The Use of Oil Contaminated Soil in Asphalt Concrete for Road Construction


Abstract—This paper investigates the ability of using the oil-contaminated soil (OCS) as a replacement of certain percentage of the aggregates in creating wearing layer of asphalt concrete used in road constructions. The Marshal design was implemented to test the stability, flow, and voids in mineral aggregates (VMA) of the specimens. The principles of the design of experiment were used to study the effect of factors on the responses with various levels. The factors are oil saturation level and the percentage of oil contaminated soil.

Keywords—Asphalt concrete, Design of experiment, Marshal Design, Oil-contaminated soil.

I. INTRODUCTION

The oil-contaminated soil (OCS) is found in great amounts in Kuwait as a result of the Iraqi invasion. Beginning February 17, 1991 Iraqi troops ignited 798 oil wells. The oil wells discharged enormous quantities of oil onto the terrestrial environment, which flowed through natural slopes and damaged around 114 km² [1].

The samples of the experiment were taken from Bahra site, where an oil pipe was exploded during the invasion causing oil contamination to the soil of that region.

This experiment mainly tests the ability of using the OCS in creating a form of asphalt concrete layer within established standards by studying the OCS presence effect on mainly soil stability. Factors considered are the saturation percentage of oil in OCS ranging between 2-4%, and the percentage of contaminated soil present in the sand mixture with the range of 30, 40, and 50 %. Main response variable is the mixture stability and other responses are the amount of flow, and the percentage voids in mineral aggregates (VMA).

II. SAMPLES

This is a fractional factorial experiment with two replications. Two factors are involved, one with two levels and the other with three levels, twelve trials were conducted in random order. Each trial consists of four samples of different bitumen levels (4%-5.5%) as the Marshall method requires.

III. LAB ANALYSIS

A. Extraction

Soil samples were demoisturized and cleaned with continuous hot toluene extraction method. The Toluene soluble hydrocarbon is calculated as weight fraction. This is a preparation step to conduct the sieve analysis.

B. Sieve Analysis

Sieve analysis is the method used to determine the grain size distribution needed in designing marshal test trials.

The process of implementing the analysis begins with the collection of a representative oven dry soil sample, then determining the mass of the sample accurately to 0.1g, afterwards pouring the soil samples into the stack of sieves which are arranged based on their sizes, and finally running the stack of sieves through a sieve shaker for about 10 - 15 minutes. Weighing the amount of soil retained on each sieve and the bottom pan[2].

The distribution represents poorly graded sand grains. Therefore, the wearing coarse layer is the most suitable layer based on the marshal design's standards of the aggregates size.

C. Specific Gravity

Specific gravity (SG) of the samples was found using the pycnometer. First a 10g of a dry soil sample was placed in a clean and dry pycnometer and weighting it WPS, then distilled water is added to fill about half to three-fourth of the pycnometer at this point WB is calculated.

Emptying the pycnometer and cleaning it. Then filling it...
with distilled water only (to the mark). Cleaning exterior surface of the pycnometer comes next, and finally determining the weight of the pycnometer and distilled water $W_A$ [2].

The SG equation:

$$SG = \frac{W_{ps}}{W_{ps} + (W_A + W_B)}$$

(1)

Results are 2.4 for contamination and 2.28 for high contamination.

D. Preparation of the Marshall Test

Table 1 is the Design table which summarizes the quantities that have been selected from each aggregate size and from the OCS.

A 1200gm sample that contains coarse, fine, and filler aggregates with OCS was prepared by taking the midpoint of each range of the aggregate as shown in table 1 (our selection column). A 30%, 40% and 50% of grain size from 4.75 mm to <75 mm was replaced with the high and low OCS. The choice of the sieve size was based on the result of the sieve analysis of the OCS.

Equipment used are: 175-190°C oven, round mold of diameter of 10 cm and 7.5 cm height consisting of a base metal and collar extension, compaction pedestal, sample extractor and a hammer [3].

E. The Marshal Test

The samples were subjected to plastic deformation by using Marshall stability testing machine to get the stability and flow values [3].

Certain calculations and analysis were further conducted to get the VMA and, hence the optimum binder content of each trial.

IV. Final Result

The final results of the optimum binder content are shown in Table II. While the required standards are shown in Table III.

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Where, $\tau_i$ is the effect of the saturation percentage level $i$.

$H_0: \beta_1 = \beta_2 = \beta_3 = 0$

$H_1$: at least one $\beta_j \neq 0; j = 1, 2, 3$  \hspace{1cm} (3)

Where, $\beta_j$ is the effect of the contaminated soil percentage level $j$.

$H_0: (\tau\beta)_{ij} = 0$ for all i,j

$H_1$: at least one $(\tau\beta)_{ij} \neq 0$  \hspace{1cm} (4)

Where, $(\tau \beta)_{ij}$ is interaction effect between the two factors.

### B. Experiment Assumptions

The following assumptions are to be investigated for the residuals:

- It is a complete randomized experiment.
- The data are independent.
- The errors follow a Normal Distribution with mean 0 and share the same variance $N(0, \sigma^2)$.

### C. Analysis of Variance

Minitab software version 14 was used to conduct analysis of variance (ANOVA).

#### TABLE IV

ANNOVA TABLE FOR STABILITY

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>AdjMS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of oil</td>
<td>1</td>
<td>3.887</td>
<td>3.887</td>
<td>3.887</td>
<td>3.01</td>
<td>0.133</td>
</tr>
<tr>
<td>% of soil</td>
<td>2</td>
<td>1.062</td>
<td>1.062</td>
<td>0.531</td>
<td>0.41</td>
<td>0.680</td>
</tr>
<tr>
<td>% of oil*%</td>
<td>2</td>
<td>1.286</td>
<td>1.286</td>
<td>0.643</td>
<td>0.50</td>
<td>0.631</td>
</tr>
<tr>
<td>of soil</td>
<td>1</td>
<td>7.751</td>
<td>7.751</td>
<td>1.292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>13.986</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Table IV, the P-value of the stability is greater than $\alpha=0.05$, then we fail to reject the null hypothesis which indicates that the stability mean values do not change at different oil saturation percentages or contaminated soil percentages. This means using either high oil saturation values or low does not influence the stability in creating asphalt concrete and the same applies on the contaminated soil percentages. Furthermore, increasing the contaminated soil percentages up to 50% will not affect the stability of the asphalt concrete.

#### TABLE V

ANOVA TABLE FOR FLOW

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>AdjMS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of oil</td>
<td>1</td>
<td>5.2008</td>
<td>5.2008</td>
<td>5.2008</td>
<td>68.58</td>
<td>0</td>
</tr>
<tr>
<td>% of soil</td>
<td>2</td>
<td>2.2867</td>
<td>2.2867</td>
<td>1.1433</td>
<td>15.08</td>
<td>.005</td>
</tr>
<tr>
<td>% of oil*%</td>
<td>2</td>
<td>0.2467</td>
<td>0.2467</td>
<td>0.1233</td>
<td>1.63</td>
<td>.273</td>
</tr>
<tr>
<td>of soil</td>
<td>1</td>
<td>0.4550</td>
<td>0.4550</td>
<td>0.0758</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>8.1892</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regarding the flow as shown in Table V, the P-value is greater than $\alpha=0.05$, then we fail to reject the null hypothesis which indicates that the flow mean values do not change at different oil saturation percentages or contaminated soil percentages and the same stability conclusion applies here.

#### TABLE VI

ANOVA TABLE FOR VMA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>AdjMS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of oil</td>
<td>1</td>
<td>2.98</td>
<td>2.98</td>
<td>2.98</td>
<td>0.08</td>
<td>0.786</td>
</tr>
<tr>
<td>% of soil</td>
<td>2</td>
<td>220.43</td>
<td>220.43</td>
<td>110.21</td>
<td>2.97</td>
<td>0.127</td>
</tr>
<tr>
<td>% of oil*%</td>
<td>2</td>
<td>30.95</td>
<td>30.95</td>
<td>15.47</td>
<td>0.42</td>
<td>0.677</td>
</tr>
<tr>
<td>of soil</td>
<td>2</td>
<td>222.63</td>
<td>222.63</td>
<td>37.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>0.4550</td>
<td>0.4550</td>
<td>0.0758</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>476.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As for the VMA in Table VI, since P-value is lower than $\alpha=0.05$, then the null hypothesis is rejected. Therefore there is a strong evidence to say that changing the level of the percentage of oil and percentage of soil affect the VMA values.

The P-value of the interaction in all properties was found to be greater than $\alpha=0.05$. Then, we fail to reject and this shows that the interaction effect of oil saturation percentage and the contaminated soil percentage is insignificant on the stability, flow, and VMA.

### D. The Main Effect

The main effect shows the effect of the oil saturation values and the effect of the contaminated soil values on the samples properties separately.

#### Fig.2 ANOVA Main Effect Plot for stability

The main effects plot of stability in Fig.2 shows that increasing the percentage of oil from low to high decreases the stability. In seeking high stability, low saturation of oil is better. It also shows that moving the contaminated soil percentage from 30% to 40% decreases the stability and it increases when moving from 40% to 50%. The max stability was found with both low oil % and 30 % soil.
From the main effect plot of flow Fig.3, it is evadable that increasing the oil percentage from low to high increases the flow, and the high oil percentage has out of the range value. When moving from 30% to 40% the flow increases while it decreases from 40% to 50%, 40% yields value out of the acceptable range.

The main effects plot of VMA in Fig.4, indicates that increasing the percentage of oil from low to high decreases the VMA. It also indicates that moving the contaminated soil percentage from 30% to 40% increases the VMA while it decreases when moving the soil percentage from 40% to 50%.

**E. The Interaction Effect**

Interaction effect is important in showing the effect of the oil saturation percentage in the presence of different values of contaminated soil percentage and vice versa.

From interaction plots in Fig.5 (a) and (b), the two lines are not parallel which means there must be an interaction between the oil saturation percentage and the soil contamination percentages. As for the VMA Fig.5 (c), at high oil percentage, VMA is found to be less than VMA values of low oil percentage, regardless of amount of soil oil contamination.

**F. Residual Analysis**

Residual is an estimate of the experimental error. It represents the difference between observed and predicted values of the sample properties (stability, flow and VMA). Residual analysis is a model adequacy checking techniques by which the underlying ANOVA assumptions can be validated [4].
From the Normal probability plot of residuals Fig.6, the residuals points are either on or near the line, so the normality assumption is adequate.

The Residual versus fitted values graph in Fig.7 is adequate. The difference between the highest and lowest residuals for each fitted value is similar except for the first fitted value this could be because of the small number of data taken.

VI. CONCLUSION

Soil stability values were acceptable when compared to standard values. In general, the resulted stability for low saturation yielded better values than high saturation level. The high oil saturation level with 30%, 40% and 50% were below the standard value in one replicate. As for the flow, values found were acceptable except for some outliers.

We can also conclude from our analysis that different levels of both contaminated soil percentage and the oil saturation percentage don’t affect stability and flow, yet they affect the voids in the mineral aggregates.

In addition, some results were inconsistence between the two replicates. This might be due to different analyst abilities and difference in quality aggregate materials. This problem could be avoided when considered as blocks rather than replicates.

Future research is directed towards projecting the design into having a Marshal design with more coarse aggregate sand.

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REFERENCES


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