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Evaluation of Indicator Tests for Identification of Segregation in Flexible Pavements – A Case Study

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ABSTRACT

Segregation of hot mix asphalt (HMA) is a continuing problem in construction practice which has caused premature distress in many flexible pavements. A study, funded by the Kansas Department of Transportation, was conducted on a newly constructed pavement to evaluate the effectiveness of indicator tests in detection of segregation.

Cores were obtained from segregated and non-segregated areas of the pavement and the unit weights of the pavement were determined using a thin-lift nuclear gauge. The change gradation on the 4.75 mm sieve was compared with the indicator tests of asphalt content, i.e., nuclear gauge unit weight, core unit weight and macrotexture.

The results of this study indicate that asphalt content is the best indicator test of segregation whilst macrotexture is the best non-destructive indicator test of segregation.

Keywords : Segregation, Macrotexture, Unit Weight

INTRODUCTION

There have been many studies on ways to identify and prevent segregation. However, little documented research has been performed to systematically develop procedures to identify segregation.

Visual observations of the HMA pavement surface texture are usually performed to identify segregation but these observations are subjective and could lead to many disagreements between contracting parties. By establishing appropriate procedures for detecting and measuring segregation, the

Kansas Department of Transportation (KDOT) would have data available to allow adoption of justifiable and defensible specifications to address segregation problems.

OBJECTIVE AND SCOPE OF STUDY

The objective of the study was to determine the effectiveness of asphalt content, pavement macrotexture or unit weight tests for the quantification of segregation of asphalt mix.

The study was conducted on a newly constructed pavement, US 183 in Philips County Kansas. The highway was not opened to traffic during the investigation or tests. The mix sampled was a BM-1B, 12.5 mm nominal size dense graded mix.

The site had several areas of coarse surface texture which appeared to be caused by end of the load segregation. The unit weights of the pavements were measured using a thin-lift nuclear gauge. Cores were obtained from coarse surface textured (segregated) and uniform surface textured (non-segregated) areas of the pavements.

The study involved field and laboratory testings designated to determine if an indicator test such as asphalt content, pavement macrotexture, or unit weight from either a thin-lift nuclear gauge of cores, could be used to quantify segregation effectively.

FIELD TESTING

The field testing was conducted together by Professor Stephen A. Cross, principal investigator, Rodney Maag, KDOT Field Engineer and construction personnel. The US 183 (BM-1B mix), was selected for sampling and evaluation purposes. Areas with signs of segregation and non-segregation were visually identified. The sampling consisted of 10 sets of 150 mm diameter cores. Five sets of three cores were obtained from segregated areas and five sets of three cores were obtained from non-segregated areas. The non-segregated core sets were obtained within 15 to 30 m of the segregated core sets and the cores for each set were obtained within 150 mm of each other. A thin-lift nuclear gauge was utilized to determine the unit weight of the surface mix for each set. Sand was used to fill surface voids for thin-lift nuclear gauge testing. The cores were returned to the Bituminous Materials Laboratory at the University of Kansas for further testing.

LABORATORY TESTING

A water-cooled diamond saw was used to separate the surface layer form the remainder of the core. The thickness of the surface layer was measured and recorded. The cores were then air-dried to a constant weight and the bulk specific gravity, macrotexture and asphalt content were determined. The following tests were performed in the laboratory.

i) **Bulk Specific Gravity**
The bulk specific gravity was determined in accordance with ASTM D 2726. If the core absorbed water more than 2 percent by weight, Parafilm was used to determine the bulk specific gravity according to ASTM D 1188.

ii) **Macrotexture**
The macrotexture of each core was determined in general accordance with ASTM E 965. The Ottawa sand was utilized since it met the gradation requirements of passing a 0.3 mm sieve and retained on a 0.15 mm sieve. The weight of the sand covering the surface of the core was measured. The macrotexture depth was determined by dividing the volume of the sand by the surface area of the core.

iii) **Theoretical Maximum Density (TMD)**
The sample was warmed at 105°C until it could be separated. The sample was cooled to room temperature prior to TMD determination. The TMD was determined in accordance with ASTM D 2041. To perform the test, a type E pycnometer was used for samples weighing more than 1000 g and a calibrated 1000 ml Erlenmeyer flask was used to weigh samples less than 1000 g. From the bulk specific gravity and the TMD results, the percent air voids were determined according to ASTM D 3203.

iv) **Asphalt Content**
All cores were dried in an oven at 105°C to a constant weight. The asphalt content of the samples were determined by the ignition method. At present, there is no standard procedure to determine the asphalt content by ignition. Thus, the method used by the National Center for Asphalt Technology (NCAT) was followed. The materials were preheated at 125°C for 25 minutes, placed in a steel basket, and weighed before being placed in the furnace at 538°C. The asphalt cement was burned off and percent asphalt content was determined from initial weight and weight of residue.

v) **Gradation Analysis**
A washed sieve analysis was performed on the material remaining from the ignition test. The gradation was determined in accordance with ASTM C 117 and C 136.

PRESENTATION AND ANALYSIS OF RESULTS

For the analysis, it was decided to quantify segregation as percentage retained on the 4.75 mm sieve. The tolerance limits, as specified by KDOT, for percent retained on the 4.75 mm sieve for BM-2 mix is ± 5%. Correlation analysis was performed on the percent retained on the 4.75 mm sieve (dependent variable) and the indicator tests (independent variables). To evaluate the reliability of the indicator test to identify segregation, a significant correlation was defined as a level of significance (alpha) of less than 0.1 or a 90 percent probability of R not equaling zero. Results of the correlation analysis for each parameter (R and alpha values) are illustrated at the bottom of the respective table of results. Regression analysis was performed to determine the best fit line and regression equation.

Aggregate Gradations

Table 1 shows the gradation analysis results of the BM-1B mix and Table 2 shows the results of the indicator tests. The average percent retained on the 4.75 mm sieve for the non-segregated cores is 49.3%, which is 4.7% finer than the JMF. The corresponding standard deviation for the non-segregated cores is 2.6%. The KDOT specified tolerance limits on the 4.75 mm sieve for BM-1B mix is ± 5%. Figure 1 shows the variation in the gradation for the segregated cores compared to the average of the non-segregated cores at locations 29, 31, 33, 35 and 37. Locations 33, 35 and 37 were outside the tolerance limit on the 4.75 mm sieve. Locations 29 and 31 were within specification limits and within 2 standard deviations of the average gradation of the non-segregated cores. As shown in Table 2, locations 29 and 31 had high average air void contents, 16.1% and 14.2%, respectively, compared to an average of 9.6% for the non-segregated cores. The cores from these locations were not segregated and had a high air void content. These properties produced a coarse surface texture, which was visually mistaken for segregation.

Indicator Tests

The results of the indicator tests and their correlation with percentages retained on 4.75 mm sieve for site 2 are shown in Table 2.

Table 1 Asphalt content and gradation analysis results.

CORE NO	SEG	SIEVE 19.0mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm	0.075 mm
		PERCENT RETAINED									
JMF		**0.0**	**8.0**	**19.0**	**54.0**	**71.0**	**81.0**	**85.0**	**89.0**	**94.0**	**95.5**
30A	NO	0.0	6.5	16.9	48.3	66.9	76.0	79.3	83.7	90.3	93.6
30B	NO	0.0	6.5	16.0	47.5	66.9	76.2	79.6	84.0	90.6	93.9
30C	NO	0.0	7.6	17.1	46.9	66.7	76.5	79.6	83.8	90.6	93.7
32A	NO	0.0	6.5	15.1	46.7	66.5	76.1	79.1	83.3	90.2	93.4
32B	NO	0.0	4.9	12.9	45.3	66.5	75.3	78.6	83.1	90.0	93.5
32C	NO	0.0	4.5	14.9	45.8	65.7	75.2	78.6	83.1	90.0	93.5
34A	NO	0.0	6.9	15.9	48.9	68.4	77.2	80.4	84.6	90.8	93.9
34B	NO	0.0	5.8	15.8	48.7	68.1	77.5	80.4	84.3	90.8	93.8
34C	NO	0.0	6.0	15.4	48.2	68.2	77.3	80.4	84.5	90.8	93.9
36A	NO	0.0	8.9	19.7	51.9	68.7	76.5	79.5	83.8	90.5	93.7
36B	NO	0.0	6.5	16.7	51.2	68.5	76.8	79.9	84.1	90.6	93.8
36C	NO	0.0	8.7	19.6	51.6	69.3	78.1	80.9	84.9	91.2	94.1
38A	NO	0.0	6.0	17.8	52.2	70.4	79.5	82.3	86.0	91.8	94.4
38B	NO	0.0	7.2	17.8	52.8	70.5	78.7	81.8	85.7	91.4	94.3
38C	NO	0.0	6.8	18.1	52.9	70.6	79.2	82.2	86.0	91.6	94.3
29A	YES	0.0	7.5	20.9	52.8	70.0	78.0	80.7	84.6	91.1	94.0
29B	YES	0.0	7.1	19.3	54.5	70.4	77.6	80.3	84.5	90.8	93.9
29C	YES	0.0	7.3	16.2	49.6	68.1	76.8	79.9	84.2	90.6	93.8
31A	YES	0.0	9.1	24.1	56.7	71.8	78.5	81.1	85.1	91.2	94.2
31B	YES	0.0	7.8	19.4	52.9	69.7	77.7	80.4	84.3	90.8	93.8
31C	YES	0.0	6.2	16.5	49.8	68.1	76.7	79.8	84.2	90.7	93.8
33A	YES	0.0	17.9	32.3	63.8	75.5	80.3	82.5	86.1	91.6	94.2
33B	YES	0.0	17.8	38.3	67.3	76.7	80.7	82.6	86.1	91.9	94.7
33C	YES	0.0	17.6	37.3	66.9	76.8	81.2	83.1	86.4	91.9	94.5
35A	YES	0.0	21.7	40.6	68.2	77.1	81.5	83.5	86.8	92.1	94.7
35B	YES	0.0	20.5	42.0	69.1	77.4	81.4	83.4	87.0	92.2	94.8
35C	YES	0.0	23.2	43.6	69.8	77.8	81.4	83.4	86.9	92.1	94.7
37A	YES	0.0	13.0	27.1	62.0	75.8	82.0	84.5	87.8	92.6	95.0
37B	YES	0.0	14.7	27.2	60.4	75.2	81.8	84.2	87.5	92.5	94.7
37C	YES	0.0	10.9	25.6	62.7	76.1	82.3	84.8	88.1	92.7	95.0

Table 2 Results of indicator test.

CORE NO.	SEG.	AIR VOIDS (%5)	ASPHALT CONTENT BY WEIGHT OF AGG. (%)	MACRO-TEXTURE (mm)	CORE UNIT WEIGHT (kN/m^3)	NUCLEAR GAUGE UNIT WEIGHT (kN/m^3)
30A	NO	8.9	5.19	0.253	21.98	*
30B	NO	8.6	5.29	0.293	22.03	23.57
30C	NO	8.6	5.29	0.240	22.05	*
32A	NO	8.2	5.35	0.226	22.16	*
32B	NO	8.6	5.47	0.236	22.08	23.02
32C	NO	8.3	5.51	0.289	22.15	*
34A	NO	13.7	5.37	0.336	20.83	*
34B	NO	13.3	5.38	0.273	20.92	22.42
34C	NO	15.2	5.55	0.345	20.46	*
36A	NO	8.1	5.28	0.242	22.20	*
36B	NO	8.6	5.48	0.282	22.09	23.05
36C	NO	8.4	5.42	0.306	22.13	*
38A	NO	9.0	5.23	0.299	22.05	*
38B	NO	8.5	5.21	0.279	22.17	23.12
38C	NO	8.6	5.23	0.258	22.14	*
29A	YES	15.4	5.08	0.442	20.50	*
29B	YES	18.6	5.01	0.492	19.73	22.08
29C	YES	14.2	5.18	0.463	20.79	*
31A	YES	15.8	4.92	0.460	20.39	*
31B	YES	14.6	5.15	0.528	20.67	21.17
31C	YES	12.1	5.25	0.416	21.27	*
33A	YES	19.4	4.54	0.738	19.77	*
33B	YES	21.0	4.37	0.880	19.37	21.90
33C	YES	21.5	4.32	0.757	19.25	*
35A	YES	16.9	4.38	0.961	20.38	*
35B	YES	18.0	4.10	0.872	20.10	22.02
35C	YES	17.5	4.27	0.915	20.22	*
37A	YES	15.3	4.84	0.491	20.62	*
37B	YES	14.8	4.92	0.450	20.73	22.33
37C	YES	15.1	4.73	0.506	20.65	*
Correlation Analysis						
Segregation, R			-0.96	-0.91	0.73	0.50
Alpha			0.00	0.00	0.00	0.00

* One test per location

** (1-Alpha) Probability R Not equal to 0

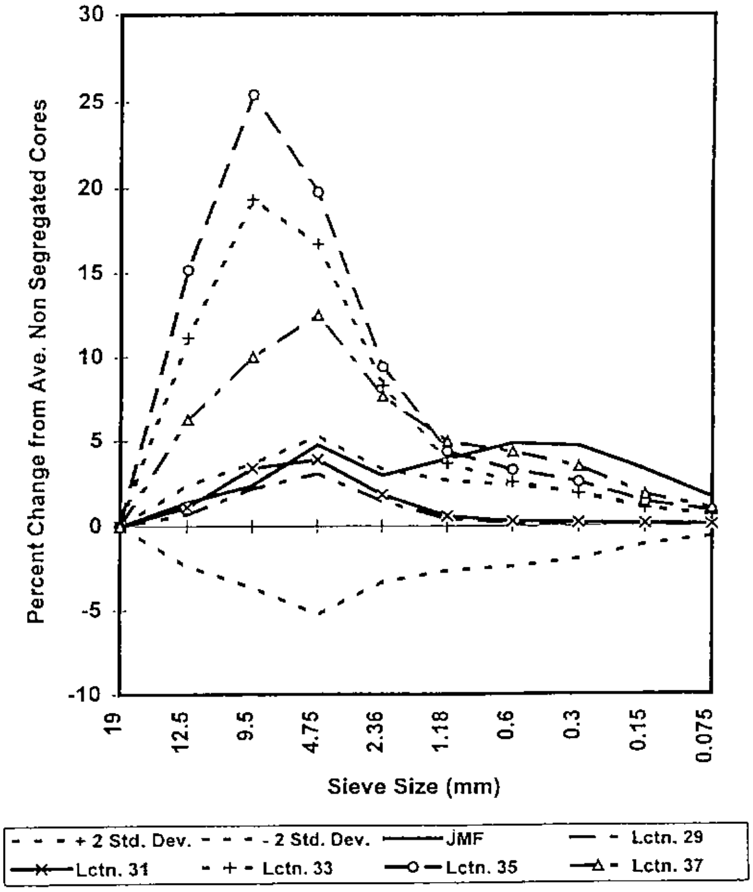

Figure 1 Variation in gradation for segregated cores compared to the average gradation of the non-segregated cores for site 2.

Asphalt Content

End of the load segregation is typically associated with lower measured asphalt contents [1,2]. Figure 2 shows the relationship between asphalt content and percent retained on the 4.75 mm sieve. The relationship has an R^2 of 0.92 and indicates that amount of segregation (coarseness) increases with decreasing the asphalt content. The relationship agrees with the results documented by [2] and Kandhal [1]. The results confirmed that the type of segregation observed was end of the load segregation. Of the indicator tests evaluated, the asphalt content was the best indicator of segregation. A change in asphalt content of 0.28 % indicates a change in gradation of 5 %, the tolenrance limit, on the 4.75 mm sieve.

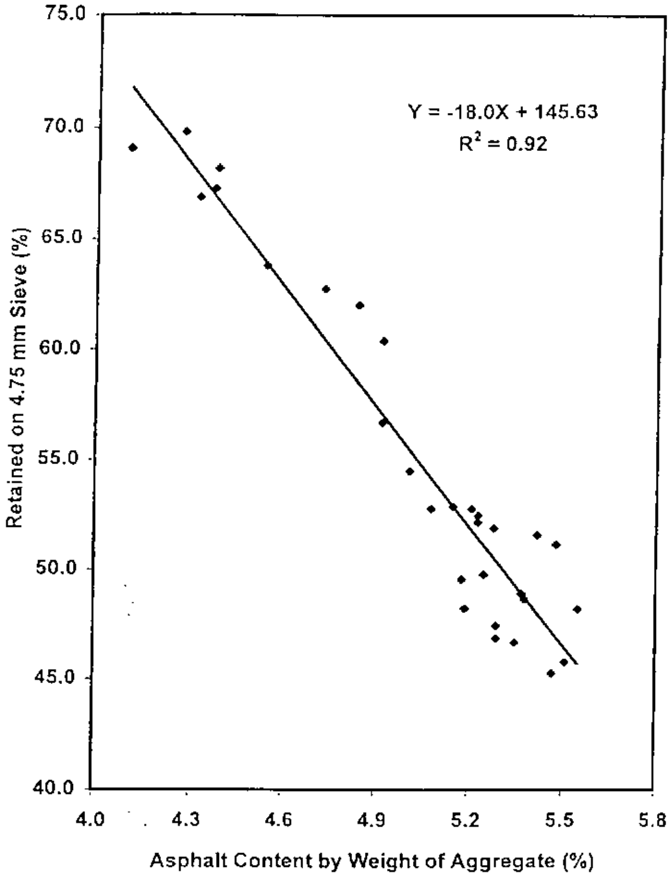

Figure 2 Percent retained on 4.75 mm sieve versus asphalt content for site 2.

Unit Weight Test Using Nuclear Gauge

The unit weight of the pavement at the core locations was determined using a thin-lift nuclear gauge. One test was performed at each location and the unit weight compared to the average gradation of the cores at the location. Figure 3 shows the relationship between thin-lift nuclear gauge unit weight and percent retained on the 4.75 mm sieve. The relationship, has an R^2 of 0.27 and indicates that the unit weight decreases with increasing percentage of mix retained on 4.75 mm sieve. A change in unit weight of 0.88 kN/m^3 indicates a change in gradation of 5 %, the tolerance limit, on the 4.75 mm sieve.

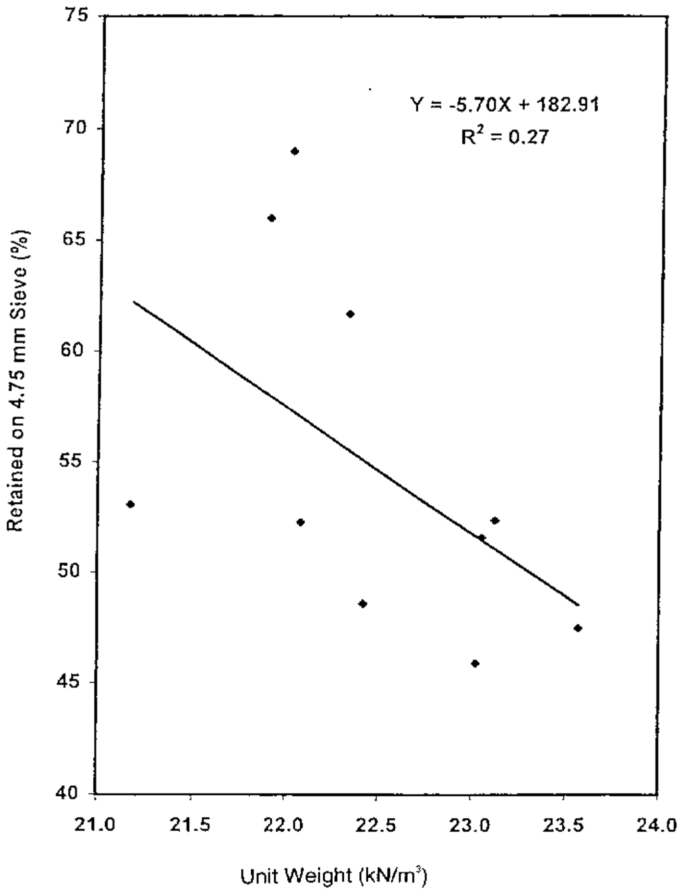

Figure 3 Percent retained on 4.75 mm sieve versus unit weight for site 2 determind by nuclear gauge.

Based on R^2 of 0.27, the nuclear gauge was not reliable for detecting segregation. The results agrees with the work performed by the Missouri Highway and Transportation Department [3] where they could not fully identify segregated areas of the pavement using a continuous density profile. Cross and Brown [4] also found that nuclear gauge unit weight was not one of the better indicators of segregation. Table 2 indicates that segregated areas have lower unit weights than non-segregated areas. However, there are many other factors besides segregation that could contribute to a low unit weight.

Unit Weight based on Volume of Core

The cores were obtained from both the segregated and non-segregation areas. Figure 4 shows the relationship between core unit weight and percent retained on the 4.75 mm sieve. The relationship has an R^2 of 0.53 and it indicates that as the amount of segregation increases, the unit weight decreases. A change in unit weight of 0.85 kN/m^3 indicates a change in gradation of 5 % on the 4.75 mm sieve. The R^2 value is better than that for the thin-lift nuclear gauge test. The core unit weights are compared to their respective individual gradations whereas the nuclear gauge readings were compared to the average gradation at each location. This difference could account for the poor relationship for the thin-lift nuclear gauge test.

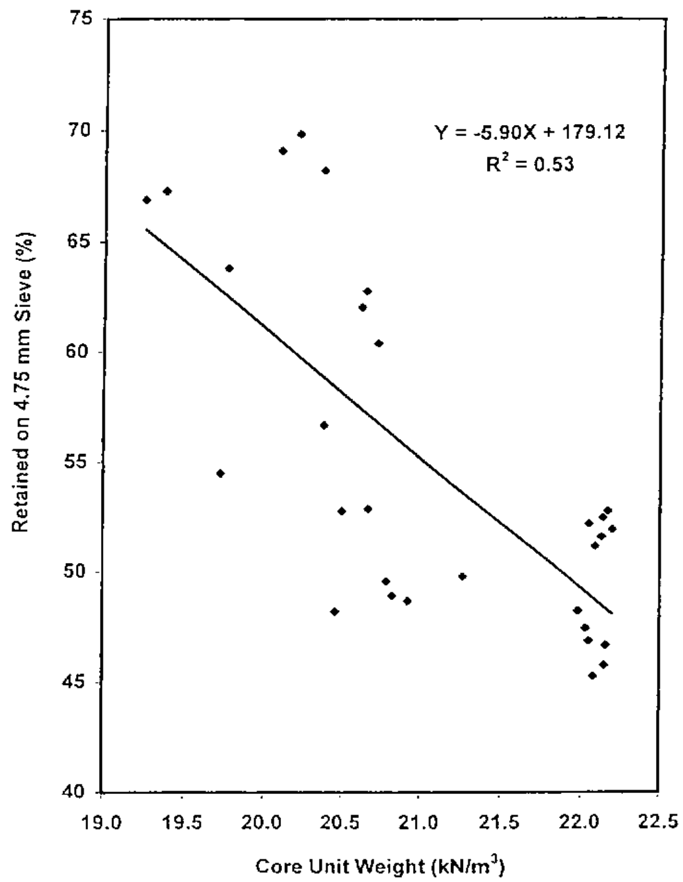

Figure 4 Percent retained on 4.75 mm sieve versus core unit weight for site 2.

Macrotexture

The macrotexture test was performed on each core in accordance with ASTM E965. The results are shown in Table 2. Figure 5 shows the relationship between macrotexture and percent retained on the the 4.75 mm sieve. The relationship has an R^2 of 0.83 and indicates that the macrotexture depth increases with increasing amount of segregation. A change in macrotexture of 0.16 mm indicates a change in gradation of 5 % on the 4.75 mm sieve. The pavement macrotexture was the best non-destructive indicator test for segregation. The relationship between pavement macrotexture and segregation agrees with the findings by Cross and Brown [4], who reported that macrotexture was the best indicator of segregation.

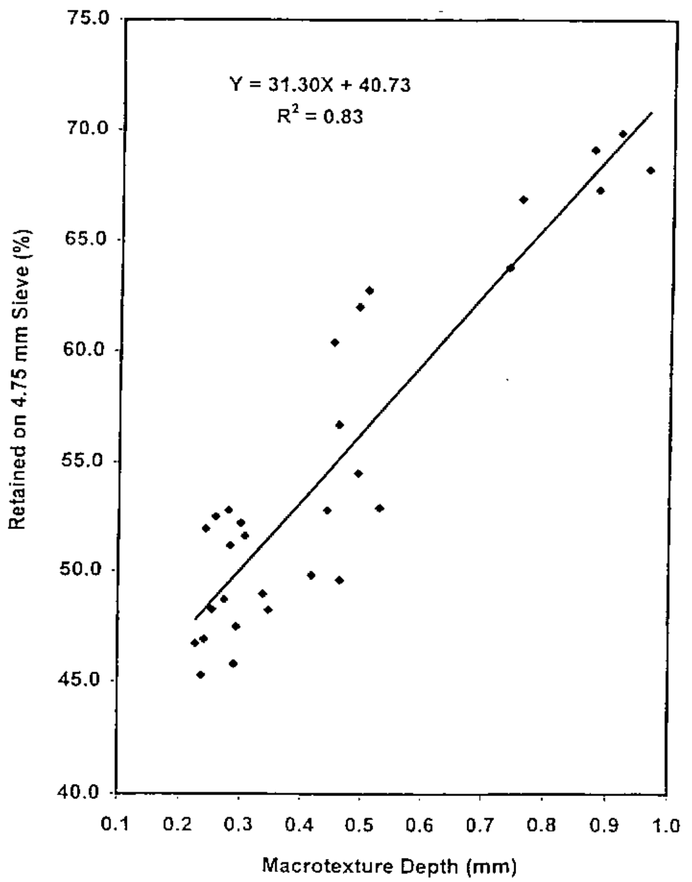

Figure 5 Percent retained on 4.75 mm sieve versus macrotexture depth for site 2

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, the following conclusions and recommendations were made:

1. For the BM-1B mix, asphalt content was the best indicator of segregation. A change in asphalt content of 0.28% could be used to indicate a mix out of specification on the 4.75 mm sieve.
2. For the BM-1B mix, macrotexture was the best non-destructive indicator of segregation. An increase in macrotexture of 0.16 mm could be used to indicate a mix out of the specification on the 4.75 mm sieve.
3. The macrotexture test is difficult to perform and it is time consuming whilst the asphalt content is not a non-destructive test. However, most nuclear gauges can measure asphalt content. Further study is recommended on combining two indicator tests, such as asphalt content and unit weight, which could help differentiate between high air voids and segregation. The ability of using nuclear gauge to determine asphalt content which has high correlation and unit weight which has low correlation, should be evaluated to determine if the nuclear gauge could reliably detect segregations.

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