Prediction Models for Modified Pavement Mixtures by Reclaimed Asphalt in Terms of Durability Indicators

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Abstract. The asphaltic pavement is often subjected to various types of distress during the service life caused by excessive load, construction practices, deficient materials, and environmental conditions. A lot of pavements may occur due to moisture damage because of the presence of water on the pavement's surface, which affects the pavement's service life. It needs periodic maintenance, which requires materials and money. So many countries take the economic side by reusing old, damaged pavement and mixed with new materials in addition to its sustainable benefits, the old material called reclaimed asphalt pavement (RAP). This study examines the effect of adding RAP on durability indicators, including tensile strength ratio, retained Marshall Stability, and durability Index, in addition to prediction statistical models for reclaimed asphalt pavement mixtures in terms of durability indicators. To achieve the goals of this study, the asphalt mixtures are designed according to the superpave system; the samples are compacted by a superpave gyratory compactor with a diameter of 100 mm and prepared with (6%, 13%, 19%, and 25%) RAP content with three conditioning periods of (1, 3, and 7) days and two aging periods (short term aging for loose mixture at 135˚C for 4 hours long term aging for 120 hours at 85˚C), and two testing temperature of 25˚C and 60˚C. The results indicated that stability increased as the RAP content increased compared to the control mix, and indirect tensile strength increased with RAP addition for both aging periods. Also, results illustrated that the tensile strength ratio for specimens tested at 25˚C is higher than that tested at 60˚C temperature.

Keywords: Reclaimed asphalt; hot asphalt mixtures; Durability; Moisture damage; Statistical modeling

1. INTRODUCTION

Recently, the vehicle’s number increased dramatically [1]. This increasing load axle has led to rapid deterioration of road surfaces, especially with the lack of periodic maintenance work [2,3]. Therefore, there is an urgent need to find a solution to the flexible pavement’s distresses [4]. These distresses of a pavement system are affected by many factors that are either traffic or non-traffic-associated [5]. Such factors include loads, stress, environmental conditions, deficient materials, construction methods, and maintenance [6]. However, one of solutions is to improve the asphalt mixture to enhance its properties to resist the extra tire loads in addition to weather conditions [7]. Several additives and modifiers have been investigated in asphalt production to improve its properties over the past years [8,9]. However, alternative materials like reclaimed asphalt are considered less expensive and environmentally beneficial [10,13]. And thus serve the sustainability that the world is heading towards today [14].

Huang [6] stated that three major traffic-associated failure modes are permanent deformation, fatigue cracking, and thermal cracking [6]. Accordingly, moisture damage is another cause of pavement failure. It should be minimized as possible, and due to pavement failure, it needs periodic maintenance and required materials, which required high costs, so recycling old pavement and reusing it for the maintenance of existing pavement is required. The past uses of RAP and rubberized asphalt have proven to be economical, environmentally sound, and effective in hot mix asphalt (HMA) mixtures across the USA and the world [15]. Many studies on recycled mixtures focus on their performance and resistance to moisture damage. Tabakovic et al. indicated that addition (10, 20, and 30%) of RAP decreases water sensitivity [16]. Rodrigo Miró et al. prepared four mixtures of RAP with (0, 15, 30 and 50%), with low penetration virgin bitumen. They evaluated moisture sensitivity (TSR) values and investigated that TSR dropped with increasing RAP content to above 80% [17].

Karim et al. [18] studied the effect of two different compaction temperatures of RAP on indirect tensile strength ratio (TSR) with four RAP contents of (20, 30, 40, and 50%). The results indicated that adding RAP to mixes significantly increases moisture damage resistance (TSR) for all percent at 110˚C. In contrast (TSR) increased to the threshold at 20% RAP and declined for another percent but was still above the standard limit at 140˚C [18]. Statistically, many studies have been implemented on statistical pavement performance analysis for recycled mixtures. McLean [16] compared general trends in performance and response associated with virgin and RAP mixes. Statistical results suggest that in most cases, RAP mix is statistically equivalent to virgin HMA mixes when comparing the performance indicators used in this study [16]. Hamdou et al. [20] used numerous statistical techniques to characterize the distress response of asphalt concrete materials due to repeated load applications for wearing course asphalt concrete after a short-term aging mixture [20]. Fattah et al. [21] developed a statistical prediction model using the SPSS software for the distress of moisture sensitivity and fatigue cracking, with different asphalt content, air-void content, aging, and temperatures as categorical variables having three, two, and three levels, respectively, analysis of variance was employed to establish the significance of both main effects and two-factor interactions on the three dependent variables [21].

The current work aims to explore the effect of adding RAP by various percentages on durability indicators of asphaltic mixture, including tensile strength ratio, retained Marshall Stability, and durability Index, in addition to prediction statistical models for reclaimed asphalt pavement mixtures in terms of durability indicators.

2. MATERIALS AND MIX DESIGN

Available local materials were used in this research, including two types of asphalt binder (40-50) and (60-70) obtained from Al-Daurah refinery in Baghdad city. The aggregate was obtained from Al-Nibaie quarry, the mineral filler (limestone dust) was obtained from the local market in Karbala, and all materials were tested according to SCRB/R9 [22]. RAP material was obtained from the stoke of reclaimed asphalt for the Mayoralty of Baghdad project office at Al-Talbia-region in Baghdad city, and an extraction test was performed to extract the asphalt from aggregate and investigate the aggregate gradation of the RAP, as presented in Figure 1. The asphalt content in RAP was 4%. A superpave mix design system was adopted with varying volumetric positions. The maximum size of aggregate of 25 mm was used in this research, as shown in Figure 2. The design asphalt contents for both asphalt grades (40-50) and (60-70) were determined as 4.4% and 4.21%, respectively, at the design aggregate structure. RAP material was added to the mix in proportions of 6, 13, 19, and 25%. The design of the mixture was according to AASHTO M323 [23]. Trail gradation blends and RAP gradation are presented in Figures 1 and 2, respectively.

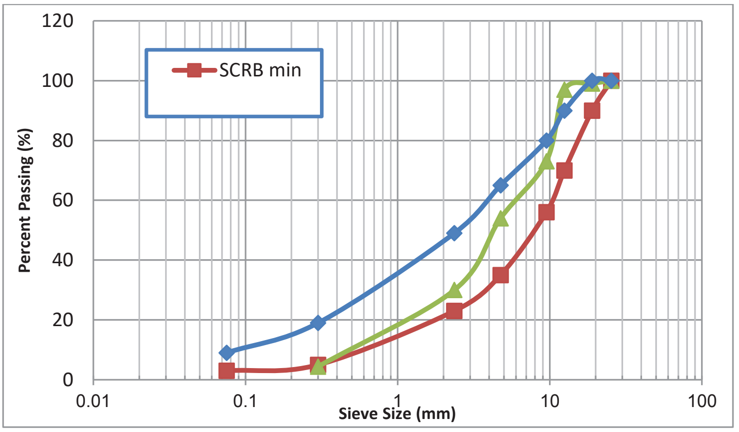


Figure 1: RAP gradation with specification limits.

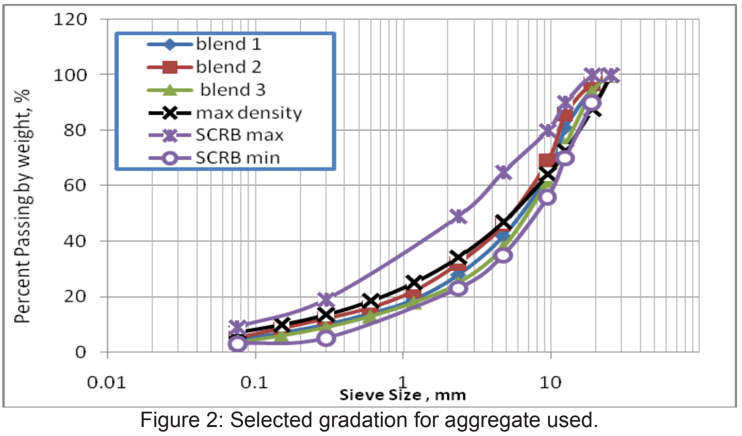
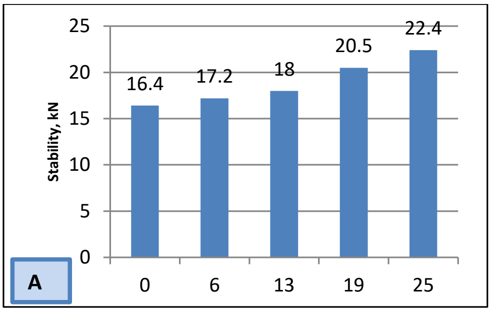


Figure 2: Selected gradation for aggregate used.

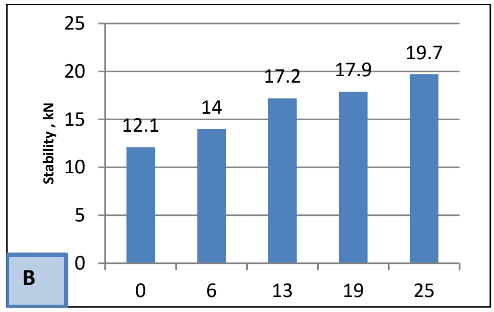
3. RESULTS AND DISCUSSIONS

3.1 Marshall Properties

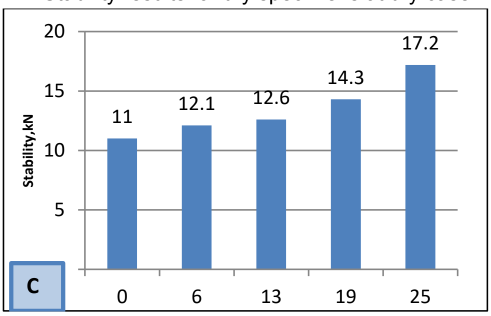
The stability results are presented in Figure 3; the results showed that the stability increased with increasing RAP contents gradually. As immersion time increases from one to seven days, the stability of the mix decreases. For example, the stability for 6% RAP content reduced by (22.8, 41.8, and 109.7%) from dry to (1, 3, and 7) immersion days, respectively.



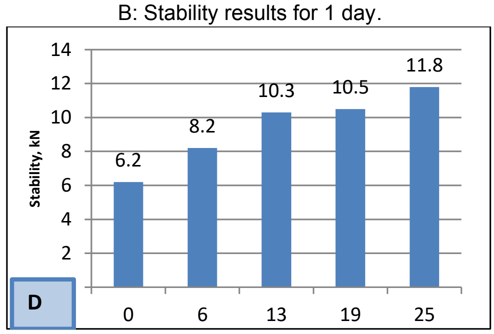
A: Stability results for dry specimens at dry case.



B: Stability results for 1 day.



C: Stability results for 3 days.



D: Stability results for 7 days.

Figure 3: Retained Marshall stability of tested specimens at dry and immersion with RAP percent.

3.2 Index of Retained Strength Test Results

The specified limit for resistance to water effect is 75%. Any mixture with a value less than 75% will be considered a moisture susceptible mixture. The results for retained Marshall Stability are shown in Table 1, which presents that the resistance increases with increasing RAP contents and decreases with increased immersion time.

Table 1: Retained Marshall Stability with immersion days.

Mixes with percent RAP, %	RMS for 1 day	RMS for 3 days	RMS for 7 days
0	73.8	67.1	38
6	81.4	70.3	48
13	95.5	70	57.2
19	87.3	70.6	51.2
25	88	77	52.7

3.3 Durability Index Test Results

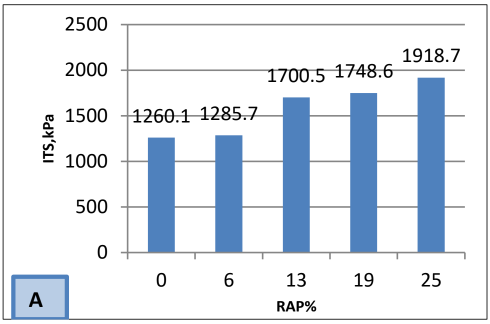
The durability results are derived from retained Marshall Stability depending on measuring the area code enclosed between two lines. Table 2 shows the results. The durability index decreases with RAP increases except that 19% RAP increased and then decreased at 25% RAP, lower than 13% RAP.

Table 2: Durability index with RAP contents.

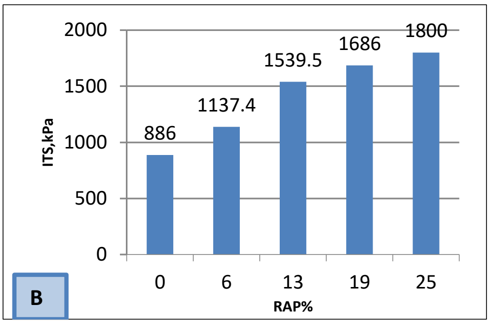
Area code	Immersion periods, days	RAP Content, %				
		0	6	13	19	25
A1	0 to1	24.3	17.3	4.18	11.8	11.14
A2	1 to 3	4.78	7.93	18.2	12.4	7.8
A3	3 to 7	8.3	6.4	3.7	5.4	6.9
	Total durability index, %	37.4	31.63	26.03	29.6	25.8

3.4 Effect of Aging Time on Indirect Tensile Strength

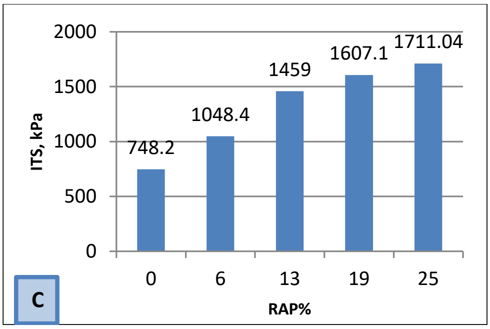
In this study, the aging was divided into two sequence processes. The first one consists of aging the loss mix in an oven for 4 hours at 135˚C, and that is called short-term aging (STA). The second process is applied after compaction, which is the long-term aging at 85˚C for 5 days (120 hours). The results are shown in Figures 4 to 7. For the comparison of all listed figures, the unconditioned specimens at 25 ˚C, an increase in tensile strength by (5, 32, 20.1, 23.5, 37.6) % for (0, 6, 13, 19, 25) % RAP contents, respectively in comparison between L.T.A and S.T.A factors. for specimens conditioned for 1 day, the ITS for long term aging specimens is higher than short term aging by (29.9, 27.9, 33.7, 14.7, 19.2) % for (0, 6, 13, 19, 25) % RAP contents respectively.



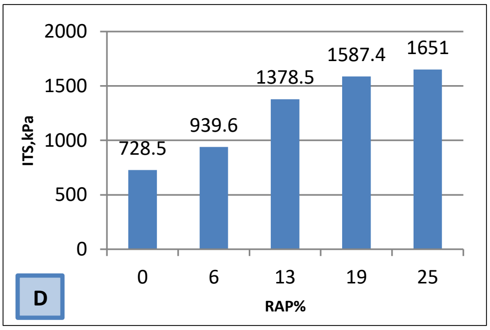
Indirect tensile strength for dry specimens.



Indirect tensile strength for 1 day.

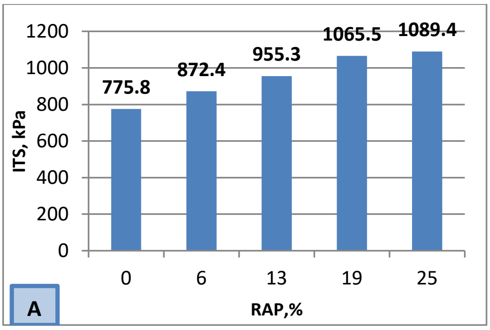


Indirect tensile strength for 3 days.

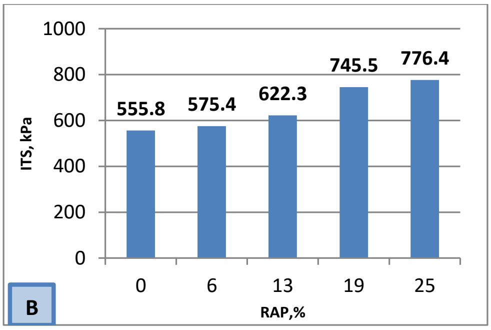


Indirect tensile strength for 7 days.

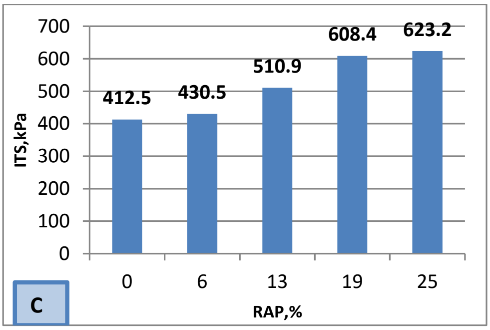
Figure 4: Indirect tensile strength of tested specimens for short-term aging at 25˚C.



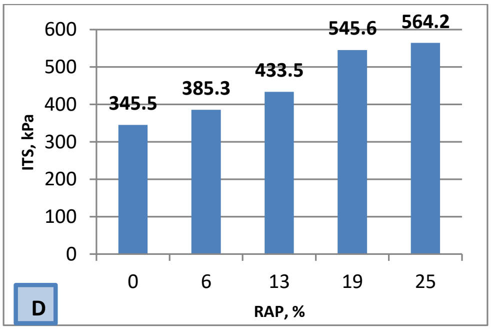
Indirect tensile strength for dry specimens.



Indirect tensile strength for 1 day.

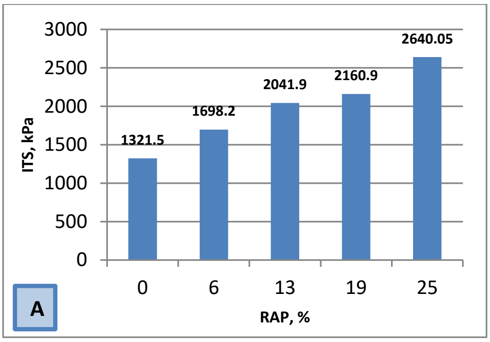


Indirect tensile strength for 3 days.

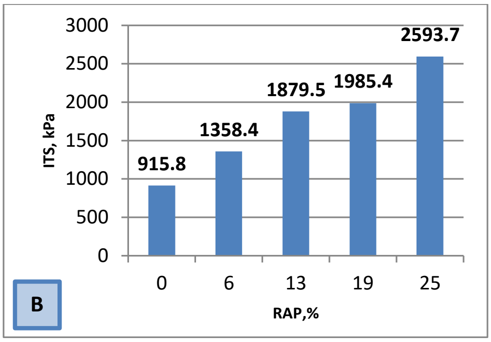


Indirect tensile strength for 7 days.

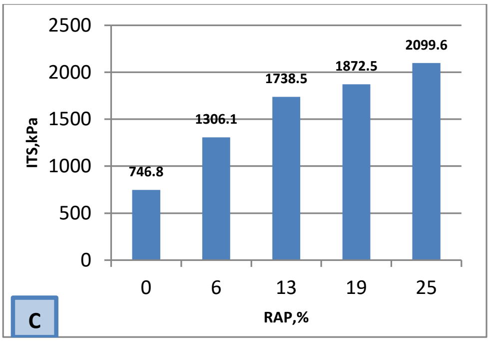
Figure 5: Indirect tensile strength of tested specimens for short-term aging at 60˚C.



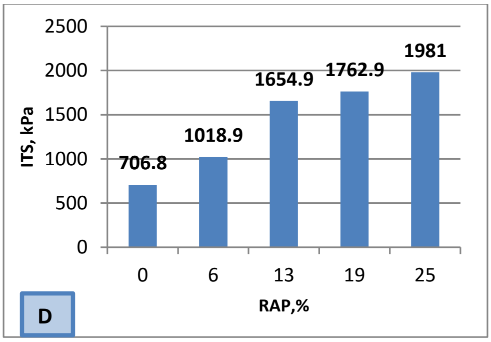
Indirect tensile strength for dry specimens.



Indirect tensile strength for 1 day.

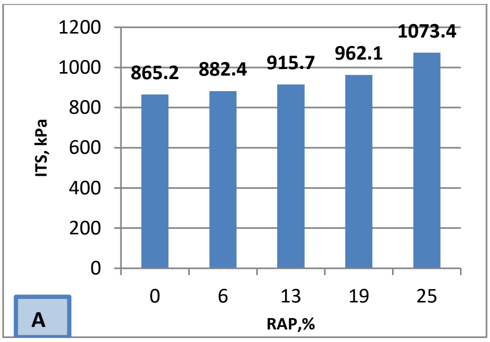


Indirect tensile strength for 3 days.

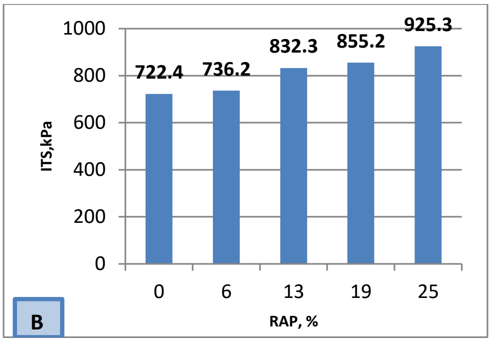


Indirect tensile strength for 7 days.

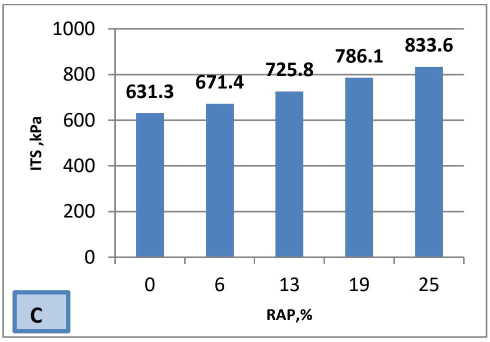
Figure 6: Indirect tensile strength of tested specimens for long-term aging at 25˚C.



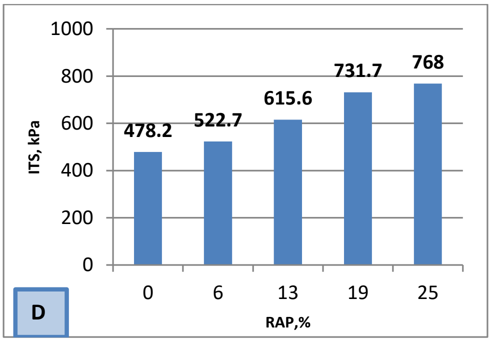
Indirect tensile strength for dry specimens.



Indirect tensile strength for 1 day.



Indirect tensile strength for 3 days.



Indirect tensile strength for 7 days.

Figure 7: Indirect tensile strength of tested specimens for long-term aging at 60˚C.

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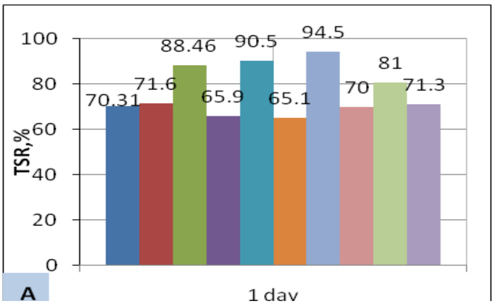
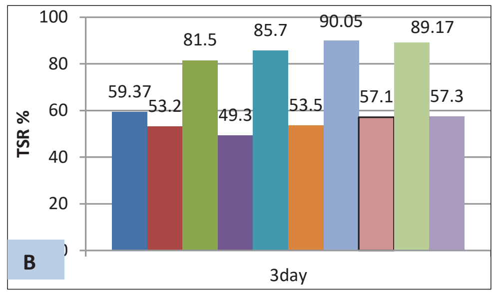
3.5 Indirect Tensile Strength Ratio with Aging Factors Results

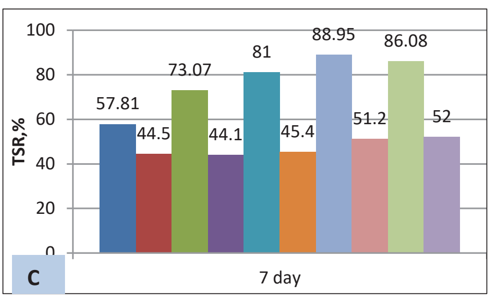
The acceptable range for TSR% is 80%; mixtures have TSR value less than 80% are considered susceptible to water effect. Figures 8 and 9 present the results for TSR% with immersion days at 25˚, and 60˚C for virgin and RAP mixes which had aged for STA and LTA periods. The TSR% decreases as immersion time increases due to the effect of water. For STA specimens, mixtures containing 6, 13, 19, and 25% RAP show good resistance to water action when tested at 25˚C. When conditioned for 1 day, LTA specimens have good resistance to water action compared to other immersion times.



Tensile strength ratio for 1 day.



Tensile strength ratio for 3 days.



Tensile strength ratio for 7 days.

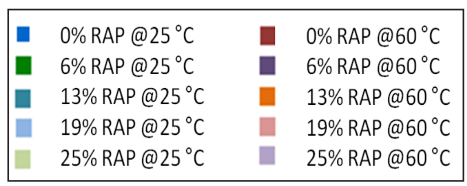
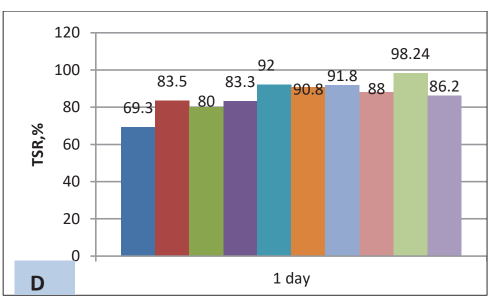
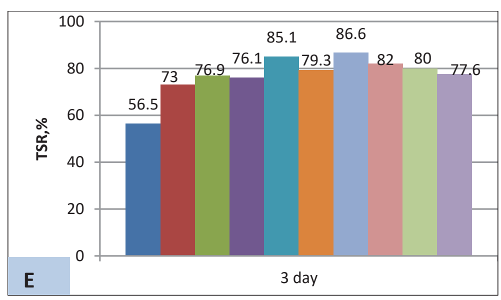


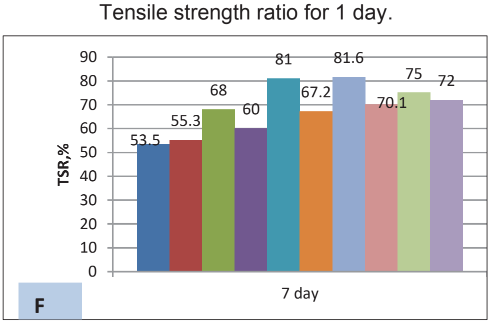
Figure 8: Tensile strength ratio or short-term aging specimens at 25˚C and 60˚C.



Tensile strength ratio for 1 day.



Tensile strength ratio for 3 days.



Tensile strength ratio for 7 days.

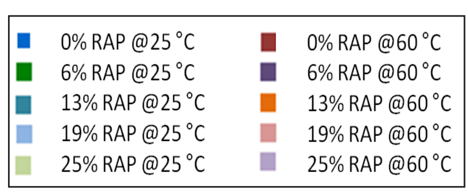


Figure 9: Tensile strength ratio or long-term aging specimens at 25˚C and 60˚C.

4. STATISTICAL MODELS

The statistical techniques were used to build models for durability indicators, including retained Marshall Stability, durability index and tensile strength ratio, and indirect tensile strength. Data results were analyzed by linear regression analysis, which explains the relationship between two or more variables. The basic assumptions to develop the best model confidence level are:

- High intercorrelation does not exist among predictor variables.
- Influential observations or outliers do not exist in the data.
- The distribution of error is normal.
- The mean of the error distribution is zero.

To achieve the desired objective, the selected model should have the highest adjusted coefficient of determination (R2), which is the square of the correlation coefficient (R) and adapts the variation ratio in the response variable illustrated by the regression model. Its value is limited between 0 and 1. The lowest mean square error (MSE), for given data. The relation between dependent and independent variables for all data included in this study is shown below:

$$\mathrm{RS} = 70.96 - 4.18\mathrm{P} - .08\mathrm{R} - 10.62\mathrm{AC} + 1.24\mathrm{S} \quad (1)$$
$$\mathrm{DI} = 39.59 - .19\mathrm{P} - .49\mathrm{R} + 8.00\mathrm{AC} - .004\mathrm{S} - .041\mathrm{RS} \quad (2)$$
$$\mathrm{TS} = 583.52 + 44.70\mathrm{R} - 43.92\mathrm{P} - .525\mathrm{AG} + 323.22\mathrm{AC} - 29.06\mathrm{T} \quad (3)$$
$$\mathrm{TSR} = 26.93 - .089\mathrm{R} - 3.061\mathrm{P} - .024\mathrm{AG} + .248\,\mathrm{T} + .023\,\mathrm{TS} + 6.68\mathrm{AC} \quad (4)$$

Where:
RS: Retained Marshall Stability, (%), DI: Durability Index, TS: Indirect Tensile Strength, (kPa) TSR: Tensile strength Ratio (%), P: conditioning Period(day), R: RAP content (%), AC: Asphalt content, S: Stability (kN), AG: Aging time, T: Testing temperature(˚C).

It is observed from mentioned equations above that there is a good correlation between independent and dependent variables, for retained Marshall Stability (RS) model, the coefficient of determination (R^2) is (88.2%) and the standard error of regression (SER) is (6.306%). While the (R^2) and (SER) for Durability index model (DI), Tensile strength model (TS), and Tensile Strength Ratio model (TSR) are (80%, 2.22%), (86.4%, 211.5%), and (71.4%, 9.57%) respectively. The models have higher R^2, proving that a regression model is a good fit for data and indicates that the independent variables have played a significant role in the developed model.

5. CONCLUSIONS

Within the data obtained from laboratory tests and assumptions, the following conclusions are drawn:

- Based on tensile strength and tensile strength ratio test results, statistical models are developed to predict the influence factors of local asphalt concrete binder course after short and long-term aging mixtures for different testing conditions and mix properties designed according to Superpave systems using statistical techniques. It can be seen in described equations 8 and 9. At the same time, statistical models for retained stability and durability index are described in equations 6 and 7. The values of R^2 give an indication that the independent variables have played a significant role in the dependent variables constituting the predicted models.
- The addition of RAP material has improved the performance of asphalt pavement mixtures in the presence of moisture and aging techniques, while low contents of RAP show a sensitive behavior to moisture effect, especially at 60˚C than 25˚C for example, addition (6% RAP) percent has a TSR of (88.5%) at 25˚C and (66%) at 60˚C.
- Higher RAP contents have improved the stability of submerged specimens in water for (1, 3, 7) days than low RAP contents.
- As the conditioning time increases, the resistance to moisture decreases due to the effect of water, and the seven days of conditioning time severely affects specimens' resistance. For example, (13% RAP) specimens aged for a long aging time and tested at 25˚C, and the tensile strength ratio decreased by (8.1%) from 1to 3days and (13.5%) from 1 to 7 days.
- The index of retained strength RS based on Marshall stability increased with increasing RAP percent and showed good resistance to water action. It is increased by (67.1, 70.3, 70, 70.6, and 77) % for 3 days and increased by (38, 48, 57.2, 51.2, and 52.7) % for 7 days for (0, 6, 13, 19, and 25) % RAP contents respectively.
- Adding RAP materials to the asphalt pavement mixtures has improved the performance of the mixtures more than the control mix. The results showed that better results were achieved at 25 % RAP addition.

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