International Journal of Advanced Engineering and Technology
ISSN: 2456-7655; Impact Factor: RJIF 5.54
Received: 13-06-2019; Accepted: 18-07-2019
www.newengineeringjournal.com
Volume 3; Issue 3; July 2019; Page No. 102-109

Modeling the volumetric properties of asphalt concrete with the aid of NDT

Saad Issa Sarsam [1], Nazar Sajad Kadhim [2]
[1, 2] University of Baghdad, Department of Civil Engineering, Baghdad, Iraq

Abstract
Construction of Asphalt Concrete is accompanied by intensive quality control testing process. Implementation of such testing process is labor, time and budget consuming. It was felt that the nondestructive testing NDT can overcome such issue, while modeling the relationship of volumetric properties of asphalt concrete with ultrasonic pulse velocity UPV is a probable quick check process in the field giving an idea to the field Engineer about the quality of the pavement. In this investigation, asphalt concrete specimens have been prepared in the laboratory and subjected to volumetric properties determination using the standard Marshal Test procedure. Specimens have also practiced ultrasonic pulse velocity test using Pundit instrument. Test results were analyzed and modeled. A nonlinear statistical model relating ultrasonic pulse velocity with the volumetric properties of asphalt concrete was obtained. It was concluded that such model can explain 93.7 % of the variation in the volumetric properties under the testing techniques implemented.

Keywords: volumetric properties; modeling, asphalt concrete; NDT; pulse velocity

1. Introduction

Nondestructive test technique NDT and modeling of asphalt concrete properties are considered as a sustainable issue. However, potential for assessing the quality of asphalt concrete materials is limited because it is only based on measurement of wave velocity, Jiang, 2007 [1]. NDT methods have been significantly improved and have shown positive potentials for use in the quality control of Asphalt pavement construction, Quintus *et al*, 2009 [2]. The ultrasonic testing of asphalt concrete is difficult because the material is viscoelastic and susceptible to temperature variation. Sarsam and Sajad, 2018 [3] stated that the ultrasonic pulse velocity increases as the asphalt content, bulk density, and volume of voids filled with asphalt VFA increase, while it decreases as the volume of voids increases. It was concluded that the ultrasonic pulse velocity increases as the Marshal stability, flow, shear and tensile strengths increases. The quality of asphalt concrete materials is often characterized by material properties such as dynamic modulus determined based on the simple performance tests, Witczak *et al*., 2002 [4]. Ultrasonic Pulse Velocity (UPV) test has been investigated by Majhi *et al*, 2016 [5] for evaluating the behavior of Hot Mix Asphalt mixtures. The effect of different mixtures parameters, including gradation, asphalt cement content, and filler contents are studied by means of UPV test and compared with experimentally derived values. It was concluded that a specific asphalt content could be determined at which the wave velocities exhibit a marked rise and after which both velocities start to decrease. Field and laboratory studies using data were estimated by Terzi *et al*, 2013 [6] to the value of Marshall Stability. Pulse, Marshall, wet density, moisture, and air void data were used as input variables. The artificial neural network (ANN) approach was implemented for estimation. Correlation values were obtained as 0.71 for the training set, and 0.75 for the testing set, respectively, for the best configurations. It was concluded that such obtained values are good, but it is not perfect. The impact of mix parameters on the UPV test was investigated by Arabani *et al*, 2012 [7]. It was concluded that for all the mixtures with different percentages of fractured particles and filler content, a specific asphalt content could be determined at which the wave velocities exhibit a marked rise and after which both velocities start to decrease. Finally, the UPV test was observed to be sensitive to the compaction method. The ultrasound pulse velocity was measured by Abo-Qudais and Suleiman, 2005 [8] on asphalt concrete specimens prepared using asphalt cement and crushed limestone at three different aggregate gradations (maximum nominal aggregate size equal to 12.5, 19.0 and 25.0 mm). The UPV measurements were performed. The collected data were analyzed for the possibility of using UPV to predict fatigue life of asphalt concrete. It was concluded that UPV was found to be higher in asphalt concrete prepared using higher sizes of aggregate.

The aim of this investigation is to model the volumetric properties of asphalt concrete with the aid of NDT. Specimens of asphalt concrete wearing, binder and base courses will be prepared and tested for volumetric properties after practicing the ultrasonic pulse velocity test. A statistical model could be obtained relating the pulse velocity with the volumetric properties.

2. Materials and methods

2.1. Asphalt Cement

Asphalt cement obtained from Dora refinery was implemented in this investigation; the physical properties of asphalt cement are listed in Table 1.

Table 1: Physical Properties of Asphalt Cement

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128)	2.610	2.631
Apparent Specific Gravity (ASTM C 127 and C 128)	2.641	2.6802
Percent Water Absorption (ASTM C 127 and C 128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	20.10	-

2.2 Coarse and Fine Aggregates
Crushed Coarse and fine aggregates have been implemented in this investigation, it was obtained from Al-Nibaee quarry, Table 2 exhibits the physical properties of aggregates.

Table 2: Physical Properties of Al-Nibaee Coarse and fine Aggregates

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128)	2.610	2.631
Apparent Specific Gravity (ASTM C 127 and C 128)	2.641	2.6802
Percent Water Absorption (ASTM C 127 and C 128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	20.10	-

2.3 Mineral Filler
The mineral filler used in this investigation is limestone dust and it was obtained from Karbala plant. The physical properties of the filler are presented in Table 3.

Table 3: Physical Properties of Filler (Limestone dust).

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

2.4 Selection of Asphalt Concrete Combined Gradation
The selected gradation in this work are according to the limitations by the SCRB, 2003 [10] for dense graded base, binder, and wearing courses, with (25, 19, and 12.5) mm nominal maximum size of aggregates respectively. Fig. 1 exhibits the implemented aggregate gradations.

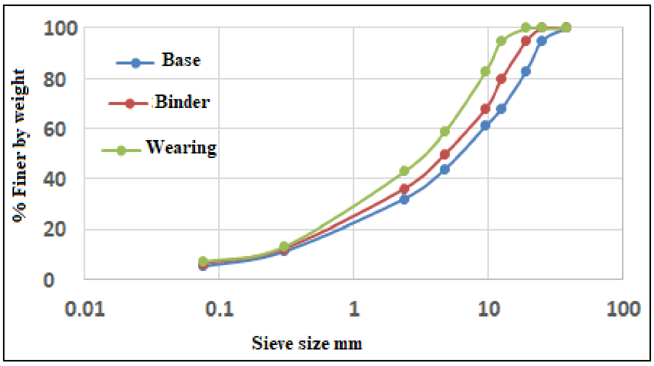


Fig 1: The implemented aggregate gradation according to SCRB, 2003

2.5 Preparation of Hot Mix Asphalt Concrete
The aggregates were dried in an oven to a constant weight at 110ºC, then sieved to different sizes, and stored separately. The required Coarse and fine aggregates were combined with mineral filler to meet the specified gradations of various asphalt concrete layers as per SCRB, 2003 [10] limitations. The combined aggregate mixture was heated to 150ºC before mixing with asphalt cement. The asphalt cement was heated to the same temperature of 150ºC, then it was added to the heated aggregate to achieve the desired amount and mixed thoroughly using mechanical mixer for two minutes until all aggregate particles were coated with thin film of asphalt cement. Marshall Size specimens were prepared in accordance with ASTM D1559, 2013 [9] using 75 blows of Marshall Hammer on each face of the specimen for binder and wearing courses specimens. On the other hand, 50 blows of Marshall Hammer on each face of the specimen was implemented for base course. Specimens with optimum asphalt content and 0.5% of asphalt above and below the optimum have been prepared for each layer. Fig. 2 shows part of the prepared specimens.

2.6 Ultrasonic Pulse Velocity Measurement
The portable ultrasonic nondestructive digital indicating tester (Pundit) was implemented in this study. The device generates and receives ultrasonic waves and has a digital display of the results. A frequency of 54 kHz and accuracy of 0.1 was implemented through this study to measure the ultrasonic pulse velocity through the specimens. The direct transmission arrangement was used in this study. The pulser and receiver were placed on opposite specimen parallel surfaces according to ASTM C597, 2013 [9]. Calibration of the pundit was done before testing to check the accuracy of the transit time measurements. Eight readings were performed and averaged for each specimen. The ultrasonic pulse velocity test apparatus is demonstrated in Fig. 3. All the prepared asphalt concrete specimens have practiced the NDT before they were subjected to Volumatic properties determination.

Fig 2: Part of the prepared specimens

Fig 3: Ultrasonic pulse velocity apparatus

2.7 Volumetric Properties Determination

The prepared asphalt concrete specimens have been subjected to volumetric properties determination according to ASTM D1559 [9]. The bulk density D (gm/cm^3), volume of voids Vv %, Voids in mineral aggregates VMA, Voids filled with asphalt VFA %, asphalt content %, filler content % and maximum theoretical density D max (gm/cm^3) were also determined.

3. Statistical Analysis and Modeling

The statistical analysis was implemented in the development of the model relating the dependent variables (ultrasonic pulse velocity) to the number of independent variables (volumetric properties). A mathematical relationship between dependent and independent variables was the goal in mind of measuring future values of those predictors and inserting them into the statistical relationship to predict future values of the target variable. It is desirable to give some measure of uncertainty for the predictions, typically a prediction interval that has some assigned level of confidence like 95%. Another task in the process is model building. Thus, a significant level of 0.05 was chosen. Model selection, fitting and validation are the basic steps of the model building process.

3.1 Identification of Dependent and Independent Variables of the Developed Model

To achieve the requirements of modeling, several variables were used. These variables are listed in Table 4.

Table 4: Independent and Dependent Variables Considered in Regression Analysis.

Independent Variables		
Abbreviation	**Description**	**Unit**
A.C	Asphalt Cement Content	%
F.C	Filler Content	%
Ca	Coarse aggregates content	%
Cu	Coefficient of uniformity	-
Cc	Coefficient of curvature	-
V. M. A	Voids in Mineral Aggregate	%
V. F. A	Voids Filed with Asphalt	%
A. V	Air Voids	%
D	Density	gm/cm^3
D max.	Maximum theoretical density	gm/cm^3
Dependent Variables		
UPV	Ultrasonic pulse velocity	mm/microseconds

3.2 Checking the Sample Size

Sample size was checked as shown in Table 5 and calculated by using equation 1, kennedy and neville, 1986 [11].

Sample Size = (Z- score) ^{2} SD (1-SD) / (significant level) ^{2}(1)

Where:

Z- score = constant value corresponding to the confidence level (for confidence level of 95%, Z-score= 1.96.

SD = standard deviation

Significant level = 0.05

Table 5: Sample size for the model.

Dependent variable	Standard deviation	Number of specimens N	Required sample size N
Ultrasonic pulse velocity (mm/microsecond)	0.123622	99	58

3.3 Checking for Outliers

The experimental work includes collecting the data and distribution of the data in group concentrated within limited margin calculated from the frequency of the data. Sometimes, due to testing mistakes or other abnormal condition, a data set is considered as extreme or outliers by checking those extreme values using Chauvinist's criterion and absolute tabulated sample size value as in Table 6. It was noticed that all tabulated values are more than the test results, thus, there are no outliers. To eliminate the data for modeling purposes to increase the R^2, the standardized residuals are removed from data matrix. The standardized residuals are an indication of how the residuals are large in the standard deviation units, and it is equal to the observed minus the estimated value and divided by the standard deviation. In the case of nonlinear regression, the residuals of high absolute value are removed resulted from observed minus estimated values, Montgomery and Peck, 2009 [12].

Table 6: Chauvinist's test

Ultrasonic pulse velocity	N	Min.	Mean	Max.	S. D.	| (min. - mean)/s|	|(max. - mean)/s|	Tabulated
	99	3.544	3.805	4.059	0.123	2.116	2.055	2.802

3.4 Testing of Normality

Kolmogorov Smirnov (K-S) and Shapiro Wilk test were used to check the distribution of variables and to develop a model. Herrin *et al*, 1995 [13] stated that the K-S statistics D is based upon the maximum distance between F (y) and F n (y); that is equation 2. Table 7. Show the result of normality checking of the model.

D = max. [F(y) – Fn (y)] ………… (2)

Where:

F(y) = Normal cumulative probabilities (From normal distribution table)

Fn (y) = Sample cumulative distribution function.

Table 7: Result of One Sample K-S Test to the model

		UPV mm/microsec	% Asphalt.	% Filler	coefficient of uniformity Cu	coefficient of curvature Cc	density	% Vv	% VMA	% VFA	% of aggregate.	D max.
N		99	99	99	99	99	99	99	99	99	99	99
Normal Parameters	Mean	3.805	4.6235	5.93	28.5241	2.6884	2.285	6.56	17.08	62.6	95.5842	2.446
	Std. Deviation	.1236	.63226	.830	8.61556	1.04040	.0591	2.55	2.239	9.94	.57846	.0110
Most Extreme Differences	Absolute	.079	.128	.245	.379	.417	.138	.121	.153	.108	.129	.265
	Positive	.079	.088	.245	.241	.417	.138	.121	.115	.108	.129	.246
	Negative	-.063	-.128	-.212	-.379	-.243	-.112	-.107	-.153	-.086	-.089	-.265
Test Statistic		.079	.128	.245	.379	.417	.138	.121	.153	.108	.129	.265
Kolmogorov-Smirnov Z		1.109	1.508	3.71	5.499	6.354	5.103	5.06	4.972	4.60	1.519	3.719
Asymp. Sig. (2-tailed)		.129c	.000c	.000c	.000c	.000c	.000c	.001c	.000c	.006c	.000c	.000c

a. Test distribution is Normal. b. Calculated from data. c. Lilliefors Significance Correction

3.5 Multicollinearity

SPSS software version (22) is employed to find the correlation between independent variables with one another using Multicollinearity (collinearity and intercorrelation). A statistical procedure using stepwise regression technique was implemented. The independent variables are eliminated according to the significant contribution of X variable on the produced model. The process is repeated with each variable until significant predictor variable remained and the insignificant ones are removed. This Would suggest that those variables with high inter correlation may be eliminated according to the decision to add or remove a variable to improve the model; at that Point, interactions among the variables are considered. A correlation matrix is produced to determine the correlation coefficients for the Variables.

3.6 Model Adequacy Assessment

There are two approaches generally used to assess the adequacy of the proposed regression models, the first one is based on examining goodness of fit measures, whereas the second approach is based on the graphical analysis of the residuals, also called diagnostic plots.

3.7 Goodness of Fit Measures

The measures of goodness of fit are aimed to quantify how well the proposed regression model obtained fit the data. The two measures that are usually presented are coefficient of multiple determinations (R^2) and standard error of regression (SER), Kennedy and Neville, 1986 [11]. The R^2 value is the percent variation of the criterion variable explained by the suggested model. It was calculated according to following equation 3.

$R^2 = 1 – SSE/ SST$……………………………. (3)

Where SSE is the error sum of squares

SST is the total sum of squares

R^2 is bounded between 0 and 1; the higher the value of R^2, the more successful is the regression model in explaining y variation. If R^2 is small, an analyst will usually want to search for nonlinear model that can more effectively explain y variation. Because R^2 is always increases as a new variable is added to the set of the predictor variables and in order to balance the cost of using more parameters against the gain in R^2, many statisticians use the adjusted coefficient of multiple determinations, which is calculated using equation (4).

$AdjR^2=1-(n-1)/(n-(k+1)) \quad (SSE/SST)$ …………………………… (4)

where n is the sample size

k is the total number of the predictor variables

Adjusted R^2 adjusts the proportion of unexplained variation upward, which results in adj $R^2 < R^2$. The second measure is the standard error of regression (SER), it is calculated according to the following equation (5).

$SER=\sqrt{SSE/(n-(k+1)}$ ……………………………………… (5)

The divisor n-(k+1) in the above equation is the number of degrees of freedom (df) associated with the estimate of SER. In general, the smaller the SER value, the better the proposed regression model.

3.8 Predictive Model

Examination of the diagnostic plots presented for the model for nonlinear regression indicates the tendency of the developed model to underestimate the low model values and to overestimate the model values in the high range.

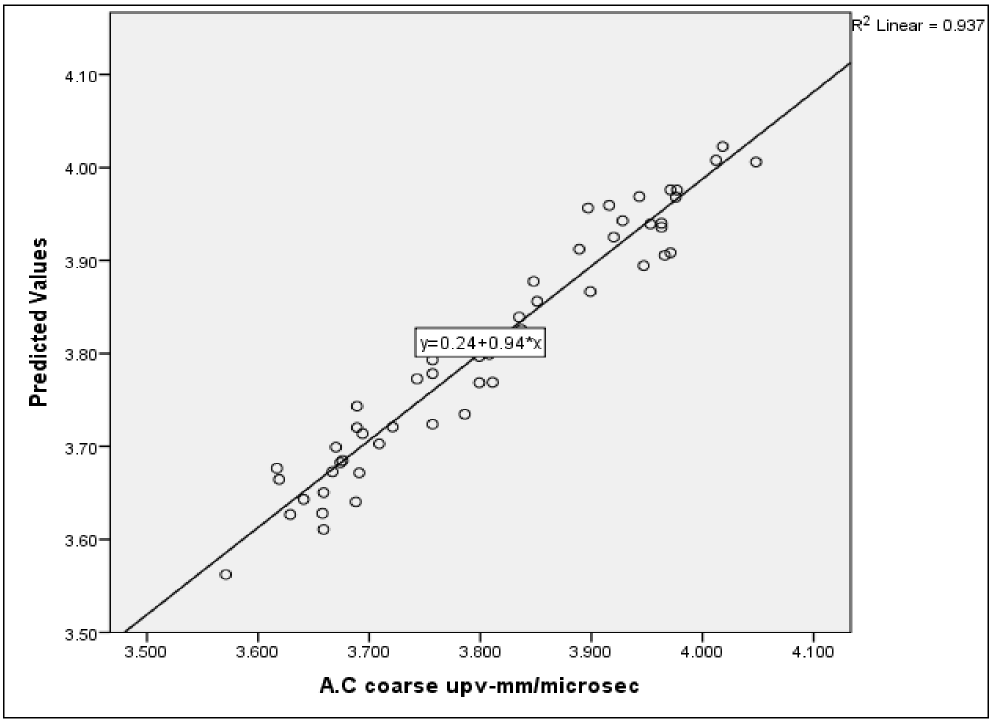
Moreover, the predictive model produces negative values. Nonlinear relations are examined for Fig. 4. Results of the obtained stepwise regression analysis are presented in Table 8. The obtained R^2 value is high and the standard errors of estimate is low. This is not the only reason; the almost nil difference in R^2 and standard error of Estimate is considered another good reason to the use of nonlinear.

Table 8: Statistical Summary for nonlinear regression Model

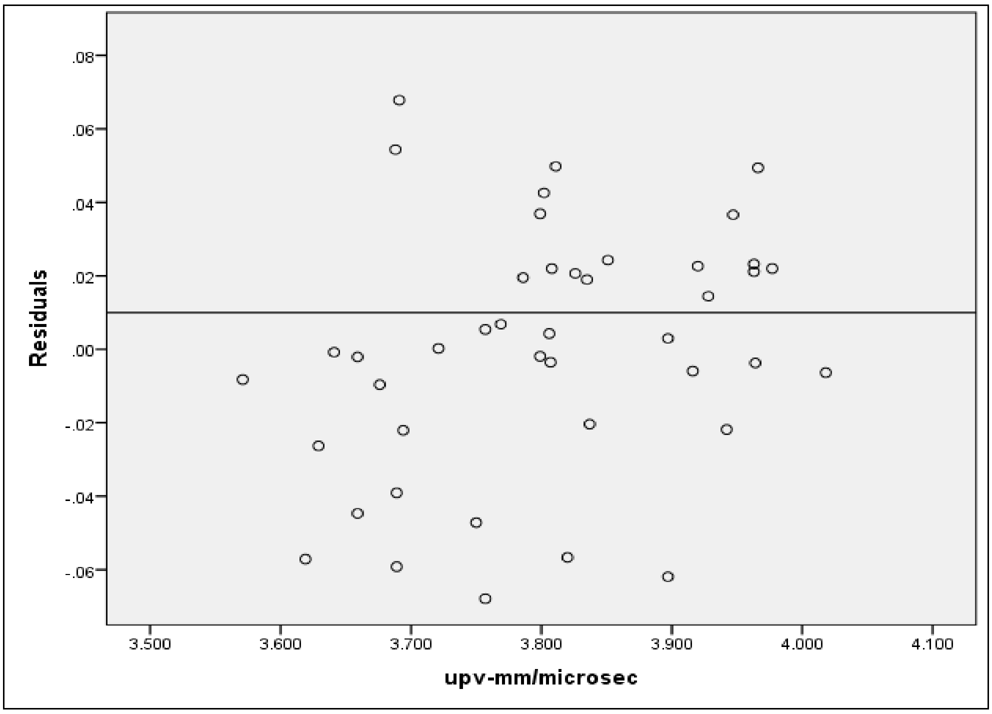
Model No.	Explained Variation (R^2)	Standard Error (SE)
Ultrasonic pulse velocity	*0.937*	0.031

4. Stepwise Regression model

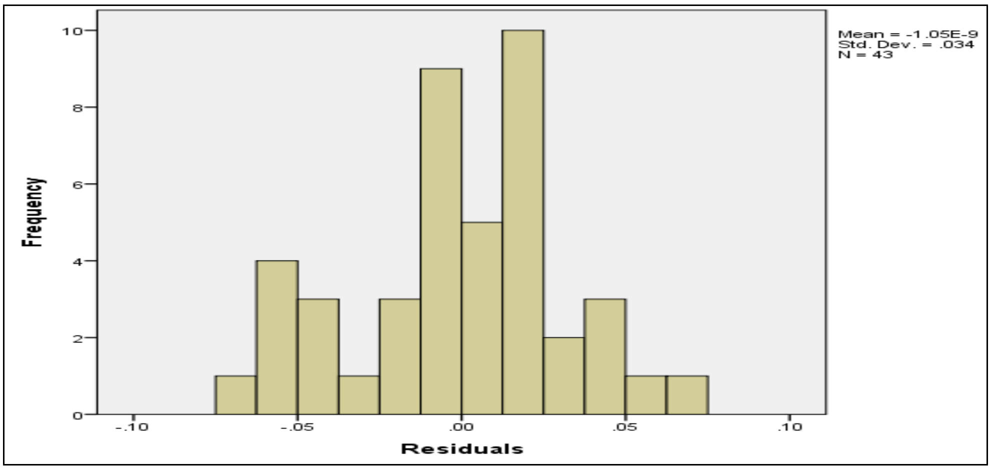
The best and commonly method used to determine parameter of prediction model is stepwise method, Kennedy and neville, 1986. This method computes the simple regression model for each independent variable. The independent variable is with the largest F-statistic, in other words, the smallest p-value is chosen as the first entering variable. SPSS software uses the F-statistics and the standard is usually set at F=3.8, which is chosen because the significant level is about 5 %. Tables 9 show the Coefficients and summary of stepwise regression for the model.



Plot a: UPV, predicted vs measured



Plot b: UPV, residual vs measured



Plot c: UPV residual vs measured

Fig 4: diagnostic plots for nonlinear model

Table 9: Coefficients

Model	Unsta dardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Loner Bound	Upper Bound
3(Constant)	15.318	2.800		5.471	.000	9.760	20.876
D Max	-4.644	1.138	-.415	-4.079	.000	-6.903	-2.384
A. C % coarse	-.124	.033	-.634	-3.808	.000	-.189	-059
Filler Content	.071	.024	.476	2.954	.004	.023	.118

A Ilanantlant Vsrishlaw A *r* MAMA i I PV-mmirnirrngarAntba

4.1 Error analysis

For nonlinear model goodness, the homoscedasticity hypothesis assumes that the error is with constant variance, the standardized residual scatter plot as solve the problem, and by setting the estimated values of dependent variable on x axis and plotting the difference of observed value and theoretical value on y axis which is standardized residual, we can decide the goodness of the model. The pattern plots as demonstrated in Fig. 5 is satisfactory and the residuals are randomly distributed.

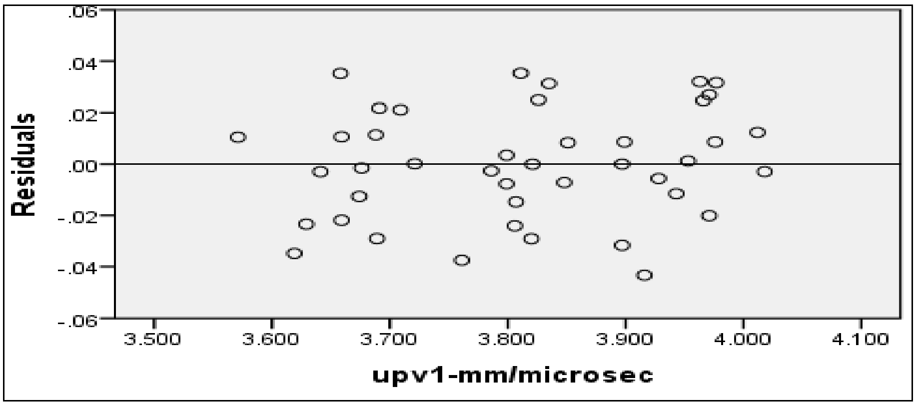


Fig 5: Scatter plot of Standardized Residual

4.2 Variance analyses of ANOVA test

To check the significant differences of the independent variable mean, the ANOVA is applied by F-test. The F -test called the test of linearity which is determined by a straight line the deviations of means. Table 10 shows the ANOVA test for the model. The results show statistically significant relation since the p-value is less than 0.05, thus the overall variables used in regression (independent variables) are effective on the dependent variable. By comparing the F ratio value with critical value from relative frequency distribution, the significances of results could be decided.

Table 10: ANOVA table for the model

Source	Weighted Sum of Squares	df	Weighted Mean Squares
Regression	2335.546	31	75.340
Residual	.072	11	.007
Uncorrected Total	2335.619	42	
Corrected Total	2.486	41	

Dependent variable: A.C coarse UPV-mm/microseconds a

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =. 971.

4.3 Checking of R-critical

A high correlation coefficient R value does not guarantee that the model fits the data well. The correlation between x and y is considered significant at the given probability level when the calculated R exceeds the tabulated R value. Table 11 demonstrates the calculated and tabulated R- value.

Table 11: Tabulated R-values for the model

Dependent	N.	R-calculated	R-tabulated
Ultrasonic pulse velocity	99	*0.937*	0.196

4.4 Model Limitation

The limitation of the data used to establish the model is presented in Table 12. The intention of the limitation is not to suggest that the modeling effort has not been successful. It merely serves to alert of the limitations of the data. Table 13 exhibits the developed model.

Table 12: The Intention of the limitation

Model	Maximum	Minimum	Mean
Ultrasonic pulse velocity (mm/microseconds)	2.74	1.88	2.297

Table 13: The Developed Model

Dependent variable	Developed model
Ultrasonic pulse velocity	$249 + 0.17\ A.C^3 - 15.8\ F.C^2 - 30.6\ Vv + 0.84\ V.M.\ A^2 + 0.181\ V.\ F.\ A + 75.9\ D\ max^3$

4.5 Measured and Predicted data for the Model

Fig. 6 shows the predicted vs. measured data for dependent variable, the model is considered good because of the small variance of the points measured as compared with predicted values. Table 14 shows the statistics of the model data.

Table 14: Model Statistics

Variable	N	Std. deviation	Min.	Max.	mean	R^2	SEE
Ultrasonic pulse velocity	99	0.118	3.55	4.03	3.815	*0.937*	0.031

4.6 Validation of the Developed Model

The graphic plotting of observed and estimated data is a most useful method of evaluating the overall performance of a regression equation. If the point which result from the plot of estimated with observed data tend to stand nearby the line drawn at 45º, then the result model is considered satisfactory. This can be done by data splitting in to two sets. 70% of data are used to build the models and 30% of it is used for the validation process. Fig. 7 show the resulting plot.

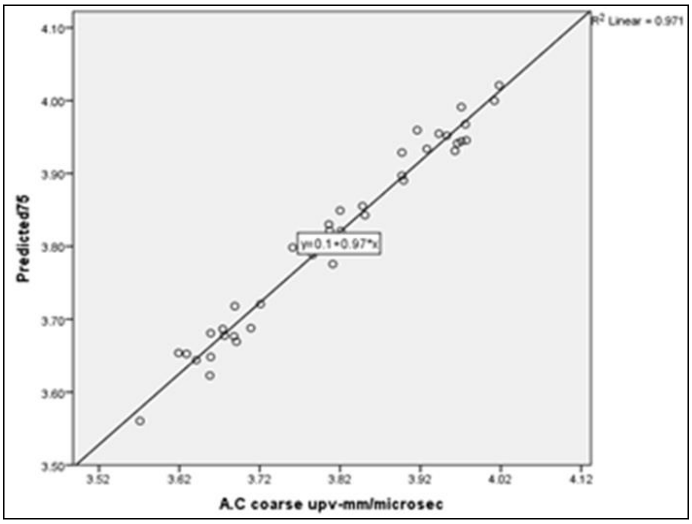


Fig 6: Scatter plot for predicted and observed values

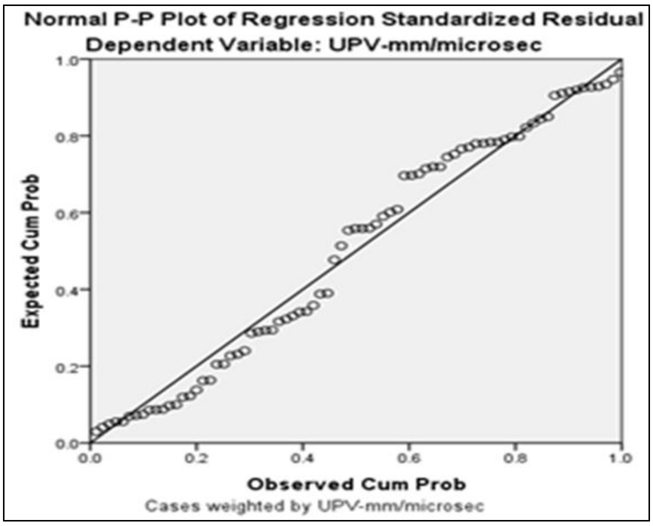


Fig 7: Estimated Value of the Model

5. Conclusions

Based on the limitations of the testing program, the following conclusions can be drawn.

1- The developed nonlinear statistical model can explain 93.7 % of the variations in ultrasonic pulse velocity among various volumetric properties of asphalt concrete.

2- The Filler content, the volume of voids and maximum theoretical Density exhibit high significant influence on ultrasonic pulse velocity among other studied parameters.

3- Such modeling is considered as a sustainable issue in predicting the volumetric properties of asphalt concrete, it can limit the testing requirements, time and cost of quality control.

6. References

1. Jiang Z. Innovative nondestructive testing (NDT) for condition assessment of longitudinal joints in asphalt pavements. MSc Thesis, University of Waterloo, Ontario, Canada, 2007.
2. Quintus H, Rao C, Minchin R, Nazarian S, Maser K, Prowell B. *et al* NDT Technology for quality assurance of HMA pavement construction. NCHRP Report 626, 2009.
3. Sarsam SI, Kadium NS. Feasibility of Using Pulse Velocity to Evaluate Asphalt Concrete Properties. Journal of Advances in Civil Engineering and Construction Materials. 2018; 1(1):51-63.
4. Witczak MW, Kaloush K, Pellinen T, El-Basyouny M, Von Quintus H. Simple Performance Test for Superpave Mix Design, NCHRP Report 465, Transport Research Board, Washington DC, 2002.
5. Majhi D, Karmakar S, Roy T. Reliability of ultrasonic pulse velocity method for determining dynamic modulus of asphalt mixtures. ICEMS 2016, Materials Today: Proceedings 4, 2017, 9709-9712.
6. Terzi S, Karasahin M, Gokova S, Tahta M, Morova N, Uzun I. *et al* Asphalt concrete stability estimation from nondestructive test methods with artificial neural networks. Neural Computing & Applications. 2013; 23(3-4):989-997.

7. Arabani M, Kheiry P, Ferdowsi B. Use of ultrasonic pulse velocity (UPV) for assessment of HMA mixtures behavior. IJST, Transactions of Civil Engineering. 2012; 36(C1):111-114.
8. Abo-Qudais S, Suleiman A. Monitoring fatigue damage and crack healing by ultrasound wave velocity. Nondestructive Testing and Evaluation. 2005; 20(2):125-145.
9. ASTM, Road and Paving Materials, Annual Book of ASTM Standards, Volume 04.03, Standard test method for pulse velocity through concrete. ASTM C597-09, American Society for Testing and Materials, West Conshohocken, USA, 2013.
10. State Commission of Roads and Bridges SCRB, Standard Specification for Roads & Bridges, Ministry of Housing & Construction, Iraq, 2003.
11. Kennedy j Neville. Basic statistical methods for engineers and scientists, JW &Son, third edition, 1986.
12. Montgomery DC, Peck EA. Introduction to Linear Regression Analysis, 2nd Edition, John Wiley & Sons, Inc., New York, 2009.
13. Herrin GD, Scheaffer R, McClave JT. Probability and Statistics for Engineers. The American statistician, Vol.49 No.2, 1995, P.238. https://citationsy.com/archives/q?doi=10.2307/2684651.