Investigating the effect of using modified recycled concrete aggregate on the volumetric and mechanical properties of hot asphalt mixes

Alireza Azarhoosh[1*]

[1] Department of Civil Engineering, Faculty of Engineering, University of Bojnord

E-mail: azarhoosh@ub.ac.ir

ABSTRACT

Coarse recycled concrete aggregates have weaker mechanical and physical properties than natural aggregate because of the porous and flimsy cement mortar. Hence, using coarse recycled concrete aggregate in the asphalt mixtures decreases their resistance to different failures. Therefore, in this research, in order to reduce the permeability and increase the resistance of adhered cement mortar, coarse recycled concrete aggregate was modified by two chemical (coating their surfaces using styrene butadiene rubber polymer) and physical (separation of cement mortar using heating) methods. The results of the dynamic creep test also show that employing coarse recycled concrete aggregate increases permanent deformation in the specimens under test because the asphalt mixture stiffness is decreased. But asphalt mixtures containing treated coarse recycled concrete aggregate have less permanent deformation because the styrene butadiene rubber polymer with the penetration into the void of coarse recycled concrete aggregate and reinforcing cement mortar, as well as removing the cement mortar by heat, increases their stability. Also, asphalt mixtures containing coarse recycled concrete aggregate have a lower fatigue life compared to the control mixture, and chemical modification of aggregates has been more effective in increasing the fatigue life of the mixtures containing them compared to the physical method. In addition, the results show that the presence of moisture reduces the resistance of controlled and modified asphalt mixtures against moisture damage, and this reduction is greater in mixtures containing coarse recycled concrete aggregate due to their high absorption.

KEYWORDS

Recycled concrete aggregate, styrene butadiene rubber polymer, fatigue life, rutting potential, moisture susceptibility.

1. Introduction

According to the literature, ~3750 tons of hot-mix asphalt and 3500 tons of natural aggregate are required for paving a road with a width of 10 m, a thickness of 15 cm, and a length of 1 km [1]. Thus, annually, a large amount of natural aggregate is incorporated in the pavement industry worldwide, and this value is on the rise due to the development of the said industry. The increasing demand for natural aggregates has led to natural resources' depletion and, consequently, environmental concerns [2].

Pasandin and Perez [3] investigated RCA incorporation in the asphalt concrete along with different additives. Contents of 5%, 10%, 20%, and 30% of RCA coated with 5% bitumen emulsion were used as part of the aggregate. The results showed that specimens containing RCA coated with emulsion bitumen possessed a higher effective bitumen content and superior performance than those containing RCA. The resistance of asphalt mixtures containing RCA and crumb rubber (as a bitumen modifier) to moisture damage was evaluated in another study. The results revealed that asphalt mixtures containing RCA had higher moisture susceptibility compared to control mixtures, and the use of bitumen modified by crumb rubber improved the performance of the mixtures [4].

2. Methodology

The optimum amount of coarse recycled concrete aggregates (CRCA) in asphalt mixtures has been determined to be 30-40% [5]. As a result, the amounts of 15, 30, and, 50% of RCA were utilized as portions of coarse aggregates in hot-mix asphalts. Furthermore, it has been shown that the film of porous adhered cement mortar is the main cause of the deficiency of performance of RCAs as aggregates in asphalt mixtures. Accordingly, to reduce the porosity and, therefore, water and bitumen absorption of CRCA (the reason for its restricted use), their surface was coated with styrene butadiene rubber (SBR). For this purpose, CRCA was first mixed with SBR at 5% by weight of CRCA and was then placed in the oven at 270-280 °C for 2 hours. Subsequently, the mixture was removed from the oven and stirred for 10 minutes to prevent aggregate lumping.

The typical procedure designated as Marshall mix design was followed to specify the optimum percentage of bitumen of the control and modified asphalt mixtures [6]. The optimum bitumen content in all types of mixtures is the bitumen content corresponding to the air void of 4%. Also, the other Marshall parameters for all types of asphalt mixtures were controlled at the optimum bitumen content with permissible values.

In order to evaluate the properties of asphalt mixtures containing CRCA, dynamic creep, fatigue and indirect tensile strength (ITS) tests were used in this research. In dynamic creep test, the sample is under the loading and unloading mode, and the changes of accumulated strain are computed in each cycle. Three separate regions can be detected in the curve obtained from the dynamic creep test (accumulated strain against cycles of loading chart). In this method, the flow number (loading cycle number at which the third region of the curve begins) correlated with the rutting potential of HMAs. This parameter further demonstrates a specific cycle in which the asphalt sample shear strength is lost, and specimen failure is initiated. To determine the flow number, the creep curve was fitted by the Francken model [7].

$$\varepsilon_p(N) = aN^b + c\left(e^{dN} - 1\right) \quad (1)$$

Indirect tensile fatigue test involves the application of consistent tensile stress to the sample along the entire length of the cylindrical specimen, perpendicular to the direction of loading. The above-mentioned testing procedure was followed under stress-controlled conditions in which haversine loading with a frequency of 2 Hz (0.1 s of loading time, and 0.4 s of rest time) was implemented. Moreover, different maximum stress levels (200 to 500 kPa), temperature of 15°C were established to assess the effects of traffic loading and environmental conditions on the fatigue life of the control and modified mixtures.

According to the European Committee for Standardization (CEN), fatigue life is characterized by the number of loading cycles leading to the fracture of the tested specimen or the induced vertical deformation of 12.7 mm (0.5 in) in the asphalt mixture. Plotting the logarithmic chart of the variation of fatigue life vs. stress level results in the application of a regression line based on Eq. (2) to determine the coefficients of K_1 and K_2:

$$N_f = K_1\left(\frac{1}{\sigma_t}\right)^{K_2} \quad (2)$$

Loading of the ITS test is carried out at a loading rate of 5.08 cm (2 inches) per minute until the sample is ruptured. The amount of load is recorded at the rupture moment. Then the ITS value of the samples is obtained using equation 3.

$$ITS = \frac{2F}{t\pi d} \quad (3)$$

The average ITS value of dry (three samples) and wet (three samples) samples is calculated separately. The moisture susceptibility or the stripping potential for asphalt mixture samples is obtained by the ratio of the average ITS value of the wet to dry samples (in percent).

$$TSR = \left(\frac{ITS_{wet}}{ITS_{dry}}\right) \times 100 \quad (4)$$

3. Discussion and Results

Flow number, which is a suitable index for determining HMA rutting potential, was computed using the Francken method. For this purpose, the Francken models were fitted to the rutting data, and the results are presented in Figure 1. The addition of base and modified CRCA until 50% decreased the asphalt concrete's flow number and rutting resistance.

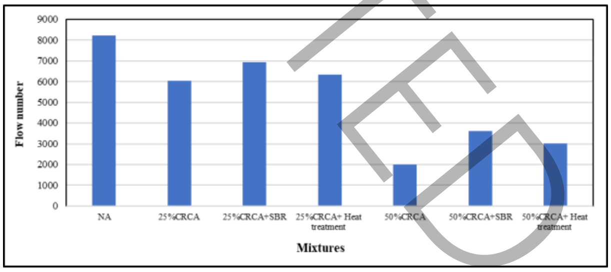

Figure 1. Flow number for the base and modified asphalt mixtures

The fatigue life of specimens was determined by the indirect tensile method (Figure 2). The use of CRCA at all values reduced the resistance of hot-mix asphalts to fatigue cracking, and the rate of reduction was greater as this value increased. Although CRCA has better adhesion to bitumen, which can help improve fatigue life, it greatly decreases the loading capacity of asphalt specimens due to its highly porous and weak cement mortars. The use of SBR coatings on CRCA surfaces improves not only their adhesion to bitumen, but also their physical and mechanical properties by penetrating the CRCA voids and reinforcing them. Therefore, asphalt specimens containing CRCA treated with SBR had a longer fatigue life than the specimens containing CRCA and were closer to the control mixtures.

Moisture creates cohesive cracks in the bitumen and adhesive cracks in the bitumen-aggregate contact surface, which expand by applying a load and cover the entire thickness of the asphalt. Therefore, all asphalt specimens (controlled and modified) had less fatigue life under wet conditions.

4. Conclusions

The following conclusions could be drawn based on the experiments performed on different materials and asphalt mixtures:

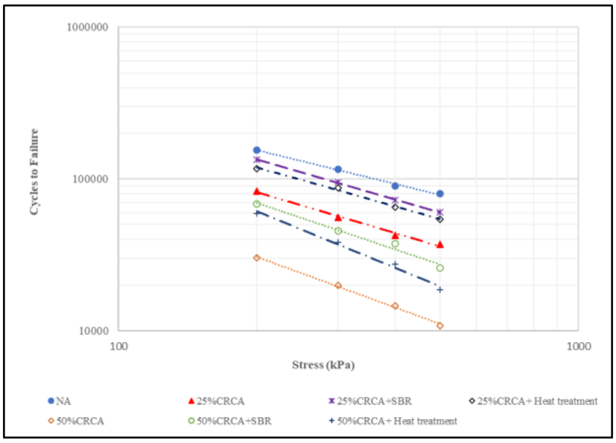

Figure 2. Fatigue life versus stress levels for the base and modified asphalt mixtures

- The flow number 50 ºC indicated that using untreated and treated CRCA reduces this index and increases the rutting potential in the asphalt concrete.
- Mixtures containing untreated and treated CRCAs have lower fatigue life compared to control mixtures due to the relatively poor mechanical and physical properties of CRCA.
- The use of untreated and treated CRCA decreases the TSR in asphalt mixtures, and hence, their resistance to moisture damage.

5. References

[1] S. Ektas, M. Karacasu, Use of Recycled Concrete in Hot Mix Asphalt and an ANN model for Prediction of Resilient Modulus, Ekoloji Dergisi, 21(83) (2012).

[2] M.M. Rafi, A. Qadir, S. Ali, S.H. Siddiqui, Performance of hot mix asphalt mixtures made of recycled aggregates, Journal of Testing and Evaluation, 42(2) (2014) 357-367.

[3] A. Pasandín, I. Pérez, Mechanical properties of hot-mix asphalt made with recycled concrete aggregates coated with bitumen emulsion, Construction and Building Materials, 55 (2014) 350-358.

[4] I. Pérez, A. Pasandín, Moisture damage resistance of hot-mix asphalt made with recycled concrete aggregates and crumb rubber, Journal of Cleaner Production, 165 (2017) 405-414.

[5] H.K.A. Al-Bayati, S.L. Tighe, J. Achebe, Influence of recycled concrete aggregate on volumetric properties of hot mix asphalt, Resources, Conservation and Recycling, 130 (2018) 200-214.

[6] ASTM. D6927–15, Standard Test Method for Marshall Stability and Flow Ofasphalt Mixtures, West Conshohocken, PA., in, 2015.

[7] L. Francken, Permanent deformation law of bituminous road mixes in repeated triaxial compression , in: 4th International Conference on Structural Design of Asphalt Pavements, Michigan, August 22-26, 1977.