for preparing asphalt mixes. The coarse and fine aggregates physical properties are presented in Table 2. The surface course-gradation was selected according to SCRB R/9 2003 specification-in Table 3. The wearing course materials gradation of mixture with limits of Iraqi specification are shown in Fig. 2.

3.3. Mineral Filler

The mineral filler material is a non-plastic material, which is passing openings of the sieve No.200 (0.075 mm). Two types of filler were used in this research: limestone dust and cement. Limestone is from the factory of lime in Karbala city, and cement is from Al-Kufa factory in Al-Najaf city. Table 4 presents the limestone dust physical properties whereas the ordinary Portland cement physical properties are presented in Table 5. Chemical properties and main compounds of ordinary Portland cement are shown in Table 6. All laboratory mentioned tests of limestone dust and cement are conducted in the National-Center-for-Construction-Laboratories-and-Research in Baghdad city.

Table 2. Coarse and Fine Aggregate Physical Properties.

Physical Properties	Designation of ASTM	Results of Test	Specification of SCRB
Coarse aggregate			
Bulk spec. g.	C-127	2.605	……
Apparent spec. g.		2.678	……
Absorption of Water,%		0.439	……
Wear from Los Angeles abrasion ,%	C-131	17.5	30 Max
Loss of soundness by sodium sulfate solution,%	C-88	3.2	10 Max
Fractured pieces, %		97	95 Min
Fine aggregate			
Bulk spec. g.	C-127	2.658	……
Apparent spec. g.		2.688	……
Absorption of Water,%		0.719	……
Sand equivalent,%	D-2419	56	45 Min.

Table 3. Selected Gradation for Wearing Course Asphalt Concrete Mixture According to Iraqi Specifications.

Sieve size		Iraqi Specifications SCRB 2003		% Passing
	mm	Min.	Max.	Wearing Course
¾”	19.0	100	100	100
½”	12.5	90	100	93
3/8”	9.5	76	90	85
No.4	4.75	44	74	58
No.8	2.36	28	58	32
No.50	300 µm	5	21	12
No.200	75 µm	4	10	6

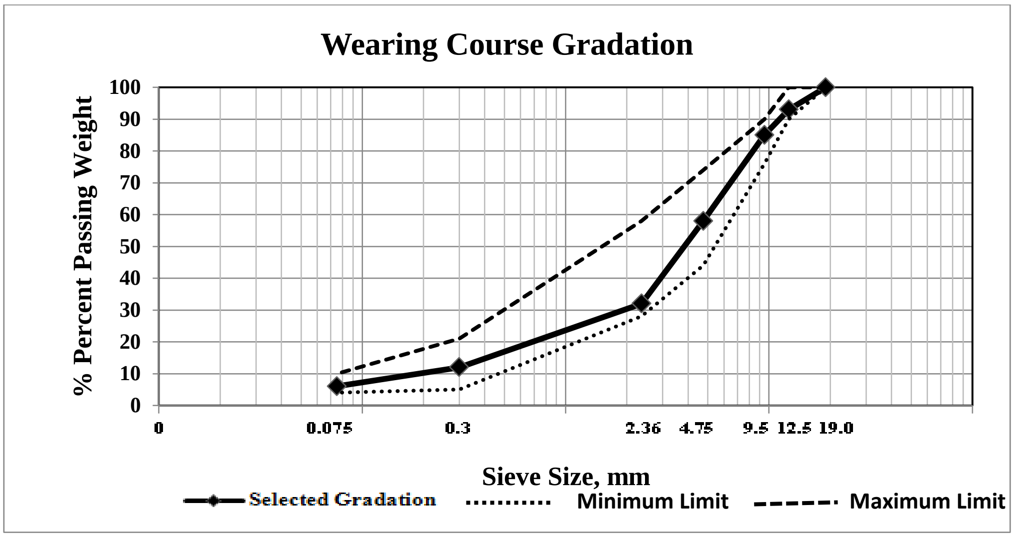

Fig. 2. Asphalt Mixture Gradation with Iraqi Specification Limits.

Table 4. Physical properties of Mineral Filler

Property	Test results
Specific gravity	2.887
Passing sieve No. 200 (0.075mm)	94

Table 5. Ordinary Portland Cement Physical Properties.

Properties	Result of the Test	Iraqi specification limits, No.5-1984
Specific surface area, Blain Method, (cm²/g).	3390	> 250
Time of Setting		
-Initial time of setting (hrs.:min)	2:34	≥ 45 minimum
-Final time of setting (hrs.:min)	4:42	≤ 10 hours
Compressive strength (Mortar) (MPa):		
3 days	18.2	≥ 15
7 days	23.9	≥ 23
Soundness (Autoclave)%	0.04	≤ 0.8

The main objective of asphalt mixture method of design is to find the asphalt and aggregate optimum quantities in order to use in the asphalt mixtures. Two traditional empirical methods of mixture design were used: Hveem and Marshall (Al-Mistarehi, 2014). The Strategic Highway Research Program (SHRP) developed the Superpave method as a design method. The Superpave method is a performance method-which reveals a direct-relation between the laboratory analysis and the performance in the field after building or construction=which is differentiated in accordance to the currently used mix design methods. Other methods of design are empirical=and=cannot=predict precisely how the pavement structure will be performed after building or construction (Anderson et al., 2007). The Superpave=Gyratory Compactor simulates the compaction in the field by introducing the shearing action of compaction equipment by applying a tilting angle while the specimen is being submitted to a constant vertical loading (Kiflat, 2013). So Superpave method will be adopted in this research in order to obtain the optimum asphalt content which found to be 4.5%.

Table 6. Ordinary Portland cement main compounds and chemical composition.

Composition of Oxide	Abridgment	% by weight	Iraqi specification limits No.5/1984
Lime	CaO	60.77	…
Silica	SiO_2	20.52	…
Alumina	Al_2O_3	5.51	…
Iron oxide	Fe_2O_3	3.27	…
Sulphate	SO_3	1.85	≤2.8%
Magnesia	MgO	1.91	≤5%
Loss on ignition	LOI	2.44	≤4%
Lime saturation factor	LSF	0.86	0.66-1.02
Main compounds (Bogues eq.)		**% by weight of cement**	
Tricalcium (C3S)		44.4	
Diacalcium silicate (C2S)		25.6	
Tricalcium aluminate (C3A)		9.08	
Tetracalcium aluminoferrite (C4AF)		9.94	

4. SELECTION OF VARIABLES

Asphalt can be classed as thermoplastic material because they gradually liquefy when heated and become solid again on cooling. Their behavior is dependent on temperature. The thermoplastic property of the asphalt binder has a significant-effect on the resilient modulus of asphaltic-mixtures (Schmidt, 1974). In this research three test temperatures are used (10, 25, and 40°C) to generate design values over the range of temperatures normally encountered in pavements.

Physical and chemical properties of: aggregate, asphalt, and composite mixture have an essential role on the modulus of resilience of the asphalt concrete. The grade of asphalt is critical to the dynamic behavior of asphalt treated mixtures (Roque et al, 1987). Asphalt consistency is related to the type of asphalt. Consistency is a qualitative term used to describe viscosity or degree of fluidity (Penetration) at any particular temperature (Tal, 1989). The high viscosity (low penetration) asphalts are called 'hard' asphalts because the material is relatively stiff (high modulus). Two asphalt types (40-50) and (60-70) are be used in this research.

Other important mix property parameters are amount of asphalt and air voids. Amount of asphalt is expressed by weight or volume percentages. Generally, as the asphalt content increases, the modulus of the mix decreases (taking other parameters into account). The percent asphalt and air voids in a mix are inversely related (Gemayel & Mamlouk, 1988). As the percentage of asphalt content increases, the percentage of air voids decreases. Three asphalt contents are used in this research (optimum asphalt content, optimum asphalt content±0.5).

One of the most important factors affecting the modulus of the asphalt treated materials is the applied load or level of stress. Two stress levels are used in this research 6.5 and 13 psi.

The geometry of the specimen and the mode of compaction can have a significant impact on the dynamic response of the asphalt materials. Often, there are differences associated with the method of compaction (impact, rolling wheel, kneading compactor, and Texas gyratory) used in the laboratory and specimens cored from field sites (Consuegra et al., 1989). The specimen geometry governs the analysis procedure. The dimensions associated with each geometry are governed by the maximum size of the aggregate. Physical and chemical properties of aggregate are affected the resilient modulus. Two types of mineral filler (cement and limestone) are used and the surface area is also considered in building the model as independent variable. The required total number of samples is equal to (2 × 3 × 2 × 3 × 2 = 72 specimens).

5. SPECIMENS' PREPARATION AND TEST

Superpave gyratory compactor device was used in the preparation of cylindrical specimens. The dimension of the specimen is 4 in. (102 mm) in diameter and 8 in. (203 mm) in height. The repeated axial load test was carried out using the Pneumatic Repeated Load System (PRLS) in Transportation Laboratory at Baghdad University. About 72 specimens have been compacted in order to build the resilient modulus model.

5.1. EFFECT OF TEMPERATURE ON RESILIENT MODULUS

The resilient modulus is highly affected by the variation of temperature. The elastic modulus decreases when the temperature increase as it can be seen in Fig 3. This is due to the softening of the asphalt binder as the temperature is increased (Ziari, 2005). Increasing temperature reduces viscosity of asphalt binder thus increases the shear strain between the particle contacts. Therefore, the stiffness of the specimen decreases at an applied deviator stress. When temperature increases from 10 to 25°C, the average elastic modulus decreases by 65.738% whereas when the test temperature was increased from 25 °C to 40 °C the average elastic modulus decreased by 97.715%.

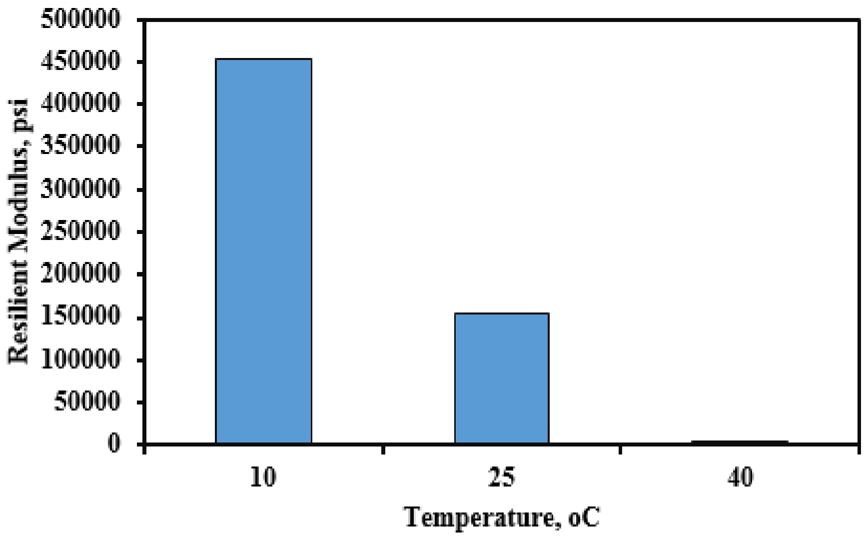

Fig. 3. Relationship between Temperature and Resilient Modulus.

5.2. EFFECT OF ASPHALT CEMENT PENETRATION GRADE

As-the asphalt cement penetration grade increases, the stiffness of binder decreases because the viscosity of the asphalt binder decreases. Fig. 4 represents the relationship between the resilient modulus and asphalt cement viscosity. It is obvious from the figure that when asphalt viscosity increases, the average resilient modulus increases. The average value of resilient modulus corresponding to asphalt grade 40-50 (viscosity = 0.5) is almost 21.331% times the value for asphalt grade 60-70 (viscosity = 0.35).

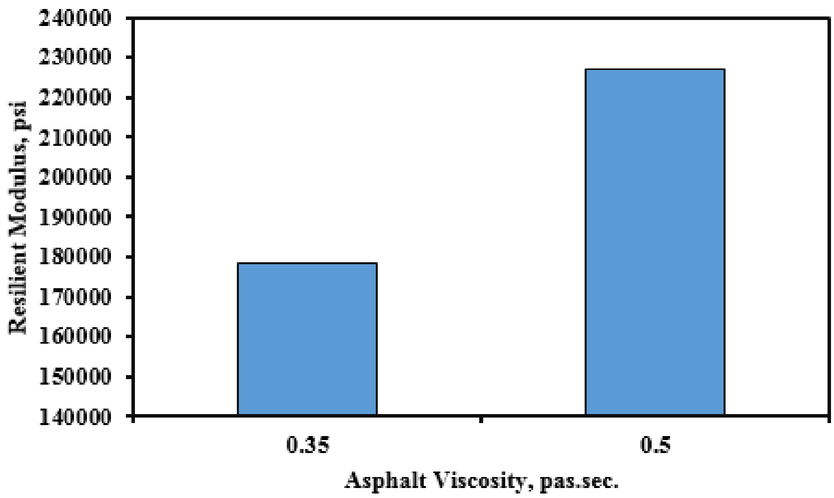

Fig. 4. Relationship between Asphalt viscosity and Resilient Modulus.

5.3. EFFECT OF ASPHALT CONTENT

Three asphalt contents were used in this research (4, 4.5, and 5) %. Fig 5 shows the relationship of resilient modulus with the content of asphalt. As presented in the figure the average resilient modulus decreases with the increase of content of asphalt because increasing the thickness of asphalt film leads to increase in the resilient strain. When the content of asphalt increases from 4% to 4.5%, the average resilient modulus decreased by 2.923% whereas when the percent of content of asphalt was increased from 4.5% to 5% the average resilient modulus decreased by 1.737%.

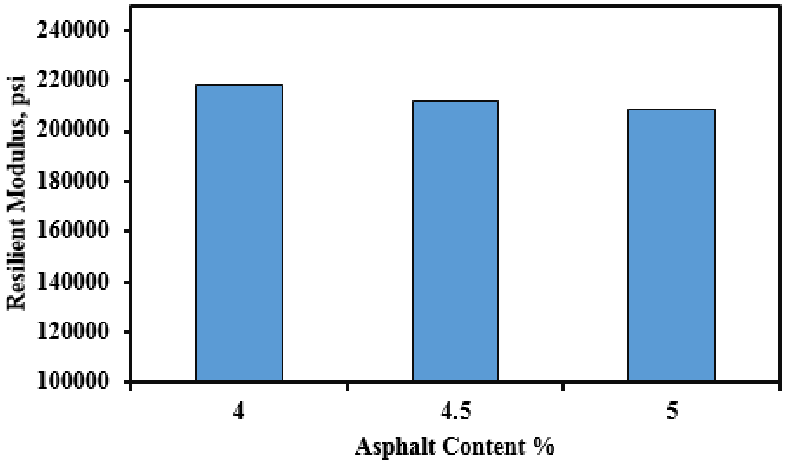

Fig 5: Relationship between Asphalt Content and Resilient Modulus.

5.4. EFFECT OF MINERAL FILLER

Fig 6 represents the relationship between the resilient modulus and the mineral filler type. It is obvious from the figure that when using cement as mineral filler in the asphalt mixture, the average resilient modulus increases by 4.422% rather than using limestone as filler in the asphalt mixture. The two types of filler differ in shape, surface texture and area, mineral composition, void content, and other petrochemical properties (Bahia et al., 2011).

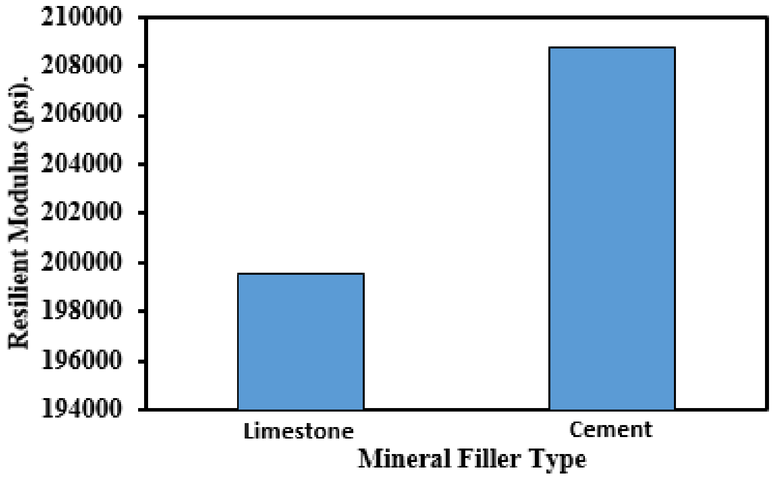

Fig. 6. Relationship between Mineral Filler Type and Resilient Modulus.

5.5. EFFECT OF STRESS LEVEL

Two stress levels were used in this research (6.5 and 13) psi. Fig. 7 shows the relationship of resilient modulus with the stress level. The figure shows that the resilient modulus increases with the9increase of stress level because the stiffness of the specimen decrease. The resilient modulus increases by 9.69% when the stress level increases from 6.5 psi to 13 psi.

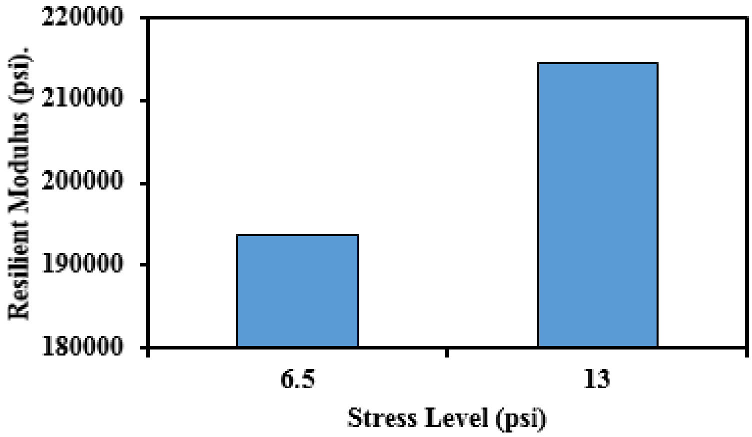

Fig. 7. Relationship between Stress Level and Resilient Modulus.

6. STATISTICAL MODEL

This paragraph presents the statistical analysis used in the development of the resilient modulus model. Linear Regression Analysis approach was used to build the model by SPSS statistical program. Resilient modulus (psi) is the dependent variable whereas the independent variables are: temperature (^oC), asphalt content (%), air voids (%), viscosity (pas.sec.), and the surface area (kg/cm2).

There are certain assumptions should be available in the data of linear regression method of analysis: Linearity, Normality of residuals and Homogeneity, and independence of residuals.

6.1. Normality Testing

The test used to check the normality of the variables is=Kolmogorov-Smirnov=test or (K-S) test. Table 7 presents the test results by using SPSS statistical program.

The K-S calculated values are less than the critical values presented by (Scheaffer and McClave, 1990) as shown in the table. Accordingly, the distribution of the model is normal.

Table 7. D-Value and K-S Test Results.

Residual value	D^+	D^-	Absolute D	K-S, $D_{n,0.03)}$
MR	0.171	-0.154	0.171	1.448

6.2. Multicollinearty

It is a method used to show the correlation statistically between the independent variables. The adverse effect of multicollinearity means that the estimated coefficients of regression tends to have a large variability of sampling. SPSS software is employed for this purpose.

95% Confidence level is employed, thus the level of significant is 0.05. Matrix of correlation is used to determine the coefficients of correlation between the variables. The coefficients of correlation between all variables are counted by applying SPSS software and the correlation matrix is setup. Table 8 shows the bivariate coefficients of correlation and determines the relationship between each of the predictor variables and the dependent variable.

Table 8. Correlation Matrix of Model Variables.

		T	Ps	Av	Visc	SA	MR
T	Pearson Correlation	1	0.000	-.663**	-.034	.306**	-.926**
	Sig.(2-tailed)		1.000	0.000	.776	.009	0.000
	N	72	72	72	72	72	72
Ps	Pearson Correlation	0.000	1	-.022	0.000	-.102	-.076
	Sig.(2-tailed)	1.000		.858	1.000	.394	.524
	N	72	72	72	72	72	72
Av	Pearson Correlation	-.663**	-.022	1	.065	-.389**	.529**
	Sig.(2-tailed)	0.000	.858		.585	.001	0.000
	N	72	72	72	72	72	72
Visc	Pearson Correlation	-.034	0.000	.065	1	.223	.122
	Sig.(2-tailed)	.776	1.000	.585		.060	.308
	N	72	72	72	72	72	72
SA	Pearson Correlation	.306**	-.102	-.389**	.223	1	-.144
	Sig.(2-tailed)	.009	.394	.001	.060		.229
	N	72	72	72	72	72	72
MR	Pearson Correlation	-.926**	-.076	.529**	.122	-.144	1
	Sig.(2-tailed)	0.000	.524	0.000	.308	.229	
	N	72	72	72	72	72	72

**. Correlation is significant at the 0.01 level (2-tailed).

6.3. Samples Number

In order to build the resilient modulus model; the number of samples must be checked, and method of validation for the predicted model should be selected. The following methods are suggested by Neter et al. (1990) for validation of a regression model:

- Check on the model predicted and coefficients attempts to make sure that the selected model agrees with the physical theory.

- Collect a new data set.
- Compare with previously developed models.
- Data splitting recommends that one should not consider data splitting unless N>2P+25, where N is a sample size, and P is the number of estimated parameters.
- Prediction the sum of squares is a form of data splitting.

In this research data splitting method is adopted by assuming part of the data for building the model and the other parts for validation. Two percents are used to check the number of samples that are used for building the model (65 and 75) % and compare with the total number of data 72 observations. SPSS program is used to select the appropriate observations for splitting data according to the normal distribution.

Table 9 represents descriptive statistics for number of samples (N = 47, N = 54 and N = 72). Table 10 represents t-test results for resilient modulus number of samples.

Table 9. Descriptive Statistics for Model No. of Samples.

N	Minimum	Maximum	Mean	Std. Deviation	Variance
47	500.70	640553.20	188069.590	199420.446	3.977E10
54	500.70	640553.20	174555.566	795703.583	3.527E10
72	500.70	696553.20	204147.881	199786.961	3.991E10

Table 10. T-Test Results for Resilient Modulus No. of Samples.

Samples Pair	t-value	df	Sig.(2-tailed)	Mean Difference	95% confidence Difference interval	
					Lower	Upper
47 and54	-0.306	45	0.761	-14772.141	-111936.47	82392.188
54 and 72	-1.258	54	0.214	-34268.926	-88883.27	20345.421
47 and 72	-0.275	45	0.784	-11665.690	-97039.819	73708.438

From Table 10, the t-test results show that using 47 number of samples or 54 or 72 don't make any difference because significant 2-tailed is greater than 0.05 confidence level.

F–Test was used to determine whether the pair of samples ((47 and 54) or (47 and 72) or (54 and 72)) have different variances. Table 11 shows the F–Test results.

From Table 11, F calculated is less than F tabulated in all pairs. Thus, the null hypothesis that the two standard deviations for all pairs are equal is accepted, and there is 95% confidence that any difference in the sample standard deviations is due to random error.

Table 11. F-Test Results for Resilient Modulus1 No. of Samples.

Pair of Samples	F Calculated	F Tabulated
46 and 54	0.892	1.60
46 and 72	0.995	1.56
54 and 72	0.873	1.52

7. REGRESSION MODELING

The regression modeling consists of three parts: variable response, mathematical function, and random errors. The mathematical function describes the deterministic variation in the response variable, and it is called the regression function or regression equation.

Multiple linear regressions are used to build the resilient modulus model because it is a function of many independent variables. The main aim of linear regression modeling is the prediction of the best model at the selected level of confidence and satisfying the principal assumptions of linear regression analysis. There is no precise rule on how to select the proportion sets of building and validating the model (Azzalini and Scarpa, 2012). In this research, the most commonly used in references the proportion sets of 75% of data will be used to build the model and the other 25% for validation in order to include the largest number of data in building the model.

7.1. Model Limitations

The data limitations used to build the model are presented in Table 12.

7.2. Fit Goodness

The goodness measures of fit are predominate to quantify how quite the data fit the suggested regression model obtained. The two measures: the standard error of regression (SER) and coefficient of determination (R2) are presented (Devore, 2000). For more accuracy, the statisticians use the adjusted value of coefficient of multiple determinations, adjusted R2 which refers to the magnitude of increasing of R2 when new variable inter the model.

ANOVA test results and summary of the regression for the model are presented in Tables 13 and 14, respectively, also the developed model is presented in Table 14.

Table 12. Data Limitations Used in Resilient Modulus Model.

Building Model Data, Sample Size = 54				
Variable	**Range**	**Min.**	**Max.**	**Mean**
T	30.00	10.00	40.00	23.056
Ps	1.00	4.00	5.00	4.491
Av	4.51	2.44	6.95	5.375
η	0.15	0.35	0.50	0.433
SA	0.01	5.97	5.98	5.974
Mr	696052.50	500.70	696553.20	233430.349
Validation Data, Sample Size = 18				
Variable	**Range**	**Min.**	**Max.**	**Mean**
T	30.00	10.00	40.00	30.833
Ps	1.00	4.00	5.00	4.528
Av	4.05	2.71	6.76	4.805
η	0.15	0.35	0.50	0.417
SA	0.01	5.97	5.98	5.977
Mr	586948.50	1202.70	588151.20	116300.478

Table 13 ANOVAb Test Results for Resilient Modulus Model.

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	1.855E12	5	3.710E11	74.587	0.000[a]
	Residual	2.387E11	48	4.974E9		
	Total	2.094E12	53			

Predictors: (Constant), SA, Ps, T, η, Av.
Dependent Variable: Mr.

From Table 13 of ANOVA results, the F statistical significance value is smaller than 0.05 then the independent variables in the predicted model do well explaining the variation in the (resilient modulus) dependent variable. From Table 14, the coefficient of determination (R2) is 0.886 that is referred to a very good relation obtained, and only 11.4% of observed variation is unexplained by the developed model. The predicted model indicated that the resilient modulus decreases with the increase of temperature, asphalt content, and air voids whereas the resilient modulus increases with the increase of asphalt viscosity and surface area.

Table 14. Regression Developed Model for Resilient Modulus.

Model		Estimated Parameter B	t	Significant (p-value)	95 % Interval of Confidence Bound Lower	Upper	SER
1	α	-12979074.90	-0.976	0.334	-39715263.30	13757113.49	70524.559
	T	-16552.594	-15.439	0.000	-18708.244	-14396.944	
	Ps	-52354.064	-2.236	0.030	-99423.660	-5284.469	
	Av	-15094.311	-1.394	0.170	-36858.449	6669.828	
	η	301011.367	2.187	0.034	24283.468	577739.266	
	SA	2306479.544	1.037	0.305	-2164849.665	6777808.752	

$$M_r = -12979074.90 - 16552.594\,T - 52354.064\,P_s - 15094.311\,A_v + 301011.367\,\eta + 2306479.544\,SA$$

$R = 0.941$, $R^2 = 0.886$, Adjusted $R^2 = 0.874$

7.3. Validation of the Developed Model

The aim of the validation process is to assess the adequacy of the proposed prediction model and measure the error or accuracy of the prediction for the validation period.

Excel software was used to validate the model. The actual split 25% data which has not been used in the building of the model was used in the validation process. Fig 8 explains the relationship between the actual versus estimated (developed) (Mr), and as presented in the figure the coefficient of correlation (R) value is 0.992 for the resilient modulus model thus the developed model is considered to be valid.

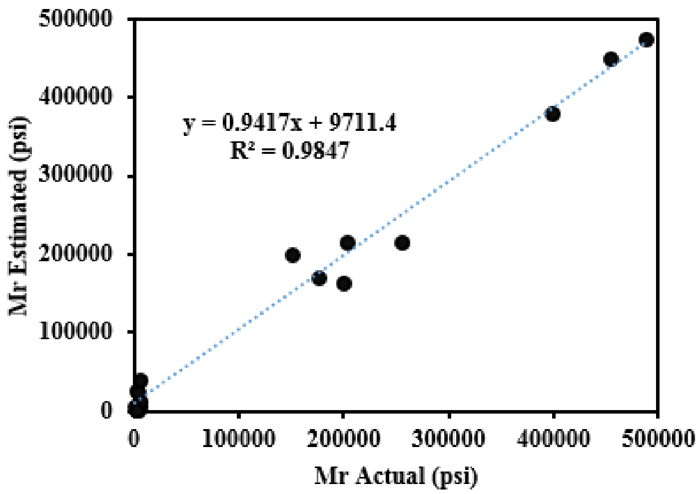

Fig. 8. Actual Versus Estimated Mr (psi).

7.4. Distribution of Error

Kolmogorov-Smirnov test has been used to exam the distribution of error; the data are presented in Table 15. Figs 9 and 10 show the histogram and scatter plot depicted distribution of error for the resilient modulus model. It can be noticed that distribution of error is normal.

Table 15. D-Value and K-S Results for Error.

Residual value	D^+	D^-	Absolute D	K-S, $(D_{n,0.05})$
Mr	0.135	-0.121	0.135	0.990

7.5. Mean Error Distribution

The error distribution mean value is determined and the distribution of mean error is zero for the proposed model.

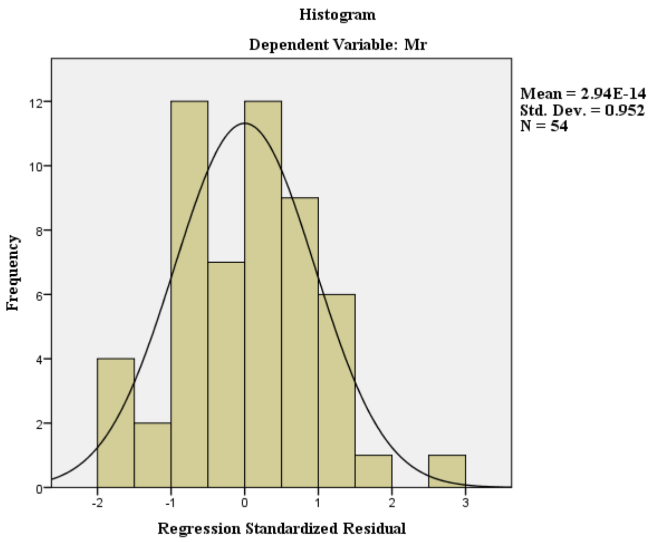

Fig. 9. Histogram Residual for Resilient Modulus Model.

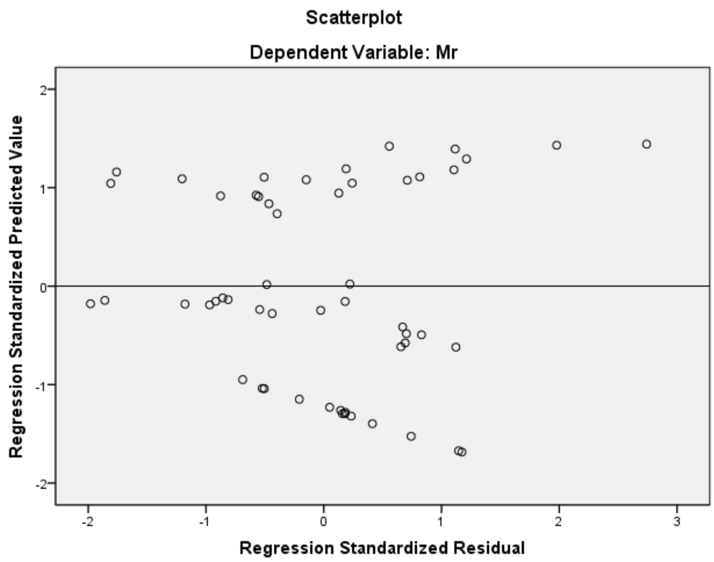

Fig. 10. Scatter Plot for Resilient Modulus Model.

8. DISCUSSION OF REGRESSION RESULTS ANALYSIS

The analysis of linear multiple regression was used to know the independent variables (temperature, asphalt content, viscosity, air voids, and surface area) effect on the dependent variable Mr.

From SPSS program, the resilient modulus model was predicted, and it was as follows:

Table 16. Resilient Modulus Model Coefficients.

Model Variables		Coefficients of Unstandardized		Coefficients of Standardized	t value	Significant
		B	**Standard Error**	**Beta**		
1	α	-12979074.90	13297386.95		-0.976	0.334
	T	-16552.594	1072.124	-1.002	-15.439	0.000
	Ps	-52354.064	23410.316	-0.110	-2.236	0.030
	Av	-15094.311	10824.511	-0.094	-1.394	0.170
	η	301011.367	137632.108	0.114	2.187	0.034
	SA	2306479.544	2223839.607	0.058	1.037	0.305

It is obvious from the values of standardized coefficient (Beta), the first independent variable temperature is highly affected on the prediction of the resilient modulus (dependent variable, Mr) because of the highest value of Beta (-1.002). Viscosity is the second variable; the value of Beta is (0.114). Beta value for the asphalt content variable is (0.110), and its rank is the third. The fourth variable is the air void; beta value is (-0.049). The last independent variable which has the lowest effect on the prediction of the (Mr) is the surface area, its Beta value is (0.058).

Table 17. Summary Results of Predicted Model.

Model	R	R^2	SER
$M_r = -12979074.90 - 16552.594\,T - 52354.064\,P_s$ $-15094.311\,A_v + 301011.367\,\eta + 2306479.544\,SA$	0.941	0.886	70524.559

The coefficient of determination (R^2) is 0.886. This means there are only 11.4 percent of the observed variation is unexplained by the developed model. This leads to a very good correlation between the actual and estimated values of Mr.

The model shows that the Mr increasing with the increase of the viscosity and the surface area whereas Mr decreasing with the increase of temperature, asphalt content, and air voids.

It can also be noticed that the data of responses variables in scatter plot, scattering around the horizontal line, therefore distribution of these data are normally distribution.

The correlation coefficient ($R_{calculated}$) is 0.941 from table of R the degree of freedom for 72 observation df = 72 – 2 = 70, then $R_{tabulated}$ is 0.232. The correlation between M_r and the independent variables in the predicted model is considered significant at 0.05 probability level because the calculated R exceeds the tabulated R value, and that means there is a strong correlation between the M_r model and response variables.

9. CONCLUSIONS

From the findings of this research investigations; it can be concluded that:

1. Resilient modulus model of the wearing asphalt concrete layer for different test conditions and mix properties was developed based on the pneumatic repeated load test device, in the following form:

$$M_r = -12979074.90 - 16552.594\,T - 52354.064\,P_s - 15094.311\,A_v + 301011.367\,\eta$$

i. $+2306479.544\,SA$

Where: Mr = the resilient modulus in (psi), T = test temperature in (°C), P_s = asphalt content in (%), A_v = air voids, η = viscosity of asphalt (pas.sec), and SA = surface area (kg/cm^2).

2. The resilient modulus of surface layer asphalt concrete mixture is highly affected by temperature; the average resilient modulus at 10 °C is about 65.738%, 99.216% times those corresponding to the test temperature 25 °C, 40 °C respectively. Also, the average resilient modulus at test temperature 25 °C is about 97.715% times that of test temperature 40 °C.
3. The average value of resilient modulus corresponding to asphalt grade 40-50 is almost 21.331% times the value for asphalt grade 60-70.
4. The average resilient modulus decreased by 2.923% when the content of asphalt was increased from 4% to 4.5%; whereas increasing the asphalt content from 4.5% to 5% the average resilient modulus decreased by 1.737%.
5. When using cement instead of limestone as mineral filler in the asphalt mixture; the average resilient modulus increased by 4.422%.
6. By increasing the stress level from 6.5 psi to 13 psi, the resilient modulus increased by 9.69%.

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