Effect of Aggregate Embedment On Chip Seal Retention Performance

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ABSTRACT

The aim of this study is to evaluate chip seal retention performance with two type of aggregate depending on the various embedment depths using Accelerated Chip Seal Simulation Device (HSKSC). To simulate the worst condition in field for chip seal in respect to aggregate retention performance, the water was poured on the specimens and performance tests were conducted in water. Major findings of this research include that increasing the aggregate embedment significantly reduces the aggregate loss. However, it correspondingly reduced the macrotexture value of the chip seal which is very important parameter for chip seal service life.

Keywords: Adhesion, Chip seals, Macro Texture, Ravelling

INTRODUCTION

Aggregate embedment depth plays an important role for chip seal retention performance (1). Aggregates used in chip seals on the granular base layer embedded both into the bitumen and substrate by roller during the construction and then by traffic effect over time. However, aggregates in chip seals constructed on existing asphalt concrete embedded only bitumen film toward the long side of aggregate. During rolling process, the individual aggregate particles are reoriented to their least dimension and embedded in the substrate and binder (2). Aggregate embedment depth typically occurs about a 50% after the initial rolling and about a 70% embedment after two or more weeks of traffic. Rolling procedure should begin immediately after the aggregate is distributed to ensure proper embedment of the chip seal. Because when the bitumen is getting cooled more rolling is required. Skilled and experienced construction and inspection personnel also constitute an important factor in a quality chip seal program (3).

If proper embedment is achieved, the probability of premature loss of aggregate is minimized. Therefore, the basic principle of determining aggregate/bitumen rate of chip seal design is to adjust optimum embedment depth of aggregate considering some parameters such as aggregate size, shape, traffic volume, climate effect, surface condition, aggregate shape etc. This design method is based on the assumptions for traffic should be or less 10 % heavy traffic, aggregate should be one-sized with a flakiness index of 15-25 %, and embedment should be 50 to 65 % after two years. In addition, the embedment depth should be more uniform across the road's surface. If a chip seal is not properly designed and constructed, several potential problems can occur. One of them is windshield damage that occurs when the aggregates are not adequately embedded in the bitumen. Another common problem is bleeding or flushing of the bitumen. Some reasons such as a high asphalt application rate, inadequate chip coverage or poor traffic techniques can create this distress. The end result is the loss of skid resistance (4, 5, 6). In this study, chip seal retention performance was evaluated with two type of aggregate depending on the embedment rate using with Accelerated Chip Seal Simulation Device (HSKSC).

MATERIALS AND METHOD

Materials

Basalt (CB) and Limestone (CK) crushed aggregates were used with the 100/150 penetration bitumen in order to fabricate HSKSC specimens. The gradations of CB and CK aggregates are between 1/2" - 3/8" (5.6 – 9.5 mm) sieves. Of these aggregates, the CB and CK were supplied by Gerede Cankurtaran quarry in the Bolu region, Sivrihisar Yellitepe quarry in the Eskisehir region of Turkey respectively. Fig. 1 presents a seen of aggregates and Table 1 shows the physical and mechanical properties of the aggregates (7).

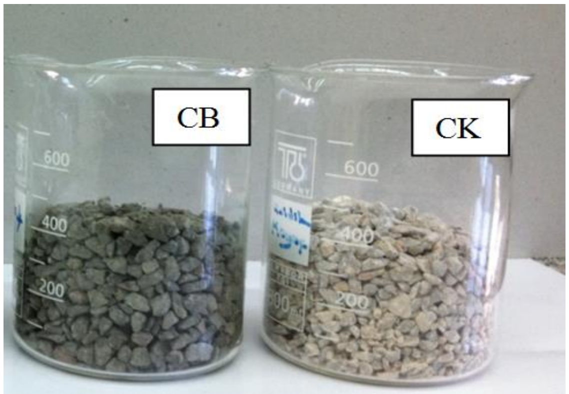

Figure 1. Aggregates used in experiments

Table 1. Physical and mechanical properties of aggregates (8-12)

Aggregate Code	Specific Gravity and Absorption Values		Los Angeles Abrasion (%)	Soundness (%)
	Dry Bulk Specific Gravity (gr/cm^3) (lb/in^3)	Absorption (%)		
CB	2.560 (0.092)	2.1	18.2	0.3
CK	2.681 (0.097)	0.2	25.2	1.2

To determine aggregate source and chemical composition whole rock major and trace element analysis was performed for the aggregates. Results of this analysis of the aggregates are presented in Table 2.

Table 2. Chemical compositions of aggregate specimens percentage of component

Aggregate Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	Loss of Ignition
CB	60.60	16.81	5.66	1.98	4.81	4.66	2.77	1.02	0.37	0.09	0.007	1.00
CK	1.51	0.39	0.18	0.26	55.24	0.09	0.07	0.02	0.09	<0.01	<0.002	42.1

Table 3. Typical properties of 100/150 penetration bitumen

Properties	B100/150	Specification
Source	Kirikkale/Turkey	
Penetration grade	100/150	
Penetration at 25 ºC (77 ºF)	133 ºC (271 ºF)	ASTM D 5
Specific gravity	1.035 (gr/cm^3)	ASTM D 70
Softening point	44 ºC (111 ºF)	ASTM D 36
Loss on heating (%)	0.8	ASTM D 6
Flash point (C)	230 ºC (446 ºF)	ASTM D 92

Method

In this study, CB and CK chip seal specimens were prepared with three different embedment depth and then aggregate retention performance was determined using with HSKSC simulator. Initially, aggregates were screened between 1/2" - 3/8" (5.6 – 9.5 mm) sieves and flat/elongated particles were dropped. Amount of bitumen rate were calculated depending on aggregate average least dimension (ALD) which is required for the determination of the quantity of a bituminous product to be sprayed in the case of normal road surface treatments. According to aggregate ALD value, embedment depths were adjusted for each specimen. As to specimen fabrication, the bitumen was heated to 150 ºC and poured on the plate according to design application rate, and the preweighted aggregate was applied to the asphalt cement immediately. Later, the aggregates were compacted using the rubberized cylinder for three full cycles along the wheel pass direction of the specimen. The specimens were cured at 25 ºC (77 ºF) for 24 hours. Before each specimen was fastened to main HSKSC device, the specimens were turned vertically and loose aggregates were removed by lightly brushing. Figure 3 presents the chip seal specimen fabrication for HSKSC test.

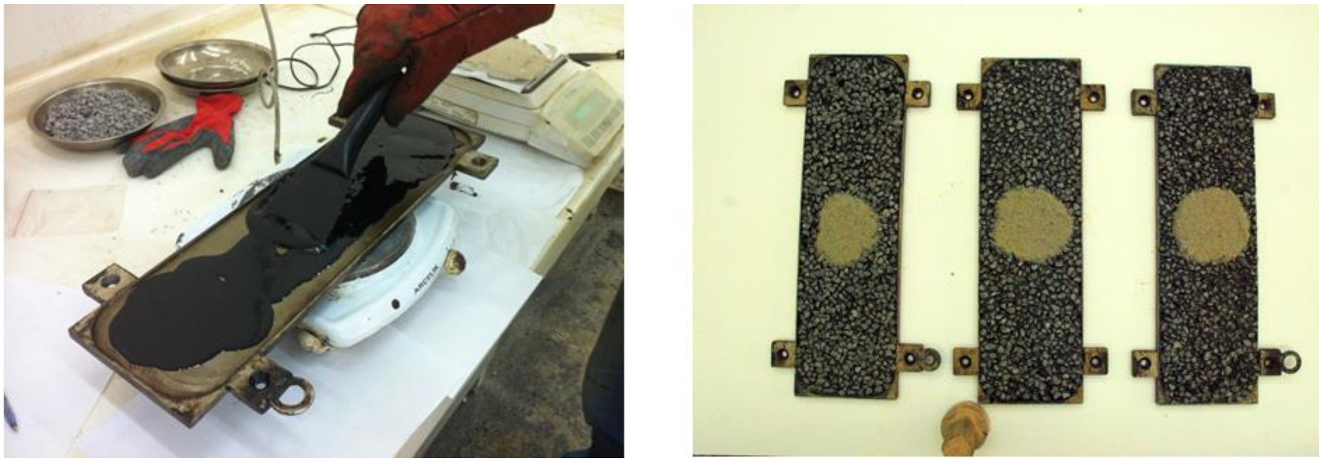

Figure 2. Specimen fabrication for HSKSC test

After fabrication of the specimens, aggregate embedment rates were calculated by determining depth of macrotexture according to sand patch test and aggregate ALD values. The steel plate prevents the penetration of the aggregate particles into the existing surface. Embedment depth is generally determined during the chip seal construction by pulling several chips out of the bitumen and visually estimating the amount of embedment. This is difficult and often subjective even if chips have a very low flakiness index. Therefore the following method used to calculate the depth of embedment and equation is given below:

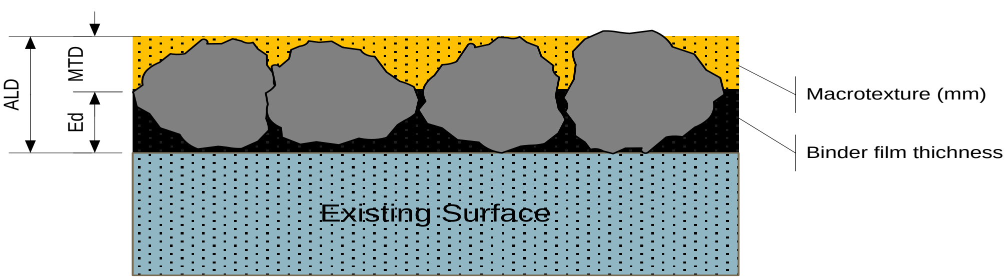

Fig. 3. Calculation of Embedment Depth

$$Ed= \frac{(ALD\text{-}MTD)}{ALD} * 100 \qquad \text{(Eq. 1)}$$

Where;

Ed = Embedment depth (%)
ALD = Average least dimension (mm)
MTD = Macrotexture depth (mm)

Aggregate retention performance of chip seal specimens was determined using with a device which is vehicle load simulator called HSKSC (13). HSKSC in a climate cabin and can apply various traffic load and climate condition to road pavement samples. The wheel mounted on the simulator can moves to back and forth on mold longitudinal direction through a pneumatic piston. Also, it is able to change position on the mold transverse direction so that multiple samples are tested at the same time and condition. The loading unit can apply up to 1500 kgf (3307 lbf) on the specimens. In this study, all chip seal specimens were tested under 500 kgf (1102 lbf) approximately. Diameter of the wheel is 48.5 cm (19.1 in.) and, it inflated to 70 psi. The wheel travels at a speed of about 1500 pass per hour, which corresponds to dynamic loading of 0.42 Hz on the specimen surface. Plates of the chip seal specimens for HSKSC testing have a rectangular shape. Its dimensions have 15 cm (5.9 in. - width) × 50 cm (19.7 in. -lenght). This dimension was determined according to width of tire (14 cm – 5.5 in.) and main mold. Hence, the wheel is in contact with the entire surface of the specimen during the traveling. All these units can be controlled by an external microprocessor-controlled, programmable electronic panel. Figure 4. shows units of HSKSC and climate cabin.

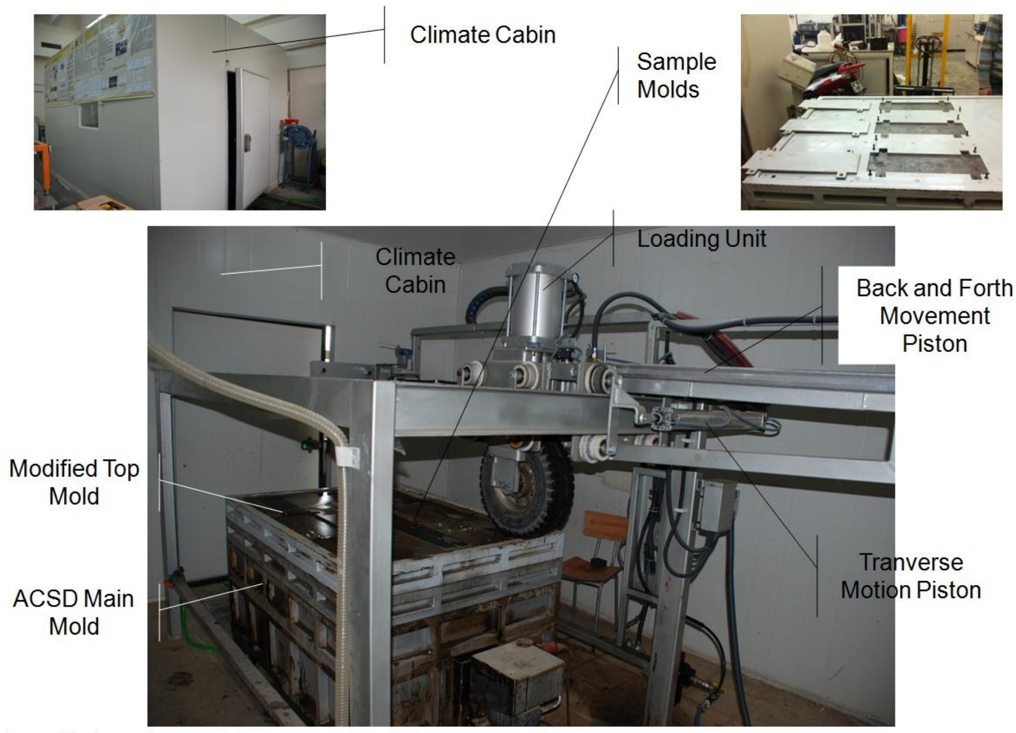

Figure 4. A View of HSKSC and climate cabin

To simulate the worst condition in field for chip seal in respect to aggregate retention performance, the water was poured on the specimens and performance tests were conducted in water. To determine the aggregate losses from the specimens, the weight of the specimens was measured before and after the HSKSC test. In addition, dislodged aggregates were collected after the test and then reweighted. The percentage of aggregate loss was calculated by equation (2).

$$\text{Aggregate Loss, \%} = \frac{W_f - W_i}{W_i} \times 100 \qquad \text{(Eq. 2)}$$

where Wf is the final aggregate weight after the HSKSC test and Wi is initial aggregate weight before the test.

FINDINGS

Depending on the aggregate ALD values specimens with three different aggregate embedment were fabricated. Embedment rates for CB aggregates are 37%, 54% and 65% and CK aggregates are 38%, 53% and 65%. Aggregate loss of two aggregates after HSKSC tests are shown in Fig. 5.

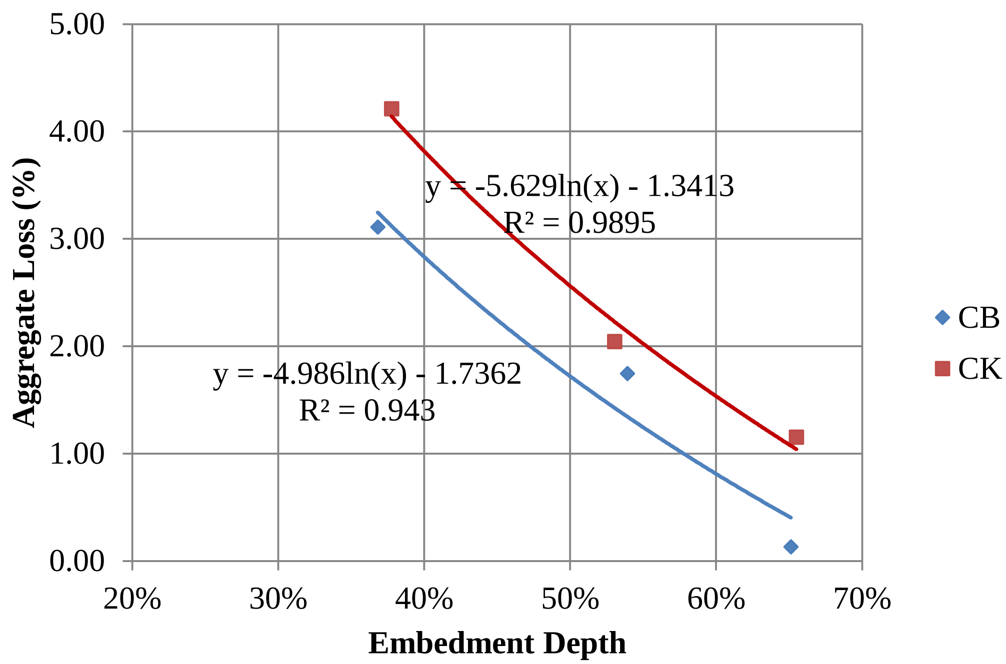

Fig. 5. Aggregate loss of chip seal depending on the various embedment depths

As it is seen in Fig. 5 increasing aggregate embedment depth significantly reduces aggregate losses for both aggregate types. Aggregate loss for CB aggregate 3.11 % was determined at 37% embedment rate. However, increasing the embedment rate to 65%, loss of aggregate was determined almost zero after HSKS test. Similar results were observed for CK aggregates. Loss of aggregate were decreased from 4.21% to 1.15% when embedment rate increasing from 38% to 65%. These results may seem like a good performance for chip seal retention performance, in terms of low initial macrotuexture depth can causes a potential risk for bleeding distress and skid resistance reduction over time. In particular, chip seals on granular base layer, aggregate embedment into the substrate over time will accelerate loss of macrotexture and several distresses can be take place. Therefore, adjusting initial embedment depth is important in future macrotexture situation. Macrotexture changing depending for CB and CK aggregates are seen in Fig. 6.

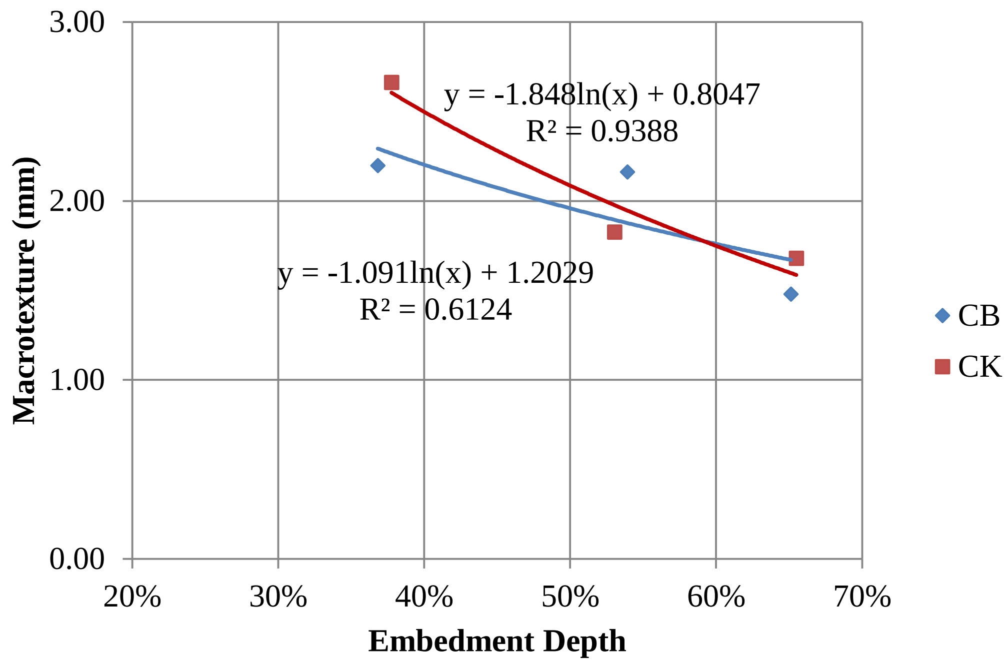

Fig 6. Macrotexture changing for CB and CK aggregates

In New Zealand, minimum chip seal macrotexture value is given as 0.9 mm for the chip seal specification (14) and it is recommended that chip seals under this macrotexture value is need to be reconstructed. Embedment depth following the chip seal construction should be at least 35% before the winter. Otherwise, aggregate loss will substantially start after winter season. Results of this study shows that increasing the embedment depth increases the aggregate retention performance, but it causes the loss of macrotexture. When adjusting of the initial embedment depth of the chip seals, macrotexture values should be taken into consideration in terms of chip seal service life and quality.

CONCLUSION AND RECOMMONDATION

In this study, chip seal retention performance with two type of aggregate depending on the embedment rate was evaluated Accelerated Chip Seal Simulation Device (HSKSC). Based on the experimental results of the study the following conclusions were made:

- Aggregate loss for CB aggregate 3.11 % was determined at 37% embedment rate while loss of aggregate was determined almost zero at 65% embedment after HSKS test. Similar results were observed for CK aggregates. Loss of aggregate were decreased from 4.21% to 1.15% when embedment rate increasing from 38% to 65%.
- Increasing the embedment rate causes to close the critical limits of macrotexture (0.9 mm) which is significantly important for chip seal service life. Therefore, adjusting of the initial embedment depth of the chip seals, macrotexture values should be taken into consideration in terms of chip seal service life and quality.

This study only focuses on the two type of aggregate with one size dimension. Also, hot applied chip seal performance with penetration bitumen was tested. Further studies should be done to determine exact initial embedment depth depending on the various situations the use of different type of aggregate and emulsions/binders under various climate conditions.

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