

# Review on Performance of Stone Matrix Asphalt by utilizing Steel Slag Aggregates

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**ABSTRACT:** In India with increase in the industrialization there is a serious problem concerned with safe disposal of waste generated from various industries like steel plants, thermal power plants, C&D waste, etc. At present for every ton of steel generated it leads to generation of around 150-200 kg of steel slag. In order to dispose, it requires large amount of land filling for its disposal. However, in the literature various researchers, industries and organizations like Nippon steel slag association (JAPAN), and HARSCO etc. indicated the use of steel slag as aggregate in the field of road construction. With this background, in this research work an attempt is made to explore the usage of steel slag in road construction by conducting laboratory study of Stone Matrix Asphalt with steel slag as aggregates. To draw the comparative conclusion SMA Mix is studied with both type of aggregates i.e.; Natural and steel slag aggregates prepared using two different fibre. Physical properties of both types of aggregate is determined as per BIS specifications, SMA Mix is designed as per IRC: SP: 79-2008 by adopting suitable gradation and wax coated cellulose fibre and bitumen coated cellulose fibre as a stabilizer. Drindown test is also performed to check the binder absorption capability of the fibre used. After finding Optimum Bitumen Content (OBC) for steel slag aggregates & natural aggregates various performance test are done for further studies such as ITS, Resilient Modulus ( $M_R$ ) for stiffness of SMA mix, Static creep and Dynamic creep test for determination of permanent deformation or rutting. By analyzing all the test results for aggregates and SMA Mix a comparative conclusion is drawn indicating the advantages and disadvantages of using Steel Slag aggregates over natural aggregates.

**KEYWORDS:** Waste utilization, Stone Matrix Asphalt, Steel Slag, Cellulose Fibre pellets

## I. INTRODUCTION

In recent years increasing traffic volume on highways are recorded across the country. Special tyre design permit to be inflated to high pressure causing high stress on pavement surface. Sometimes roads are subjected to overloading also, conventional Dense Graded asphalt mixes are not adequately rut resistant under these heavy traffic conditions. So design mix of Stone Matrix Asphalt (SMA) was adopted. SMA is a gap graded asphalt mixture with a high- coarse aggregate content (70 to 80 percent), high filler content (8-10 percent) and a high bitumen content (min.5.8 percent) because of this stabilizing additives such as cellulose fibre is used to prevent binder drain down. The result is a durable mixture that has excellent stone to stone contact and that is very resistance to rutting.[P.S.kandhal].

SMA was developed by Dr. Zichner in Germany during 1960s as a mix resistant to premature wear damage from studded tyres. However it was discovered soon SMA was also highly rut resistant. It has been used in Europe since 1970s. The first SMA project in the US was placed in 1991 in Wisconsin. Over 15 million tons of SMA has been placed in US with excellent performance results. Early SMA pavements in US were constructed using Germany's "recipe" type specifications. No rational mix design was available. The National Center for Asphalt Technology (NCAT) conducted national comprehensive research project to develop a rational mix design method for SMA especially to ensure stone to stone contact despite the use of geologically different aggregates with different particle shape and angularity. Subsequently, The US national manual for designing and constructing SMA pavements was developed to provide guidance for its implementation across US. [B. Krzysztof].

Severe rutting was observed in India on some national highways especially due to overloaded truck. To alleviate that situation, SMA was introduced in India. The national specification for SMA for the Indian Road Congress (IRC) was developed in 2008. Since then, SMA has been placed on many national highways and has performed very well.

## II. LITERATURE REVIEW

**Maslehuddin M. et al. (2002)** this research work was conducted to evaluate the mechanical properties and durability characteristics of steel slag aggregate in comparison with crushed limestone aggregates when used for production of concrete by assessing water permeability, pulse velocity, dimensional stability tests. The results were positive with respect to durability characteristics of concrete with steel slag aggregate also unit weight of concrete is 17 % higher than conventional concrete. They have also concluded that for reducing the unit weight of concrete steel slag aggregate may be proportioned to 50% coarse aggregate and 50% fine aggregate with natural aggregates .

**Ameri M. et al. (2013)** in this laboratory study electric arc furnace (EAF) steel slag is used to evaluate the performance of warm mix asphalt mixture. The steel slag was used as fine and coarse portion of aggregate gradation in HMA mixture and as coarse portion of aggregate gradation in WMA mixture. They have derived following conclusions:

- Steel slag aggregate improve the Marshall Stability of hot mix asphalt mixtures.
- Moisture susceptibility of warm mix containing steel slag was improved.
- Warm mix asphalt containing steel slag aggregates showed higher resilient modulus ( $M_R$ ).
- Steel slag aggregates improved resistance to permanent deformation in warm mixture.

**Pasetto M. et al. (2017)** this research work is concerned with verifying the utilization feasibility of steel slags in warm mix-modified asphalt concrete. To evaluate the combined effect of manufactured EAF steel slags and warm chemical additive, a comparative analysis is carried out taking into account unmodified binder as well as mastics and mixture prepared with only natural aggregates. The presence of warm chemical additive seemed to affect the elastic response of binder and mastics, improving their fatigue and permanent deformation resistance without a clear effect on stiffness properties. In particular the potential higher stiffness and rutting resistance of steel slag mixtures are limited whereas the possible lower fatigue resistance is positively counterbalanced.

**Shaopeng Wu et al. (2006)** in this research work the researcher's aims to explore the feasibility of utilizing steel slag as aggregate in Stone Matrix Asphalt (SMA) mixture and properties of such asphalt mix are evaluated as well. X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Mercury Intrusion Porosimetry (MIP) were employed to study the composition, structures and morphology of aggregates. Volumetric properties and pavement performance of SMA mixture with steel slag were also evaluated as compared to that of basalt as aggregates. In short, the successful utilization of steel slag as aggregate in pavement construction can provide a new more cost effective approach for aggregate resources and decrease the threat of solid waste management. They have derive following conclusions:

- Steel slag obtained by hot-sprinkling method is very suitable aggregate with porous structure for preparing SMA mixture after 3 year aging.
- All the volumetric properties of SMA mix containing steel slag as aggregate can meet the related requirement of specifications, though the substitution of steel slag for basalt slightly increases the optimum bitumen content.
- Expansion rate of SMA mix with steel slag is below 1% after 7 days, which ensures the stability of steel slag in SMA mixture.
- Compared with SMA mix with basalt, the high temperature properties of SMA mix with steel slag is improved, the better physical properties of steel slag enhances the ability of resisting permanent deformation at high temperature.

The critical value of  $dW/dV$  (area under stress strain curve) for SMA mixture with steel slag is also increased, which results in the better resistance to low temperature cracking.

**Mehnood A. et al (2012)** this study aim to investigate the suitability of steel slag aggregates in Stone Matrix Asphalt mixture in Iran. In this work asphalt used was 60/70 penetration grade with Stiren- Butadien -Stiren copolymer (SBS) as a modifier, since it has higher resistance to permanent deformation in comparison to other modifiers. Various performance tests were performed such as Marshall Stability, Indirect tensile strength and Resilient Modulus to evaluate the SMA mix prepared with steel slag aggregates and limestone aggregate. With this they concluded as follows:

- As replacing the coarse portion of limestone with steel slag leads to better results in comparison with mix that contains steel slag as the fine portion.
- Steel slag used in coarse portion in SMA mixture increased Marshall Stability and decreased flow values. Hence mix with steel slag coarse aggregate have higher Marshall Quotient (MQ) values, which indicates the high stiffness and resistance to permanent deformation.

- MSR and TSR values obtained which indicates that utilizing steel slag as the coarse portion of aggregates can enhance the resistance of mixture to moisture damage.

Dynamic creep test results indicated that mixture containing steel slag as the coarse portion are more resistant to permanent deformation and have lower rut depth.

**Al-Hadidy A.I. et al. (2011)** in this work investigation related to the benefits of modifying asphalt and SMA mixture in flexible pavement are done. 70/100 penetration grade asphalt cement and 5% styrene-butadiene-styrene (SBS) triblock copolymer were selected. Unmodified and modified asphalt binder were subjected to physical and compatibility tests. Performance test, including Marshall Stability, Static Indirect Tensile Strength and Static Compressive strength at 25 and 60°C, tensile strength ratio, index of retained strength, rutting resistance, low temperature cracking, and resilient modulus were conducted on unmodified and SBS modified SMA mixtures. The regression relationships between the performance tests were obtained. A mechanistic-empirical design approach was used to estimate the improvement in the service life of the pavement or the reduction in the thickness of the SMA and the base layer for the same service life caused by modifying the SMA mixture.

Further conclusions derived through this study are as follows:

- The performance test result shows that SBS modified asphalt perform better than control mixtures.
- Temperature susceptibility can be reduced by including SBS in the asphalt mixture.

The results of multilayer elastic analysis indicate that using SBS modified SMA as surface layer in pavement reduces the number of construction material used but the actual saving would depends on the designer's decision in reducing the thickness of an individual layer.

**Aline C. et al. (2014)** this research work presents the study of the behavior of natural fibers i.e.; coconut and cellulose fibers on SMA mixture using two different design methods which is Marshall and Superpave. The work concerned with replacement of natural cellulose fibers by coconut fibers and the specimens were tested using several common laboratory procedure such as Draindown test, indirect tensile strength, resilient modulus, and fatigue life and moisture susceptibility. The Draindown tests result justify that coconut fiber can be used in SMA mixture as a replacement for cellulose fiber to control binder draindown during production. For the two design methods, the SMA Mix containing coconut fibers underperformed with respect to mixtures with cellulose fiber and without fiber when they are tested for fatigue life.

**Jens G. et al. (2017)** in this research work they have presented the comprehensive investigation on the fundamental performance properties of different types of asphalt mixtures prepared with 100% LD Slag aggregate and a conventional asphalt mixture containing natural gabbro aggregates. Various testing were performed to evaluate the parameters, in this study low temperature cracking was addressed through thermal stress restrained specimen tests. Penetration tests and cyclic compression tests were used to evaluate the response of asphalt binder and asphalt mixture to permanent deformation due to repeated loading respectively. Some major conclusion drawn from the study as follows:

- The use of LD slag in mastic asphalt leads to advantageous deformation resistance compared to mastic asphalt with natural gabbro aggregates.
- The fatigue resistance and stiffness of the asphalt surface, asphalt binder and asphalt base mixture are at comparative level.

The level of resistance to thermal cracking is comparable for all asphalt mixture regardless of whether LD slag or natural aggregate Gabbro was used.

**Awanti S.S (2013)** in this research work experimental investigation is carried out on Stone Matrix Asphalt (SMA) prepared using polymer modified bitumen PMB 70 with SBS and coconut fibre to prevent draindown of asphalt. Results were compared with SMA mixture prepared with neat bitumen VG 30 and coconut, cellulose fibers as a stabilizers. Various tests such as static ITS at different temperature, fatigue test and permanent deformation test are carried out to evaluate the performance of SMA mixture. By this study following conclusions are derived:

- The OBC obtained for SMA with PMB 70 is 0.3% higher than SMA with VG 30 and coconut fiber as draindown stabilizer. This may be due to higher viscosity of PMB 70 compared to VG 30 bitumen.
- The binder Draindown in PSMA-ctf is 36% lower than SMA-ctf.
- Static ITS values for PSMA-ctf at 10, 20, 30 & 40 °C temperature is higher than SMA-ctf.
- The moisture susceptibility of PSMA-ctf is marginally lower than SMA-ctf.
- PSMA-ctf shows 36% higher fatigue life when compared to SMA-ctf at tensile stress of 0.6 MPa at 30°C.

PSMA-ctf Shows 42% higher rut resistance when compared to SMA-ctf.

**Punith V. S. et al. (2010)** in this study work they have dealt with the viability of using reclaimed polyethylene (PE) derived from low density PE carry bags in shredded form collected from domestic waste as stabilizing fibers to evaluate the performance of Stone Matrix Asphalt. Conventional SMA mixture were used for reference prepared using 60/70 grade asphalt and cellulose fiber as a stabilizer. The utilization of PE-modified binder was also investigated as stabilizer in SMA mixture. The performance of these mix was evaluated by conducting draindown, moisture susceptibility test, aging test, rutting test, creep test, permeability test and fatigue life tests. To study the behavior of SMA mix with different additives, mixture were designed by Marshall and Superpave Gyrotory Compactor. Some major conclusions drawn through this study as follows:

- Draindown test result showed that reclaimed PE fiber can be effectively used as stabilizer in SMA to retard draindown of binder and mineral filler.
- The compaction of mix by the gyrotory compactor shows improved performance properties for SMA in terms of creep, aging, permeability, dynamic modulus and TSR as compared to mix compacted by Marshall method.
- Fatigue life of mix at 25°C (400 micro strains) with PEMB compared to that with PE fiber and cellulose fiber was found to be higher by 2.8 and 6.7 times, respectively.

SMA prepared with PE fibers showed improved performance with respect to properties like resistance to rutting, aging, cracking and moisture damage compared to mix with cellulose fibers.

**Sarang G. et al. (2014)** in this study SMA mixture prepared with shredded waste plastics as a draindown stabilizer. For sample preparation waste plastic is first dry mixed with aggregate and stabilizer then VG 30 grade bitumen is added. Samples are prepared using Superpave Gyrotory Compactor (SGC). Stripping test for loose mix and volumetric properties, tensile strength, moisture susceptibility characteristics were determined. The result concluded from this study are –

- The optimum bitumen content at 4% air voids for conventional SMA Mix was 6.41% and for the mix with waste plastic it decreased to 6.19%, 6.04%, 5.92% & 5.74% with WP content 4%, 8%, 12% & 16% respectively.
- Shredded Waste Plastic can be utilized as draindown stabilizer.
- Stability & ITS values were improved with the presence of WP. The optimum content of WP is found out be 8%, at this content stability increased by 37%.

Mix modified with WP have better moisture resistance. TSR value improved to 85-95% for the mixes with WP.

**Xue Y. et al. (2008)** in this research work municipal solid waste incinerator (MSWI) fly ash is used for partial replacement of fine aggregate or mineral filler in SMA. In place of coarse aggregates BOF slag aggregates were used as a part of coarse aggregate for preparing the mix with PG76-22 binder and polyester fiber as stabilizer so the SMA mix contains 90% solid waste material by mass. SMA samples was prepares by SUPERPAVE mix design and Marshall Mix design method and comparative performance study is done. Performance test includes Marshall Stability, water sensitivity, fatigue life, resilient modulus and rutting. As from test results it is concluded that SUPERPAVE mix showed better result as compared to Marshall Mix in almost all performances. Optimum replacement percentage of MSWI ash is obtained as 8-16%. The leaching behavior of waste asphalt matrix is mainly controlled by chemical stability and adhesiveness of mix.

### III. CONCLUSION

In this research work municipal solid waste incinerator (MSWI) fly ash is used for partial replacement of fine aggregate or mineral filler in SMA. In place of coarse aggregates BOF slag aggregates were used as a part of coarse aggregate for preparing the mix with PG76-22 binder and polyester fiber as stabilizer so the SMA mix contains 90% solid waste material by mass. SMA samples was prepares by SUPERPAVE mix design and Marshall Mix design method and comparative performance study is done. Performance test includes Marshall Stability, water sensitivity, fatigue life, resilient modulus and rutting. As from test results it is concluded that SUPERPAVE mix showed better result as compared to Marshall Mix in almost all performances. Optimum replacement percentage of MSWI ash is obtained as 8-16%. But the quantity of ash used in the mix have some limitations. If it is used in higher than optimum amount it reduces the strength of mix in terms of fatigue and moisture absorption. Keeping all these points in consideration, finally it may be concluded that solid waste can be used in the mix beneficially to improve the quality of the conventional mix. The leaching behavior of waste asphalt matrix is mainly controlled by chemical stability and adhesiveness of mix.

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