# Effect of Using Crumb Rubber with Warm-Mix-Asphalt Additive in Laboratory and Field Aging

Mustafa Akpolat, Baha Vural Kök

***Abstract*****—**Using a waste material such as crumb rubber (CR) obtained by waste tires has become an important issue in respect to sustainability. However, the CR modified mixture also requires high manufacture temperature as a polymer modified mixture. For this reason in this study, it is intended to produce a CR modified mixture with warm mix asphalt additives in the same mixture. Asphalt mixtures produced by pure, 10%CR, 10%CR+3% Sasobit and 10%CR+0.7% Evotherm were subjected to aging procedure in the laboratory and the field. The indirect tensile repeated tests were applied to aged and original specimens. It was concluded that the fatigue life of the mixtures increased significantly with the increase of aging time. CR+Sasobit modified mixture aged at the both field and laboratory gave the highest load cycle among the mixtures.

***Keywords*****—**Crumb rubber, warm mix asphalt, aging, fatigue.

## I. Introduction

THE durability of bitumen is identified as the resistance to aging [1], [2]. The aging is known as the hardening of the bitumen due to various factors. The main mechanism of aging of bitumen is oxidation and loss of lower molecular weight volatiles during the production of hot mix asphalt (HMA) and in service life. As a principal mechanism, oxidation aging is an irreversible chemical reaction between components of bitumen and oxygen. The hydrogen is reduced with the combination of hydrocarbon compounds and oxygen in the oxidation processes [3].

The aging in bitumen mixtures may be investigated under two headings as short-term and long-term aging. Short-term aging occurs during the storage of the bitumen and transfer of it to the plant, or during mixing of the aggregates, transport to the application area, and spreading and compaction processes; while, the long-term aging occurs during the service life of the pavement [3], [4]. It has been reported in previous studies that in the first process, some substances in the asphalt become volatile causing the asphalt to become hardened; and in the second process, oxidation occurs in a slow and long-term manner and is known as the real hardening, which causes decreases in adhesion in the end [5]. Aging is considered as an important factor influencing the viscoelastic-viscoplastic properties of asphalt mixtures. After aging, asphalt coatings have higher rigidity and better wheel track resistance; however, due to the high rigidity, they are also prone to fatigue and thermal crack formation [4]. In the study, it was reported that the viscosity of the binder and the stiffness of the mixture increased after short- and long-term ageing [6].

The effect of aging in flexible coating performance also depends on internal and external variables along with time. Internal variables are the binder-aggregate properties, the percentage of the binder in the mixture, the asphalt film thickness and air void percentage. External variables are defined as the aging during production (short-term aging) and environmental effects (long-term aging) [7].

Wang et al. investigated the thermo-oxidative aging mechanism of asphalts modified with CR, and reported that the CR modified asphalt improved the thermo-oxidative aging with the increase in CR, and this was a result of the resolution of the CR in the binder in further aging stages [8].

It was denoted that the rutting parameter of binder after long-term aging reduced with the increase of CR content [9], [10]. The study showed that warm mix additives such as Rediset, Sasobit and Evotherm decreased the rate of hardening occurring in the bitumen in time [11].

Different aging procedures were applied to pure and modified mixtures. The samples were aged both in the laboratory and field. The indirect tensile repeated tests were carried out on the samples.

### A. Materials

B 50/70 pure bitumen obtained from Turkish petroleum Refineries was utilized as original binder. The properties of the pure binder are given in Table I. The CR used in the bitumen modification was obtained from Samsun Akın Kaucuk (waste rubber) Company. The CR was crushed mechanically to a diameter of 0.3–0.6 mm. Sasobit, was obtained from the Sasolwax Company. Sasobit, which is an organic warm mixture additive, is an aliphatic hydrocarbon obtained with the Fischer–Tropsch Method. Evotherm, which is a chemical warm mixture additive, was obtained from the MeadWestvaco Company. Images of the additives are shown in Fig. 1. The pure bitumen was blended with the additives by using high shear mixer (Fig. 2) in the laboratory. The bituminous mixtures containing pure and modified binders were produced with lime stone. The properties of used aggregate and gradation of the mixtures are given in Table II.

### B. Method

Firstly, the pure binder was modified with 10%CR, 10%CR+3% Sasobit and 10%CR+0.7% Evotherm. The modified binders were produced by high shear mixer at 2000 rpm, 170°C and 45-minute mixing processes. The combination of the binders and representation are given in Table III.

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TABLE I
BITUMEN PROPERTIES

| Properties | Standard | B50/70 |
|---|---|---|
| Penetration (1/100cm) | ASTM D5 | 51.25 |
| Softening point (°C) | ASTM D36 | 52.2 |
| Penetration index (PI) | | -0.61 |
| Specific gravity | | 1.032 |
| Viscosity (cP, 135°C) | ASTM D4402 | 600 |
| Viscosity (cP, 165°C) | ASTM D4402 | 175 |
| Mixing temperature (°C) | | 165.8 |
| Compacting temperature (°C) | | 152.8 |

(a) (b) (c)

Fig. 1 (a) CR (b) Sasobit (c) Evotherm

Secondly, the bituminous mixtures were produced with these binders according to Marshall mix design. The optimum bitumen content was determined at 5.3% for the unmodified mixture. Pure and modified mixtures were subjected to aging procedure at the laboratory and field. The specimens were kept at 60°C for 1 week, 2 weeks, 3 weeks and 4 weeks in the laboratory, and 12 months with 2 month periods in the field. Fatigue tests were carried out in order to evaluate the repeated tensile properties of the mixtures. The test was performed at 25°C under 400 kPa stress by using an UMATTA test device (Fig. 3). The test was continued until the specimens split entirely. The experimental program is given in Fig. 4.

Fig. 2 High Shear Mixer

TABLE II
PHYSICAL PROPERTIES AND GRADATION OF AGGREGATE

| Seive size (mm) | 19.1 | 12.7 | 9.52 | 4.76 | 2.00 | 0.425 | 0.18 | 0.075 |
|---|---|---|---|---|---|---|---|---|
| Passing (%) | 100 | 94.0 | 81.0 | 50.0 | 30.0 | 15.0 | 10.5 | 5.5 |
| Specific gravity (g/cm$^3$) (Coarse, fine, filler) | | | | 2.552 | 2.580 | 2.713 | | |
| Abrasion loss (%) (Los Angeles) | | | | | 29 | | | |
| Soundness (%) ($Na_2SO_4$) | | | | | 4.5 | | | |
| Stripping resistance (%) (Nicholson) | | | | | 70-75 | | | |

TABLE III
BINDER COMBINATIONS

| Additives | Additive content by weight of binder (%) | | | |
|---|---|---|---|---|
| CR | 0 | 10 | 10 | 10 |
| Sasobit | 0 | 0 | 3 | 0 |
| Evotherm | 0 | 0 | 0 | 0.7 |
| Representation | 0-0 | 10-0 | 10-3 | 10-7 |

Asphalt pavements are subjected to short-time of loading by each wheel passing. These loads lead to micro deformation resulted from a decrease in the stiffness of the material. These micro deformations cause the deterioration of the asphalt layer which are known as fatigue cracks in the long service life of the pavement [12]. Fatigue cracks are the most common deterioration type originated from repeated loads. Fatigue cracks accelerate after the initial crack with continuous traffic loads [13], [14].

Fig. 3 Fatigue test equipment

## II. RESULTS AND DISCUSSION

### A. Fatigue Test Result

The variations on load cycle number with the aging time are given in Fig. 5 for laboratory aging. It is seen that the load cycle increases significantly with the increase of aging time.

When the cracking is considered, it was determined that the load repetition number of the samples that were aged for 1 week, 2 weeks, 3 weeks, and 4 weeks increased at a rate of 6.8-fold, 10.6-fold, 14.6-fold and 20-fold, respectively, when compared with the unaged samples. For the pure samples, while the increase in the load repetition number that occurred in the first week was 6.8-fold, it was determined to be 1.5-fold between the first week and second week, 1.4-fold between the second wek and third week, and 1.4-fold between the third week and fourth week. This rate shows similarities for other mixture types. This is assessed as the indicator showing that the mixture is aged a great deal in the first week.

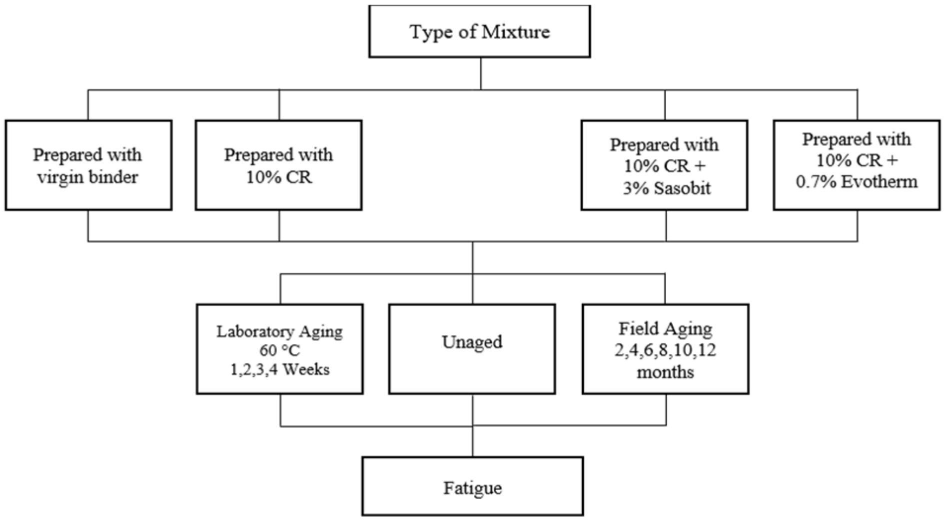


Fig. 4 Experimental program

When all the mixture types that are aged in the laboratory are compared with each other, it is seen that the best performance is given by the CR+Sasobit-modified mixtures. In addition, it was also determined that as the aging duration increased, the CR+Evotherm-modified mixtures gave higher load repetition values when compared with the only CR-modified mixtures.

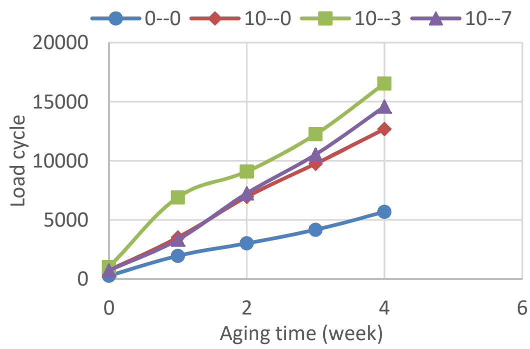


Fig. 5 The variations on load cycle of laboratory specimens with the aging time

In Fig. 6, the relationship between the load cycle and the aging period of the mixtures following the aging in the field was presented. It can be observed in the figure that with increasing aging period in the field (except the 8$^{th}$ month), the fatigue life of samples increased. However, due to the fact that the 8$^{th}$ month was a winter month and the consequent effect of the rain on the samples, a slight decrease in the number of load cycles was observed for the samples.

As it is the case in laboratory aging, the best performance in terms of fatigue life was observed in CR+Sasobit-modified mixtures in field aging conditions. Again, if the laboratory and field aging values are compared for CR and CR+Evotherm-modified mixtures, it is seen that as the aging duration increases, the CR+Evotherm-modifed mixtures show better performances when compared with CR-modified mixtures, which is also the case in mixtures with similar properties in field aging studies.

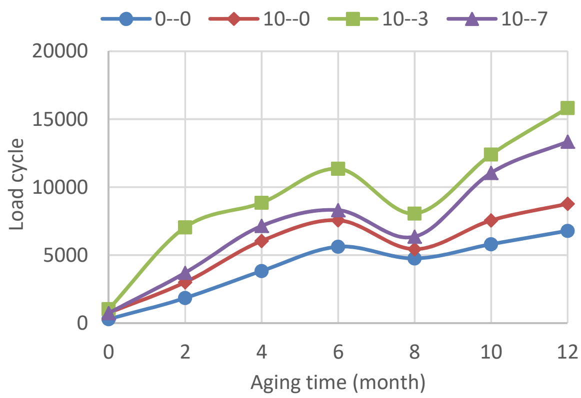


Fig. 6 The variations on load cycle of field specimens with the aging time

*B. Result of Fatigue Index*

Fatigue Index (FI) was also identified by multiply the load cycle number and deformation.

The changes in fatigue indices after laboratory and field ageing are given in Table IV. According to the results, for pure binder, CR, CR+Sasobit and CR+Evotherm-modified mixtures, there are 18.1-fold, 8.2-fold, 14-fold and 10.6-fold increases, respectively, between the ageing indices after 4-week ageing; and the fatigue indices of the samples that are not aged. These values ranged as 24.9%, 8.3%, 8.9% and 9.3% for the field aged specimens. When the samples that were aged in laboratory for 4 weeks are considered, it was determined that the 42.9%, 42.3%, 44.8% and 36.7% increases that occurred in the fatigue indices occurred in the first week for pure binder, CR, CR+Sasobit and CR+Evotherm-modified mixtures.

TABLE IV
FATIGUE INDEX OF THE TEST RESULTS

| Mixing type | Unaged | Fatigue index (FI) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Laboratory aging (week) | | | | Field aging (month) | | | | | |
| | | 1 | 2 | 3 | 4 | 2 | 4 | 6 | 8 | 10 | 12 |
| 0-0 | 918.84 | 7122 | 8947 | 11434 | 16603 | 5408 | 9187 | 17744 | 14029 | 15405 | 21014 |
| 10-0 | 2047.49 | 7069 | 10626 | 13356 | 16710 | 5848 | 11152 | 13003 | 11553 | 12061 | 16903 |
| 10-3 | 2278.21 | 14243 | 15363 | 20918 | 31831 | 12295 | 12900 | 18937 | 14699 | 16488 | 21098 |
| 10-7 | 2080.73 | 8101 | 13553 | 17991 | 22085 | 8599 | 11712 | 13325 | 11905 | 14828 | 19322 |

### *C. Result of Aging Index*

The ratio of the repeated load number of aged samples to that of the unaged ones was identified as the aging index (AI) and represented in Figs. 7 and 8. The 61.4%, 50.1%, 62.7% and 47.5% of the whole aging of pure, only CR, CR+Sasobit and CR+Evotherm modified mixtures occurred at the first week in the laboratory, respectively (Fig. 7). These values ranged as 49%, 38.2%, 53.4% and 42.5% at the second month for the field aged specimens (Fig. 8). A linear increase was observed in the aging index after one week for laboratory and two months for field specimens. The aging trend is in harmony with the specimens in both the laboratory and the field.

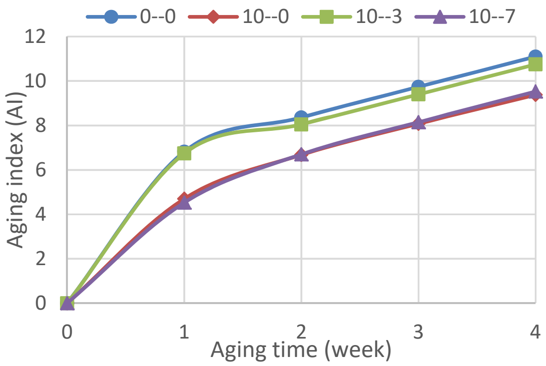


Fig. 7 The variation on the aging index of laboratory specimens

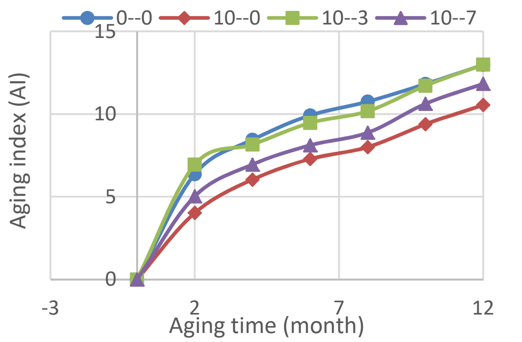


Fig. 8 The variation on the aging index of field specimens

## III. CONCLUSION

In this study, asphalt mixtures produced by pure, 10%CR, 10%CR+3% Sasobit and 10%CR+0.7% Evotherm were aged under different conditions in the laboratory and the field. The specimens were kept at 60°C for 1 week, 2 weeks, 3 weeks and 4 weeks in the laboratory and 12 months with two month periods in the field. Fatigue tests under repeated tensile mode were applied to the aged and unaged mixtures. It was concluded that the increase of aging time induced a significant increase in the fatigue life of the mixtures. The mixture including both CR and Sasobit has the highest load cycle number within all the mixtures after laboratory and field aging. In the comparison of the fatigue lives following both laboratory and field aging, it was determined that 4-week laboratory aging was equal to 12-month field aging for mixtures with pure binders, CR+Sasobit additive and CR+Evotherm additive. For mixtures with CR binder, it was determined that approximately 3-week laboratory aging was equal to 12-month field aging. Using the WMA additive with CR induced a reduction in the aging effect of the mixture. In the study, the ratio of the repeated load number of aged samples to that of the aged ones was identified as the aging index (AI). Considering the samples that were subjected to 4-week aging in the laboratory, 61.4%, 50.1%, 62.7% and 47.5% of the observed aging of the modified mixtures with pure binders, CR additive, CR+Sasobit additive and CR+Evotherm additive, respectively, occurred in the first week.

The values ranged as 49%, 38.2%, 53.4% and 42.5% in the second month for the field-aged specimens. The unmodified mixture gave the highest and the CR modified mixture gave the lowest AI indicating a susceptible and durable behavior to the aging effect, respectively. Fatigue Index (FI) was also identified by multiply the load cycle number and deformation. A good correlation was established between the AI, FI values of laboratory aged and field aged mixtures.

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