ABSTRACT

With increase in traffic and extreme environmental changes, pavement engineers have focused on reducing the premature distresses and increasing the pavement design lives by modified the asphalt materials. Several investigations focused on reducing the viscosity-temperature susceptibility of the asphalt binder by modifying it with additives. One of such additives that have been successful is crumb rubber (CR). Though CR modified binder is used with different types of gradations; gap- and open-graded gradations have shown better performance than conventional dense-graded (DG) mixes.

The main objective of this research study was to develop laboratory mix design practices for asphalt-rubber gap-graded (AR-Gap) mixtures suitable for heavy traffic conditions through the evaluation of their structural performance characteristics. The mix design practices were developed in lines with the globally accepted Superpave mixture design procedure usually used for conventional dense graded asphalt mixes. The research study used a total of 49 different asphalt binders (~8000 data points from ten test techniques), 28 types of asphalt mixtures (27 AR-Gap and 1 DG mix) covering seven mixture performance tests producing over 10000 data points from 894 specimens to arrive at the objective.

CR modified / AR binders were prepared in the laboratory using a blender-stirrer combination developed at the Indian Institute of Technology Kharagpur. The digestion time was statistically optimized and recommended to be 90 min for an asphalt-CR blend at 170-180 ^{o}C mixed at 2000 rpm. Conventional binder consistency and advanced rheological tests on AR binders with varying base binders and CR dosages showed an improvement in the binders‟ strength and elasticity with the inclusion of CR. AR binders also showed lower viscosity-temperature susceptibility than the virgin binders. The increment of binder properties was directly related to the stiffer base binder properties and higher CR dosage. A CR dosage of 20% was recommended and selected for further binder studies.

AR binders modified with different CR gradations were prepared and analyzed to elucidate the effect of CR gradation on AR binder performance characteristics. Conventional consistency and advanced rheological test results were statistically analyzed to determine the significant effect of CR gradation. Artificial Neural Network (ANN) modeling and Ashby plots were utilized for better understanding and easy AR binder selection. Additionally, thermogravimetric analysis and Fourier Transform Infrared Spectroscopy tests on selected binders indicated that CR inclusions improved the binders’ thermal stability and augmented the sulfoxide bond in AR binders. Based on the studies, fine CR gradations were proposed for the development of superior AR binders and to blend AR-Gap mixtures.

The gap gradations used globally were analyzed based on basic gradation checks as per The Asphalt Institute guidelines, and two gradations from seven types were chosen for further evaluation. The study also developed eight trial gradations and based on the gradation checks, one gradation amongst the eight gradations was chosen for advanced analyses and performance evaluation. Superpave mix design procedure was found to be more appropriate than Marshall mix design for producing AR-Gap mixtures since Superpave is based upon kneading compaction efforts that closely simulates prevalent field conditions and eliminates aggregate degradation usually found with Marshall mix design.

AR-Gap mixture characterizations were carried out with the help of resilient modulus (Mr) and dynamic modulus ($|E^*|$) tests. Statistical analysis on Mr, $|E^*|$, and ϕ explained the significance of gap gradation, AR binder type, and binder content in the mixture characteristics. Further, $|E^*|$ and ϕ master curves helped interpret the effect of test temperatures and frequencies on viscoelastic properties of AR-Gap mixtures. The $|E^*|$ predictive model with very good statistical goodness of fit measures ($R^2_{adj} = 0.88$; $S_e/S_y = 0.34$) assisted in understanding the correlations between $|E^*|$ and the various AR-Gap mixture parameters.

Performance of AR-Gap mixtures towards three major distresses: permanent deformation, cracking (thermal and fatigue), and moisture damage were assessed. Wheel tracking test was employed for investigating the rutting resistance. Static and dynamic semi-circular bending (SCB) tests were utilized for assessing the cracking resistance of AR-Gap mixtures. Further, indirect tensile strength (ITS) and tensile strength ratio (TSR) results were used to study the moisture susceptibility of the AR-Gap mixtures. Based on the performance tests, it was adjudged that AR-Gap mixtures performed exceedingly well against the various distresses making them suitable pavement construction materials.

Euclidean distance approach was utilized for ranking the AR-Gap mixtures. Based on the normalized Euclidean distance (NED) approach, the AR-Gap mixture design parameters for superior performing AR-Gap mixtures were determined. The best AR-Gap mixtures as determined from NED were demonstrated in the field by constructing AR-Gap pilot test sections. A set of recommendations was developed based on the laboratory studies carried out as part of this research to develop superior performing AR-Gap mixtures.

Overall, this research provided a good background on AR binders, its basic characteristics, and advanced performance behavior for the development of binder material for reducing various pavement distresses. Further, this research also focused on developing superior AR-Gap mixtures based on the investigations with various gap aggregate gradations

and their performance characteristics with different AR binders at various pavement conditions. It is envisioned that this research study will set a strong venue to advancing the current state-of-the-art pertaining to AR-Gap mixtures.

KEYWORDS: Asphalt-rubber, Gap gradation, AR-Gap mixtures, Superpave mix design, Rutting, Fatigue cracking, Thermal cracking, Moisture damage, Euclidean distance, Best performing AR-Gap mixture