ABSTRACT

India has the second largest road network in the world with over 5.6 million km of roadways spread across the country. Currently, 98% of the Indian roads are flexible pavements, constructed using dense graded bituminous mixes as wearing course. The dense graded bituminous mixes are to be impermeable to water with an air void content in the range of 3–5% by mix volume and are designed using well-graded aggregates and bituminous binders. During rain due to surface water flow dense graded mixes raises concerns related to hydroplaning, skidding, and splash and spray. Dense graded bituminous surfaces during rain also have reduced visibility and increased glare due to presence of surface water film, which has a significant effect on the road safety aspects. It has been estimated that 20% of road accidents occur during wet weather conditions and mainly attributed to lack of skid resistance, visibility, splash and spray, etc. Hence, in high rainfall and hilly regions it will be quite helpful to have wearing courses that have high permeability and can quickly drain out the surface water, without compromising the performance aspects. Open graded friction course (OGFC) is a special type of hot mix asphalt (HMA) mix that acts as a drainage layer to permit the surface water to migrate laterally to the edges of the pavement. OGFC has benefits in terms of improved skid resistance, higher visibility, reduced hydroplaning, reduced glare, lower tyre-pavement interaction noise and enhanced safety. OGFC has been in use in various parts of the United States and European countries, but in India its use is still

not established. Unlike other developed countries, there are no well-formulated specifications/guidelines for implementing the OGFC technology in India.

OGFC mixes are designed for a high percentage of air voids content, generally above 18% of mix volume. To attain the high proportion of air voids, OGFC generally uses a uniform grading of aggregates. The coarse aggregates in OGFC comprise more than 90% of the total aggregates. The macro-texture derived from the aggregates of OGFC surface also promotes frictional characteristics of the road surface. The coarse aggregate skeleton in OGFC mixes provides the stone-on-stone contact necessary for the distribution of traffic loads and hence these mixes demand high quality aggregates for desired performance and service life. Construction of a vast capacity of infrastructure in India has not only imposed pressure on natural aggregates but has also led to severe environmental challenges because of large-scale mining and quarrying. Further, in many regions environmental concerns have put restrictions on exhausting mountains and rivers for extraction of natural aggregates. Moreover, the quest for achieving sustainability in highway construction has compelled researchers to explore alternative aggregate materials. The use of the waste materials and industrial by-products as an alternate aggregates is gaining widespread interest as an encouraging approach to meet the rising aggregate demands. Waste material utilisation has the simultaneous benefits of reducing the dependency on natural aggregate sources while advancing environmental and economic stewardship. India is the world's third largest steel producer (after China and Japan) with 101.4 million tonne (MT) steel production in 2017. Steel slag is a by-product of the steel manufacturing industries. About 12 MT of steel slag is generated annually in India, but merely 20% is put to applications and the rest is indiscriminately dumped in nearby landfills as a waste.

With this background, the current study set out to investigate OGFC mixes with electric arc furnace (EAF) steel slag (a waste from steel industry) as partial replacement of

coarse natural aggregates. Experimental variables in the present research included two types of aggregates (natural and EAF steel slag), two types of modified binders (PMB: polymer modified binder and CRMB: crumb rubber modified binder) and five substitution percentages (0%, 25%, 50%, 75% and 100%) of coarse natural aggregates with EAF steel slag aggregates. The present study began with characterisation of EAF steel slag aggregates in terms of physical properties, chemical composition, morphological analysis, and toxicity evaluation. This was followed by design of OGFC mixes at all EAF slag percentages to determine the following design attributes: stone-on-stone contact condition, air voids content, unaged abrasion loss, aged abrasion loss, and binder draindown. The OGFC performance parameters evaluated in this study were resistance to moisture-induced damage, frictional characteristics, permeability and clogging characteristics, resistance to permanent deformation (static creep, dynamic creep, Hamburg wheel tracking and stiffness modulus), and fatigue life. The properties of EAF steel slag-OGFC mixes were compared with those of control mixes (with no steel slag).

Favourable physical and chemical characteristics of EAF steel slag aggregates in terms of higher angularity, rough surface texture, high specific gravity, low flakiness and elongation index and high calcium oxide content, enabled them to show a desirable performance as a coarse aggregate in OGFC mixes. In comparison to OGFC mixes with natural aggregates, increase in EAF steel slag content up to 75% resulted in improvement in OGFC mix properties including air voids content, stone-on-stone contact, and abrasion loss in unaged and aged conditions for both PMB and CRMB binders. Even after 100% replacement of coarse natural aggregates by EAF steel slag, OGFC mixes met all design requirements and showed performance comparable to the OGFC mixes with natural aggregates. Both PMB- and CRMB-OGFC mixes on substitution of coarse natural aggregate with EAF steel slag showed improved performance when evaluated using static creep,

dynamic creep, Hamburg wheel tracking, stiffness modulus and fracture life tests. OGFC mixtures with 75% substitution of coarse natural aggregates with EAF steel slag presented the best performance in terms of permanent deformation, stiffness modulus and fracture life among all the combinations studied. The study concludes that 75% is the optimum content for replacement of the coarse natural aggregates with EAF steel slag in OGFC mixes with both PMB and CRMB binders. Replacement of the natural aggregates with EAF steel slag aggregates in OGFC mixes may be considered as an encouraging option, which can save the rapidly diminishing natural aggregates, and can be a significant step in the direction of sustainability in highway construction.

Keywords: *electric arc furnace steel slag; open graded friction course; polymer modified binder; crumb rubber modified binder; waste reuse.*