Predicting Stability and Flow Properties of Hot Mix Asphalt using Field and Laboratory Tests in Wasit Governorate

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ABSTRACT

The Mechanical Marshall test and statistical analysis have been used to examine pavement site measurements extracted from 43 cores of the Kute-Badra asphalt road section. The study included a theoretical and a practical aspect, and was based on the practical aspect of the Marshall Test. A carrying device was used to perform laboratory tests on hot asphalt samples, and the results were compared with the indices of Iraqi specifications for the largest value for stability and flow. It was found that the hot asphalt mixture matches the Iraqi and international.

Keywords-stability; flow; hot mix asphalt; Marshall test; field measurement test; Marshall quotient

I. INTRODUCTION

The purpose of pavement roads is to provide a smooth surface over which vehicles can move safely. Pavements must be able to transfer the load of the wheel to the substrate so that its bearing capacity is not exceeded. Many factors affect the durability and serviceability of asphalt pavements, including heavy traffic loads, temperature [1, 2], wetness [3], design and execution errors [4], and inadequate maintenance. Over time, these causes lead to pavement deterioration [5]. Iraq's temperatures often elevate above 50°C, whereas most of the country's roadways experienced extreme distress due to unmanaged heavy traffic, and lack maintenance [6]. Most of Iraq's paved roads are designed and implemented using flexible Hot Mix Asphalt (HMA), as the paving consists of several layers to bear the load imposed by vehicles and to mitigate the impact of weather conditions [7, 8]. Furthermore, the tiling structure should to be able to perform multiple functions including bearing capacity, safety, slip resistance and water drainage [7-11]. The main aim of this research is to predict the performance of HMA using ANOVA software, in laboratory and field (Wasit Governorate). To achieve this, Marshal and field test data including field core samples collected from roads during construction were gathered abd stability, flow, and density tests were carried out.

Authors in [12] analyzed the asphalt mixture as a viscoelastic material and found its viscous-plastic creep value and realized the possibility of using these properties to assess the stress-strain behavior of paving roads. It was found that the values of viscous-plastic creep depend on the dimensions of the model, which is not a real property of the material because the properties of the asphalt mixture depend on the type of mixture [13], the dimensions of the model [14], the state of stress [15], and the waveform formed by the applied stress [15]. To resist permanent distortions, authors in [16, 17] studied the tensile strength of asphalt mixtures computed from the axial tensile test, the semi-circular (semi-circular) henna tensile test, and the indirect tensile test with the use of the finite element method. Experiments were conducted to find out the variables examination, deformation rate and temperature. In [18] finite elements were used to study the strain. Authors in [19] dealt with the mechanism of designing and evaluating the paving mix. Authors in [20] presented different factors affecting the modulus of elasticity of asphalt mixtures. The results of laboratory tests were analyzed using statistical experiments and considering five factors [21].

II. HOT MIX ASPHALT

A. Characteristics

HMA mixtures are applied for paving the surface layer of expressways, whether in urban areas or cellular roads [22]. Crushed graded stones, sand, and powder are mixed together to create the aggregate. This aggregate is then coated with hard asphalt to achieve the necessary fluidity of the solid asphalt [23]. Both aggregate types and hard asphalt are heated before mixing to ensure an appropriate degree of mixing and operation, hence the term hot mix [24]. The process of mixing aggregates and solid asphalt is carried out in asphalt mixing stations (the mixer), where the aggregate is heated in a dryer, and asphalt in its own tank to appropriate temperatures [25].

B. Stability and Flow

Asphalt mixtures are the main component of the paving layers in most modern methods [26]. Ensuring the quality of the asphalt mixes is necessary. This is accomplished by reaching certain values of a number of engineering and mechanical characteristics, among the most crucial of which are flow and stability [27]. Globally, there are many kinds of asphalt mixtures for pavements of this type, but heating asphalt mixtures are the most common [21]. A stable pavement maintains its shape and smoothness under repeated loading. Pavement instability leads to the appearance of cracks, ripples, and other signs of mixture shifting [6, 21, 28]. Increased moisture causes a decrease in the durability of the paving, causing an increase in instability, which is reflected in the paving sector as a whole [8, 29]. The flow number is used in pavement infrastructure design to assess if a HMA mixture is suitable for flexible pavement and can withstand permanent deformation [28, 29]. The flow number rises with an increase in effective binder content, air voids, voids in mineral aggregates, and voids filled with asphalt [19].

III. STUDY AREA AND FIELD MEASUREMENTS

A. Study Area

Wasit City is the largest city in the Diwaniyah Governorate. The Badra and Jisan road is regarded as an important route whose development and use have social and economic significance because it connects Iraq with the neighboring nations.

B. Field Measurements

The typical phases of experimental activity in the measuring and laboratory fields are depicted in Figure 1. A section of the Kut-Badra road selected by the Wasit government was used for the core sample collection (Figure 2). To guarantee the samples' stability and flow, they were randomly taken from a specified location (the Kut-Badra road) in Wasit. These samples complied with Iraqi road criteria. When extracting samples for evaluating the asphalt, it is essential to take samples from the right, middle, and left sections of the road to ensure a comprehensive assessment. After determining the number of samples from the road, the sampling device connected them to a water source. Water is crucial for preventing the cutting knife of the sampler from corroding due to the heat generated by the friction with the asphalt layer. Cutting was paused when the water color lightened. For the preparation of in situ samples, material was taken at the time of asphalt placement.

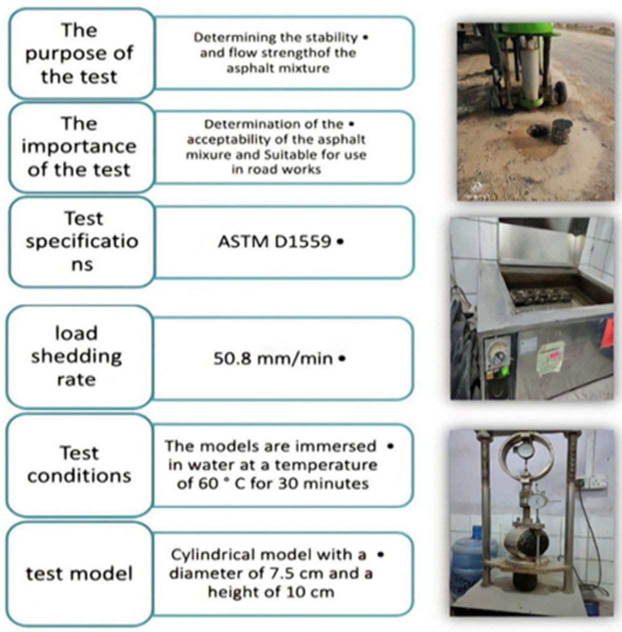

Fig. 1. Chart of the experimental laboratory work.

IV. MARSHALL TEST

A common and reliable technique for determining the load and flow rate of asphalt specimens is the Marshall test (Figure 1).

Fig. 2. Core extraction.

A. *Stability and Flow Test*

The specimens were submerged in water bath with temperature of 60 °C + 1 °C for 30 minutes before performing the stability test. After that, they were put into the Marshall Stability Testing Machine and were loaded at a steady 5 mm per minute rate for until failure. The Marshall stability is defined as the overall maximum Force (kN) that results in specimen failure. Volume is taken into account while calculating the stability value. The flow value is the entire amount of deformation, measured in increments of 0.25 mm, that occurrs at maximum load. The duration between taking the specimen out of the bath and finishing the test shouldn't be more than 30 seconds (Figures 3-4).

Fig. 3. Water bath.

Fig. 4. Marshall specimen extractor.

V. RESULTS AND DISCUSSION

The values that were extracted from the examination of asphalt samples will be compared with the values of the Iraqi standards for stability, flow, and density, which are:

- Maximum stability of the Marshall model: 11 kN
- Marshall model density: 2.3 g/cm^3
- Marshall model flow: 2.318mm

A. *Stability*

The results of the Marshall stability test (Figure 5) will lead to a better understanding of the test and more rational use of it in the design of highways and airports. The results (a sample can be seen in Table I) of the totally 43 collected samples are very close (8.4-11 kN) to the largest allowed value for stability in Iraqi specifications. Every place along the road has a varied level of stability, nonetheless, despite those differences, it is indicated that this route performs exceptionally well.

B. *Marshall Quotient (MQ)*

MQ is a measure of mixture stiffness that is expressed as the ratio of stability (kN) to flow (mm). It is commonly acknowledged that the MQ measures a material's ability to withstand shear loads, persistent deformation, and rutting. Table I in appendix displays the results of the MQ values. The MQ value indicates the stiffness of the mixture. It may be rising in some areas and falling in others. The MQ values of the sampled mixes varied from 5.6 to 2.666 kN/mm. Furthermore, the asphalt concrete's high modulus value makes it more rigid and deflection-resistant.

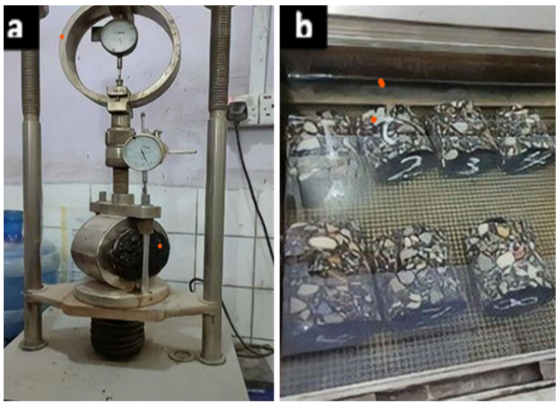

Fig. 5. (a) Flow and stability setup, (b) specimens immersed in water.

C. *Flow*

The flow determines the permanent deformation properties of asphalt mixtures. From the results (Table I) we can see that it is very close to or greater than the value required by the Iraqi specifications (Figure 8).

D. *Density*

The density of the asphalt was calculated according to the type of asphalt mixture (base layer, bonding layer, or a surface layer). The acquired values were very close to the Iraqi specifications, according to which the density should be equal to 2.3 g/cm^3. After failure, it was noticed that the density values decrease in a small percentage. The maximum density before failure was 2.317 g/cm^3 and the minimum was 2.21 g/cm^3, while after failure they were 2.215 g/cm^3 and 2.2 g/cm^3, respectively. As shown in Figure 9(b), the relationship between density and flow is inverse.

TABLE I. COLLECTED DATA (SAMPLE)

NO.	Stability kN	Flow mm	Density (before) g/mm^3	Density (after) g/mm^3	Reduction	MQ
1	10	2.4	2.219	2.134	96	4.167
2	11	2.2	2.317	2.215	100	5
3	10.5	2.3	2.227	2.095	96	4.565
4	9	2.8	2.211	2.084	95	3.214
5	10.1	2.3	2.225	2.101	96	4.391
6	8.9	3	2.213	2.099	96	2.967
7	9.3	2.9	2.21	2.093	95	3.207
8	9.9	2.3	2.217	2.133	96	4.304
9	8.5	3.2	2.215	2.089	96	2.656
10	8.4	3.1	2.213	2.088	96	2.71

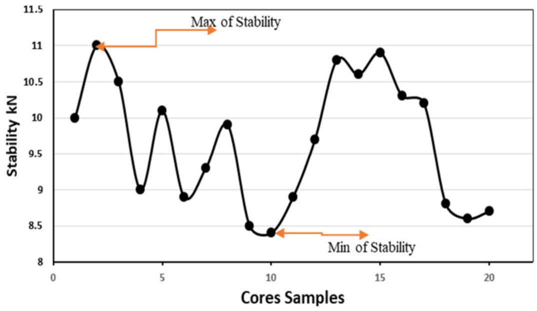

Fig. 6. Stability results.

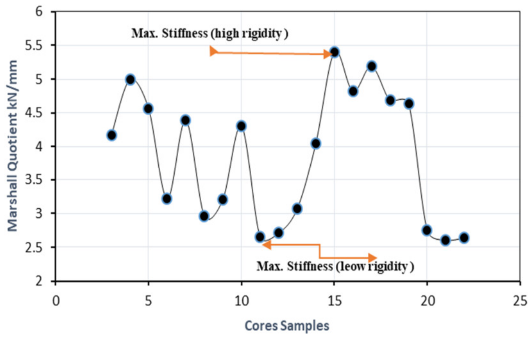

Fig. 7. Marshall quotient results.

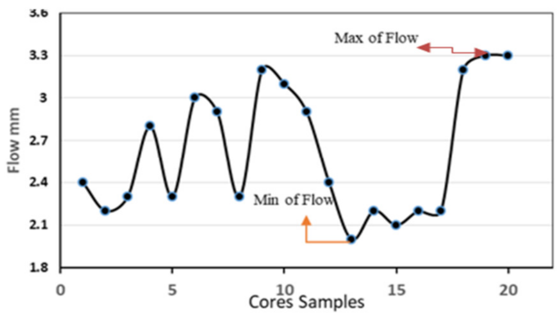

Fig. 8. Flow results.

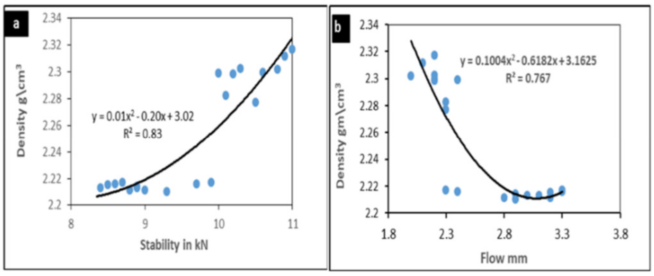

Fig. 9. Density vs (a) stability, (b) flow.

VI. STABILITY AND FLOW PREDICTION MODEL

Statistical methods were employed for predictions made by the models to assess the chosen roadways' stability, flow, and behavior in the research area. For the Stability and Flow model development, the considered data included the density before and after failure, and compaction ratio, and the air void content. A total of 43 core samples were investigated. The sample size (N) was calculated according to [16]. For confidence level = 95%, the degree of freedom (df) = 42 and t = 2.09. The variation is:

$$v=\sigma/x \tag{1}$$

where σ is the standard deviation and x is the mean value. For these values the error is:

$$\text{Error} = tv/(\sqrt{N}) = 0.044957 \tag{2}$$

The model's performance is statistically assessed by computing the coefficient of determination (R^2), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) for the training and validation as specified in Tables II-IV. Validation revealed nearly identical R^2 and MAE values of 74%, 0.06, and 82% and 0.21, for stability and flow, respectively.

TABLE II. SUMMARY OUTPUT OF THE FLOW MODEL

Regression Statistics	
Multiple R	0.872023
R^2	0.760425
Adjusted R^2	0.748446
Standard Error	0.598044
Observations	43

TABLE III. SUMMARY OUTPUT OF THE STABILITY MODEL

Regression Statistics	
R^2	0.832444
Adjusted R^2	0.824066
Standard Error	0.205446
Observations	43

VII. VALIDATION RESULTS

Half of the observed data were not used in the development process and were used in the validation process of the Stability and Flow models. The predicted and measured stability and flow values for the training and validation datasets are shown in Figures 10 and 11. The computed R^2 values are fairly close. This shows how well the established model predicts Stability and Flow in terms of generality and consistency. The comparison indicates that the model has the ability to predict the behavior of asphalt mixtures.

TABLE IV. FLOW MODEL ANALYSIS BY ANOVA TEST

df		*SS*	*MS*	*F*	Significance *F*			
Regression	2	8.387857	4.193928	99.36312	3.04E-16			
Residual	40	1.688324	0.042208					
Total	42	10.07618						
	Coefficients	Std. Error	*t* Stat	*P*-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.27259	0.48728	-4.66382	3.43E-05	-3.25742	-1.28776	-3.25742	-1.28776
Density before g/mm^3	2.030748	0.255447	7.949789	9.25E-10	1.514471	2.547025	1.514471	2.547025
Density after g/mm^3	0.280607	0.333542	0.841295	0.405184	-0.39351	0.954721	-0.39351	0.954721

Multiple regression was used to construct the stability and flow models. The resulting equations are:

For the Stability model:

Stability = 8.92317+3.189762 * Density before (g/mm^3) + 2.464789 *Density after (g/mm^3)

For the Flow model:

Flow= 2.27259 + 2.0307259* Density before (g/mm^3) + 0.280607 * Density after (g/mm^3)

Regarding the goodness of fit, as it can be seen in Table V, $\chi^2 < \chi^2c$. Thus, there is no significant difference between the observed and the predicted value.

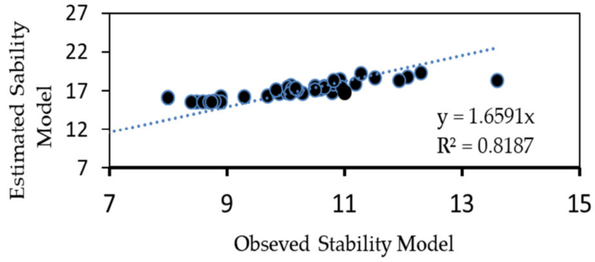

Fig. 10. Estimated vs developed stability model.

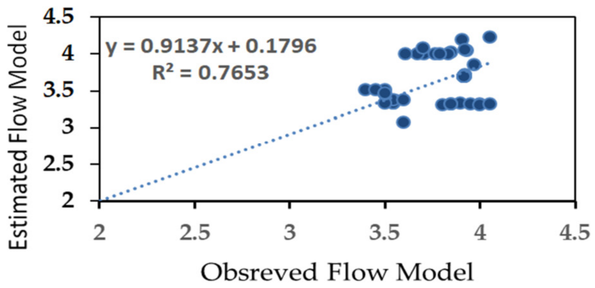

Fig. 11. Estimated vs developed flow model.

TABLE V. CHI-SQUIRE – TEST

Variable	χ^2 value	χ^2c - value
X: Observed model	35.6580000	44.47955
Y: Predicted model		

N = 43, *df* =42 confidence level = 95%

VIII. CONCLUSIONS AND FUTURE WORK

Within the specifications and limitations of the materials and the laboratory tests used to achieve the objectives of the study, and from the research results and outputs, the following conclusions can be drawn.

Excellent stability and flow characteristics were acquired, and the asphalt utilized complied with Iraqi regulations. This ensures that the road's pavement will last for a long time despite the stresses applied from heavy traffic and Iraq's weather. In this point, other researchers, such as the authors in [2], added microcapsules able to release oil in pavement cracks, even though they disregarded proper bedding and edging arrangements during the paving process, which this influence how long the asphalt mixture will last, thus it is important to pay attention to the right conditions in order to obtain pavement of prolonged life span.

Attention must be paid in checking the sources of processing hot asphalt mixtures so that they are composed or produced from raw materials conforming to the required specifications. If there is a change in the percentage of air spaces in the asphalt mixture, whether increase or decrease, it will affect the stability of the asphalt mixture and thus the occurrence of defects in the road and reduce its durability, so hot asphalt mixtures must be well designed.

Regarding future work recommendations, conducting laboratory tests for the anticipation of shrinkage or the use of falling weight deflectometers could be considered, through which it is possible to know the possibility of the occurrence of various road defects and cracks. We were unable to conduct this test due to the unavailability of the device in the laboratory.

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