ABSTRACT

One of the first steps in designing Hot Mix Asphalt (HMA) with Reclaimed Asphalt Pavement (RAP) material as per existing guidelines, including the Indian Roads Congress guidelines (IRC:120, 2015), is determining the RAP content that is allowed in the resulting mix. The allowable RAP content in the mix for a chosen fresh bitumen grade is usually determined mathematically (using blending equations) or graphically (using blending charts). The use of these blending equations/charts requires knowledge of the physical/rheological properties of the bitumen extracted and recovered from the RAP material. For the other steps of the mix design, such as for selecting gradation for the target mix or for estimating fresh bitumen quantity in trial mixes, in addition to the physical/rheological properties of the RAP bitumen, knowledge of RAP aggregate gradation (white curve) and bitumen content of the RAP material is also necessary.

Most existing guidelines recommend using the Solvent Extraction Method to extract bitumen from the RAP material. Subsequently, the bitumen is to be recovered from the decanted solution from solvent extraction either by Abson Recovery (or) Rotary Evaporator method. The recovered bitumen needs to be characterized for its physical/rheological properties. It was reported in several studies that the traces of the solvent remain in the recovered bitumen even after careful recovery and causes erroneous prediction of bitumen properties. This, in turn, influences the selection of allowable RAP content in the resulting mix, resulting in a mix with inferior performance. This issue is more evident in hot recycled mixes with high RAP content. This can be addressed if the need to recover the bitumen and subsequent testing can be waived for the design of hot recycled asphalt mixes. This can be accomplished by identifying the indices from indicative tests on the 100% RAP material that can indicate the RAP characteristics and allow the classification of the RAP materials of different sources into various categories based on their characteristics. If allowable RAP limits for these classification categories were developed, the requirement to recover the RAP bitumen for mix design purposes could be waived. Accordingly, the objective of the present study is to propose an approach for designing hot recycled asphalt mixes that waive the requirement to determine the RAP bitumen properties, which otherwise require bitumen recovery and subsequent testing on the recovered RAP bitumen.

The present study considered the Fragmentation and Cohesion tests as potential indicative tests. The indices derived from these two tests were evaluated as potential

indicators of the RAP characteristics. The RILEM Technical Committee 237-SIB originally proposed these tests to characterize RAP for cold mix design purposes. These two tests can be conducted using conventional apparatus routinely used for quality control tests and are likely to be available at most field laboratories. The fragmentation test is an impact test that measures the particle resistance to fragmentation under a series of impact loads. It involves determining the percentage of material passing through the control sieve (% PCS) (1.7 mm) after the load application. The fragmentation value is the sum of all the % PCS values obtained for all the fractionated RAP material fractions. The cohesion test is an Indirect Tensile Strength (ITS) carried out on a cylindrical specimen made of 100% RAP material conditioned and compacted at a selected temperature. In the present study, in addition to ITS, air voids and other parameters obtained from the load-displacement curve of the ITS test were also considered.

For the present research, fourteen different RAP sources with varying characteristics were obtained by milling distressed bituminous pavements in the various geographical regions of the country. Eleven RAP sources were used for the original investigation, and three were used for validation. The fragmentation test was carried out at three different test temperatures (5, 20, and 40°C). The cohesion test was carried out on specimens compacted at five conditioning/compaction temperatures (70, 100, 140, 170, and 190°C). The RAP material was kept for preconditioning in the oven for 4 hours prior to mixing and compaction at the compaction temperature. The detailed correlation analysis suggested that the RAP could be effectively characterized based on the indices derived from these two tests, i.e., S_{frag} from the fragmentation test and $S_{air\text{-}voids}$ from the cohesion test. The S_{frag} is the slope of the linear regression equation obtained for the normalized fragmentation value and the test temperature. $S_{air\text{-}voids}$ is the linear regression equation slope obtained from normalized air voids value and compaction temperature. The results suggest that S_{frag} can explain the variability in the physical properties of the RAP. Further, the index was found to have the potential to estimate the difference in % of fines passing through 4 mm in the black and white curves (RAP material and RAP aggregate gradation). $S_{air\text{-}voids}$ were found to correlate well with the bitumen content and difference in % of fines in the black and white curve.

Hierarchical Clustering on Principal Components (HCPC) obtained for the RAP characteristics suggested that all the tested RAP sources can be clustered into five distinguishable categories based on which the S_{frag} and $S_{air\text{-}voids}$ classification limits were

proposed. The HCPC analysis on test indices (S_{frag} & $S_{air\text{-}voids}$) also resulted in similar clusters of RAP sources, confirming the hypothesis that test indices (S_{frag} & $S_{air\text{-}voids}$) are an indicator of RAP characteristics. It was noted from this analysis that the cluster hierarchy is in terms of the combined influence of bitumen properties and bitumen content. The recommended classification approach was further verified by analyzing test results on three additional field RAP sources and four laboratory-aged RAP sources that were not part of the original investigation.

The allowable RAP limits for each RAP category were proposed by following Balanced Mix Design (BMD) approach, i.e., Volumetric Design with Performance Verification approach against fatigue, moisture damage, and rutting resistance. Ten RAP sources were chosen for the mix design among the fourteen sources considered in the study. The allowable RAP limits were developed for these ten sources with a dense-graded Bituminous Concrete Grading-I (BC-I) mix (as per Ministry of Road Transport & Highways) as the target mix. The allowable RAP content limits for each category were nearly the same, thus further validating the hypothesis that the RAP sources with similar characteristics can be grouped into a category and may have similar allowable RAP content. It was also noted that when the rejuvenator was used in the mix, these allowable limits were found to increase. Similarly, allowable RAP content limits could be higher if gap-graded mixes were considered target mixes. The agencies can adopt the procedure adopted in the study to develop similar limits (allowable RAP content) for the typical mixes used by the respective agency.

Based on the findings of the above investigation, the study proposed a rational approach for designing hot recycled asphalt mixes that involve selecting allowable RAP content based on the RAP category. RAP category is dictated by S_{frag} and $S_{air\text{-}voids}$ obtained from associated tests on 100% RAP material. The study also proposed regression equations for estimating RAP characteristics such as bitumen content and RAP aggregate gradation using S_{frag} and $S_{air\text{-}voids}$. Practitioners can use these predictive equations to estimate the RAP characteristics necessary for the subsequent steps of the mix design. Adopting the proposed approach allows the practitioners to design the hot recycled asphalt mix without requiring to recover the bitumen from RAP material and thus waives the subsequent testing on RAP bitumen. It is envisaged that such efforts alleviate some of the technical challenges in carrying out the mix design of hot recycled asphalt mixes and promote using RAP material in road construction.

Keywords: Reclaimed Asphalt Pavement; RAP characterization; Fragmentation test; Cohesion test; RAP classification; Hot Recycled Asphalt Mixes; Allowable RAP content