

ABSTRACT

Today, the pavement engineers around the globe are facing challenges to construct road networks that are not only are efficient, cost-effective and long-lasting, but also be sustainable by nature. This situation is more relevant for the developing economy like India which has second the second-largest road network in the world having 5.6 million km of roads. More than 90% of Indian highways are paved with bituminous mixes that constitute more than 92% of aggregates by weight. On the other hand, mining restriction, environmental protection regulation and appreciating land costs has led to the reduction in availability of aggregates as well as increased the overall cost of road construction. The glass and dimensional limestone (known as Kota stone in India) industries produce a substantial amount of fine glass powder and Kota stone dust during the polishing of glass and stone slabs. Incorporation of these industrial wastes in bituminous mixes as fillers not only can fulfill the demand of conventional stone dust filler, but also, resolves the problems related to environmental pollution, shortage of disposal land and other associated issues. However, there are very few reported studies that investigated the influence of wastes described above on the behavior of bituminous concrete mixes.

This study investigated the potential of Glass Powder (GP), Kota Stone dust (KS), and Glass - Hydrated Lime composite (made with glass powder and hydrated lime) (GL) as fillers in bituminous concrete mixes. A comparison was made with the bituminous concrete mixes containing conventional stone dust (SD) as filler. This study emphasized on exploring the influence of type and quantity of the aforesaid fillers on the rheological behavior of the bituminous mastics as well as on the cost, constructability and performance of bituminous mixes on pavement distresses and performance.

The entire study is divided into six different phases, with each phase dealing with a specific objective. Firstly, the physical and chemical characterization of GP, KS, SD and hydrated lime (HL) was performed. All waste fillers had finer particle size and lowered specific gravity than conventional SD. The porosity of GP was higher while the porosity of KS was lower than conventional SD respectively. The mineralogical composition of KS, HL, SD, and GP predominately comprised of large quantities of calcite, Portlandite, dolomite and silica, respectively.

In the second phase, the bituminous concrete mixes with fillers added in four different proportions (4, 5.5, 7.0 and 8.5% by weight of aggregates) were designed using Marshall method and their optimum bitumen contents (OBC) were determined. The Apparent Film Thickness (AFT) of all mixes was also calculated. Glass - Hydrated Lime composite (GL) filler was prepared by fixing the proportion of hydrated lime at 2% and assigning a balanced part to GP. It is done to avoid the possibility of formation of moisture-sensitive mixes due to high silica content in GP. With the exception of GL mix having 8.5% filler, all bituminous mixes fulfilled the Marshall and volumetric requirements of the specification. Mixes containing waste fillers displayed higher Marshall stability than conventional SD mixes at lower filler contents (4 and 5.5%). Mixes containing GL fillers displayed highest Marshall stability in most cases. OBC of all mixes decreased with the increase in filler content, and mixes having GL and KS mixes displayed lowest OBC followed by GP and SD mixes. Fineness, porosity, and mineralogy of fillers influenced Marshall stability and OBC of the mixes. Based on the filler content and effective bitumen content in the mix, the filler bitumen ratio for each mix was calculated which was used to prepare bituminous mastics to correspond to each mix.

In third phase of the study, rheological properties of bituminous mastics were evaluated to identify the rutting, fatigue and ageing potential. The consistency of bituminous mastics was determined using softening point analysis which was found to increase with an increase in filler content. The rheological analysis of all mastics was done using frequency sweep test at 25°C and 46-70°C. The linear viscoelastic (LVE) limit of mastics was found to decrease with the increase in filler content and a decrease in temperature. The increase in complex modulus and decrease in phase angle was also observed with the increase in filler content at each loading frequency. For all mastics, the rate of increase in complex modulus with frequency was found to increase with the testing temperature. GL mastics displayed highest complex modulus and lowest phase angle followed by GP, KS, and SD.

The rutting resistance of bituminous mastics at 46-70°C was determined using Superpave rutting parameter and Multiple Stress Creep and Recovery (MSCR) test. The rutting resistance of short-term aged mastics was found to increase with an increase in filler content and a decrease in temperatures. GL mastics displayed the highest rutting resistance followed by GP, KS, and SD mastics. The fatigue resistance of mastics at 25°C was determined using the Superpave fatigue parameter and LAS test. The fatigue resistance of mastics was found to decrease with the increase in filler content. In general, SD mastics displayed the highest fatigue resistance followed by KS, GP, and GL mastics. LAS test also suggested that the fatigue life of mastics decreased with the increase in applied strain. Fatigue resistance of bituminous mastics was also evaluated using a new approach based on the percentage recovery parameter of long-term aged mastic determined by MSCR test. This approach delivered an almost opposite trend

than two former methods and suggested that fatigue resistance of mastics somewhat improved with an increase in filler content. The ageing susceptibility of the mastics was determined at 25⁰C and 64⁰C using the Ageing Index (AI) based on the complex modulus of short and long-term aged mastics determined using a frequency sweep test. The ageing susceptibility of mastics was found to decrease with the increase in filler concentration and with a decrease in temperature. In general, GL and SD mastics displayed highest and lowest long-term ageing resistance respectively.

In the fourth phase of the study, the performance of various bituminous mixes against primary distresses was assessed. The rutting resistance of various mixes was determined using the Marshall quotient and uni-axial unconfined static creep and recovery test. Rutting resistance of bituminous mixes increased with the filler content which was attributed to the lowering of VMA and AFT of the mixes. GL mixes had the highest rutting resistance followed by GP, KS, and conventional SD mixes. The moisture resistance of the bituminous mixes was determined using the modified Lottman test and retained Marshall stability test and was found to decrease with the increase in filler content due to the simultaneous lowering of AFT. The SD and KS mixes fillers exhibited superior performance against moisture due to the presence of minerals like dolomite and calcite. Mixes containing GP failed to display required moisture resistance. However, it was observed that up to 5% of GP could be used as filler after the addition of 2% of hydrated lime. Hydrated lime consisted of Portlandite which inhibited the moisture-sensitive nature of GP and mixes having 7% GL (5% GP+ 2% lime) as filler delivered satisfactory moisture resistance. Active and passive adhesion of mixes was done using mixing time analysis and Texas boiling water test and both were found to decrease with the increase in filler contents. Cracking resistance of bituminous

mixes at 0°C and 25°C was found to increase with an increase in filler content. In general, GL mixes displayed the highest cracking resistance followed by KS, GP, and SD mixes. The fatigue life of mixes was determined at 25°C with Indirect Tensile Fatigue Test and they were found to increase with filler content. GL mixes displayed the highest fatigue resistance followed GP, KS, and SD mixes. However, fatigue life of mixes followed a similar trend as that of percent recovery values obtained using the MSCR test. Ravelling resistance of mixes was determined using standard and wet Cantabro tests. Ravelling resistance of all mixes in wet condition was found to decrease with the increase in filler content. However, in the case of standard testing, ravelling resistance of all mixes was found to improve up to a certain filler content. The sensitivity of various mixes against long-term ageing was determined using Ageing Index corresponding to five different properties (Marshall stability, Marshall quotient, indirect tensile strength, tensile strength ratio, and Cantabro loss). In the majority of the cases, the ageing sensitivity of bituminous mixes was found to increase with an increase in filler content. In general, GL and SD mixes displayed highest and lowest long-term ageing sensitivity respectively. The resilient modulus of mixes was determined and GL mixes displayed the highest resilient modulus followed by KS, GP, and SD mixes.

In the fifth phase of the study, the design of flexible pavements with granular base and subbase was done for standard traffic by employing all studied mixes in the surface course. An attempt was made to determine the minimum thickness of the surface course which can satisfactorily support the design traffic. For all mixes, the increase in filler content tends to decrease the required thickness of the surface layer. Pavements with GL mixes needed the minimum layer thickness followed by KS, GP, and SD mixes. It was observed that the replacement of SD with various waste fillers could result in up to

a 24% reduction in thickness. The cost comparison of per km for a two-lane bituminous surface layer made with different mixes was done. The surface course prepared with waste fillers was found to be significantly economical than conventional mixes and resulted in considerable saving of up to 39%. KS mixes were found to be the most economical followed by GL, GP, and SD mixes.

In the final phase of the study, a novel ranking methodology to rank various bituminous mixes based on their overall performance was proposed. This methodology is an amalgamation of the laboratory performance of the mixes and the priority assigned by the designer to a particular property (i.e., rutting) as per field conditions. Mixes prepared with KS and GL at higher filler contents delivered much superior performance than conventional SD mixes. On the other hand, GP mixes displayed overall poor performance. KS mixes prepared at 8.5% filler exhibited overall better performance, while, GP mixes prepared at 4% filler shown overall poor performance. Hence it was concluded that the, utilization of studied wastes as alternative fillers in optimum proportion can limit consumption of natural resources, provide a solution for waste disposal, and can form superior performing bituminous concrete mixes in an economical and eco-friendly manner.