DOI: 10.56452/2021SP-8-026

ISSN: 0974-5823 Vol. 6 (Special Issue 3, November 2021)

International Journal of Mechanical Engineering

Utilization of Steel Slag in Flexible Pavement and its Environmental Impact-A Review

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HIGHLIGHTS

- Steel slag may be suitable as an alternative aggregate for Dense Bituminous Macadam Base layer.
- The effect of SS on the properties of DBM needs to be addressed.
- The use of slag as aggregate for roads construction of flexible pavement is good selection.
- SS recycling is the best selection from environment and health point of view.
- It is recommended to use the slag under beneath of the surface layer.

Abstract: Bituminous for mix can be prepared and used in a pavement section for a binder course use different types of additives like waste materials. Modifying bituminous mix is expected to gives higher life. This paper presents the utilization of the steel slag which is used as a replacement material for coarse aggregate and fine aggregate of different sizes. The gradation requirement is fulfilled by DBM grade –II. A various tests were executed to Characterize the physical properties of aggregate, steel slag and bitumen. The chemical test on steel slag should also show good results. Mechanical properties of these mixtures are evaluated by Marshall Stability. It was observed that steel slag used as a coarse aggregate improved the mechanical properties of the mixture and thus it is suitable for the use in construction of road.

Keywords: Steel Slag, Waste Recycling, Marshall Stability, Flow Value, Sustainable material.

Introduction

Steel slag has been extensively recycled and utilized in many valuable uses in developed nations andareas like the Europe, the United States, Japan, and Singapore.

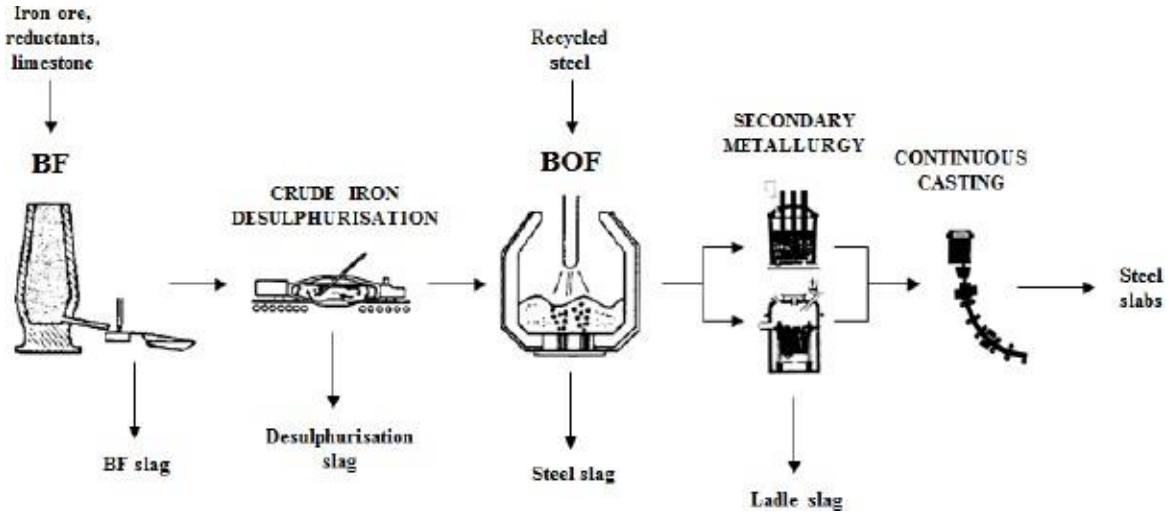
It involves building roads. The technological aspect, the regulatory environment, and the viability of the business. It has a strong history. However, due to various factors, this has not been the case in many other nations. The state of the economy, the way the waste recycling sector is organized, the public receptivity, a historical problem, or administrative constraints This essay provides information on steel utilization

STEEL SLAG GENERATION

The production of steel produces steel slag. Quicklime, which is a primary fluxing agent, interacts with the impurities in iron or steel scrap, primarily silica, to generate a mineral complex that separates from the clean steel. Steel slag hardens into a rock-like substance after being discharged and cooled, which can then be processed to take the place of natural rock in the construction sector [1-3].

DOI: 10.56452/2021SP-8-026

Basic oxygen furnace and electric arc furnace are the two primary forms of steelmaking slag that may be distinguished from one another by their type of furnace (EAF). The qualities of slag are similar, but depending on the particular steelmaking process, production control, and slag processing, variances occur across different products even within same type of slag.



STEEL SLAG RECYCLING

The years, steel slag has been used in a wide range of industries, including [1,3-10]:

- Materials used in the compositions for asphalt pavement
- Sub-base and road base
- Aggregates in concrete
- Insulation from minerals
- Ballast for railways
- Application in the environment (e.g., acid mine drainage treatment)
- Clinker from cement
- Fill and embankments
- Fertilizer and soil enhancer
- Vitrified slag

Several researches have affirmed that ss can be used as an alternative aggregate in different pavements and concretes. The former Favours physical and mechanical properties including high density, high strength and high abrasion resistance [11-14].

The presence of some mineral's phases, such as dicalcium and tricalcium silicates confers SS cementitious properties and potential to be used in composite cement [15-16].

The production amount of SS is 100-150 kg per ton of molten steel [17]. The Brazilian steel production represented roughly 54% of the Latin American production in 2019 (1st place), and 2% of the global production (9th place).

Approximately 35 million tons of crude steel were produced in Brazil per year in the past five years, giving a total of 4.5 million tons of SS every year [18].

China is the world leader in crude steel production, corresponding to 51% worldwide production [18]. However, the properties of SS are found to be in compliance as per the specification which is same as for the crushed aggregate [19]. The stability, bulk density increased with increase in percentage of SS in the mix irrespective of the steel slag proportion and size. This indicated high stiffness.

The air voids are reduced as the percentage of steel slag increased [20].

Literature Review

(Mahdi Zalnehad, Ebrahim Hesami, 2019), In order to evaluate the performance of SS in micro surfacing mixture, two types of bitumen emulsion are Cationic quick setting and Cationic slow setting used together with three types of mixture in which 100% of silicious aggregate used as control mix then SS was replaced by 61% and 100% aggregate of control mix. Totally due to properties of friction, durability, stiffness of steel slag, high adhesion to bitumen and preventing the formation of some deterioration like rutting, stripping and polishing the aggregate. It is recommended to be used in micro surfacing mixture.

(Kaushik Mendapara, Ravindra Solanki, Himanshu Gupta, 2017), The marshal stability and flow value analysis for the various DBM grade1 mixture with binder and with different %age replacement of bitumen with plastic waste, waste Tyre tube and jute fiber are reported. Fiber like natural fiber, jute fiber, waste plastic fiber added in bituminous mixture as per the weight of bitumen in DBM. Increase Marshal stability, flow, OBC and strength.

(Marta Skaf, Javier Bartolome, Hernan Gonzalo Orden, 2021), To reduce dependent on natural aggregate and to provide a use of industrial by product. The mix is coarse bituminous concrete (AC22G) for base course. Mix is prepared as partly steel aggregate with LF Slag as fine aggregate and mineral powder with limestone aggregate CA, secondly EAF slag as CA with LF slag as FA. So LF Slag as FA in coarse bituminous mixture is feasible. Replacement of limestone with slag fulfilled all the requirements.

(Dang Tung, Manh Tuan, Tan Phong, Ryoichi Sato, 2021), the current steelmaking slag production status and its potential to use as mineral aggregate in base\sub-base layer of road. From the result the steelmaking slag can satisfy all the mechanical requirements. Approx. 150-200kg steelmaking slag is produced when manufactured 1 ton of crude steel. The SS can be replaced mineral aggregate applied in sub-base layer based on requirement from TCVN8857 & JIS A5015.In Resilient modulus the SS was about 34 to 78% higher than mineral aggregate. The thickness of pavement when using SS can be reduced about 3-5cm in comparison to mineral aggregate. Good alternative material for mineral aggregate in term of mechanical as well as environmental proper ties.

(*Marco Pasetto, Nicola Baldo,2012),* This paper shows the study of the result of laboratory evaluation and a theoretical study on the fatigue behavior of bituminous mixture with reclaimed asphalt pavement aggregate and Electric Arc Furnace steel slag. Done by 4 point bending test. With respect to reference mix composed by a natural aggregate, the bituminous mixture with RAP aggregate and steel slag have presented improved fatigue properties and performance. In the conclusion the use of 30% of EAF slag and 20% of RAP aggregate increase the fatigue life from 154% to 191%. The comparison between the mixture leads to the similar quality evaluation. But the energy criterion showed increase in fatigue life quantitatively higher than those of classical approach based on 50% reduction of its initial stiffness.

(Jayalakshmi S., Lincy Fernandez, Anooja Faustine, Anjana A,2022), To enlighten the research about key advances developed in last 10 years for utilizing native laterite soil in base and sub-base layer. In various researches laterite soil treated with lime, cement and other additives, showed considerable enhancement in compaction, UCS and CBR. Laterite alone does not satisfy all the requirement for base and sub-base. Reduction in plasticity of laterite soil increase in workability and reduction in moisture holding capacity and swell potential are obtained by the addition of pulverized steel slag to native laterite.

(Deepak Raghuvanshi, Avinash Mishra, Tarun Kumar, 2022), Showed some literature related to the use of steel slag and C&D waste as filler in asphalt concrete. Using SS and C&D waste as filler in asphalt conc. Leads to sustainable and environmentally friendly pavement. Under microwave irradiation steel slag filler-based asphalt mastic may release more heat than limestone filler-based asphalt mastics. The combined filler should have percentage of less than 75% by volume. The inclusion of steel slag powder increases the water damage resistance of asphalt mix when compared to other filler.

(Liz*asoain Arteaga, Lastra Gonzala Pedro, 2014*), Fatigue behavior of asphalt mixes contains EAF steel slag is evaluated in both aged and unaged condition. Six sets were prepared, each set is replacing various portion of limestone coarse aggregate with EAF steel slag. Marshall testing (acc to ASTM D-6927), 4-point bending fatigue test and expansion potential are done. Aggregate gradation was selected based on maximum nominal size 12.5mm.

In the conclusion the steel slag in mix result in increased Marshall stability and have greater fatigue life. Fatigue life increase with increase in steel slag (unaged). Fatigue life do not change (aged).

(Haibin Li, Canyang Cui, Jun Cai, Mingming Zhang, Yanping Sheng,2022), this paper review on utilization of steel slag in road semi rigid base. The possibility of using SS in semirigid base and evaluates the performance of SS base course. Performance evaluation is done by Cement stabilized soil, Lime fly ash stabilized steel slag and Cement flyash stabilized Steel slag.

Steel produced industry is large hence required crushing for base course. After that it meet the required properties. Gradation itself is not fully utilized. The applicability of SS base in rainy and cold area is not clear. The impact of SS base on environment has yet to be assured.

(M.S. Al Kawari, M. Hushari, 2019), Doses and Radiation risk estimation of adding steel slag to asphalt for road construction in Qatar. For radioactivity estimation of adding steel slag samples taken, the slag sample prepared for measurement by low background Gamma ray spectroscopy. Loose steel slag aggregate may not use internally in direct contact with humans. It could be used in external construction application below the ground surface.

Asphalt made up to 40% SS aggregate could be used safely. For environmental point of view its use in surface layer is not recommended. Concrete made up to 50% SS could be used in construction.

(Mahmoud Ameri, Saeid Hesami, Hadi Goli, 2013), The SS was used as fine and coarse potion of aggregate gradation in Hot Mix Asphalt. Firstly, Marshall Method is done acc to ASTM D/559. In second phase, Marshall, ITS, Dynamic Creep in HMA is done. In third phase Warm Mix Asphalt were prepared. Based on Marshall test result replacing coarse portion in Hot Mix Asphalt with SS aggregate increase in Marshall Stability, flow. Based on other test (using SS aggregate with WMA). better adhesive properties, better resistance to moisture damage and hence more durable. Better aggregate interlocking. Higher MQ parameters and hence more durable, flexible and energy absorbing mixture.

(*M.Arabani, A.R. Azarhoosh,2012),* To determine the mechanical properties of asphalt mixtures so that new aggregate is needed to build and maintained road by using waste material as aggregate in pavement industry. The mechanical property of mix contains RCA were poor because mixing and compaction altered RCA particle and removed weak cement mortar from aggregate. When RCA as fine aggregate and SS as coarse aggregate and fine aggregate the Marshall stability increase and flow decreases. In Dynamic creep, deformation was 40 % less then control mix. In ITS FA: RCA + CA: SS mixture 2.35 times greater modulus than that of control mix.

(Tanvi Gupta, S.N. Sachdeva, 2019), The potential use of AOD SS in concrete production. Five mixes along control mix were made by partially replacing cement with AOD SS varying 10%, 15%, 20%, 25%. Concluded that AOD SS can easily be replaced by cement in construction of rigid pavement. With some amount of water in all mixes, replacement of AOD slag by cement did not reduce slump value by a higher degree slump value 25-50mm which is suitable. Addition of higher %age of AOD SS as cement replacement reduce mechanical properties like compressive and flexural strength. Hence 25% replacement of cement SS is proved favorable. Higher amount of AOD SS I.e., more than 25% can also be used for construction of low traffic volume rigid pavement and village road.

(Shaopeng Wu, Yongjie Xue, Qunshan Ye, 2006), The feasibility of utilizing SS as aggregate in SMA and properties of such asphalt mixture are evaluated as well. All the volume performance of SMA mixture containing SS as aggregate can meet the required though the substitution of SS of basalt increases the optimal bituminous content slightly.

Expansion rate of SMA with SS is below 1% after 7 days which ensure stability of SS. Compared with SMA mixture with basalt, the high temperature properties of SMA mixture with SS is improved. The better physical properties of SS enhance the ability of resisting permanent deformation.

(Kavyashree L Magadi, Anirudh N, K M Mallesh,2014), In this paper the SS which s used as replacement material for CA of different sizes for different bituminous mix I.e., 37.5mm down, 20mm down, 12.5mm down at different percentage. All the mixture with SS satisfies MORT&H standards. The OBC was reduced when 12.5mm down SS was used in mix because of more bulk density and less void. The stability, bulk density increases with increase in percentage of SS in mix. The air void reduces as the percentage of SS increases. The ITS ratio is found above the limits, higher ITS of steel slag mixture indicate better cohesive strength then mixture prepared with natural aggregate.

(S. Patel, R.R. Pai, M.D. Bakare, J.T. Shahu, 2020), To corroborate the significance of falling weight deflectometer in comparing the field performance and service life of pavement and service life of pavement sections construction with waste material in base/ sub base. LWD test concluded for stiffness, found that the in-situ stiffness modulus of base and sub-base layer with waste mixture are significantly higher than conventional WMM & GB.

(Sabrina Sorlini, Alex Sanzeli, Luca Rondi, 2012), To evaluate mechanical properties and environmental suitability of EAF slag in paving mixture. Mechanical POV- The fragmentation and wear resistance provide acceptable result; the value of accelerated polishing coefficient and water absorption were comparable with natural aggregate. Chemical POV- Slag sample had a relevant content of total Chromium, Barium, Aluminum, Iron, Magnese. The release of pollutant from leaching test cannot be regarded as negligible although it resulted lower than the limit. Free lime and magnesium oxide concrete responsible for expansive phenomena.

(Vitor A. Nunes, Paulo H.R. Borges, 2021), The recent advances in the utilization of SS in activities other than steelmaking. The potential use of steel slag as binder and aggregate in cement-based minerals notability in

AAM (Alkali activated material). The major obstacle is the variable chemical composition of SS expansion issue. These issues are determinate to mechanical strength and durability. It has great filling capacity as fertilizer and improves the stability and characterize of soil. SS has been considered a good filtering removing material for waste water treatment, removing heavy metal such as Fe, Mn, Cd. The significant challenges for SS application in Portland cement-based material construction to be the potential volumetric expansion and the low reactivity thus decrease the mechanical strength.

(*Malluru Swathi, Thavamani Andiyappan, Gurunath Guduru,2021),* The asphalt mixes containing a high percentage of SS are susceptible to high void space. This is major reason that SSA usage is limited. To provide a framework to design asphalt mixes with a high proportion (upto 100%) SSA with aggregate fraction of varying specific gravity by bailey method of gradation selection. The SSA have superior physical properties compared to NA. Owing the presence of free lime on the surface of SSA, the asphalt mixes with this aggregate have shown more resistance to moisture damage than the NA mix.

(Dikshant Sharma, Prachi Kushwaha, Nishant Sachdeva, 2021), Review of contemporize practice of use of recycled concrete aggregate in pavement construction has been done. C&D waste accounts for 25% of the total waste generated around the globe. It is clear that RCA in careful proportion can be used with natural aggregate without strength loss. Excessive proportion mix of recycled aggregate resulted in loss of characteristic strength of concrete. The incorporation of RCA in construction work centers the harmful effect of C&D waste on ecology and surroundings.

(Ahmad Goli, 2021), The study of feasibility of using recycled steel slag aggregate in HMA. Rutting resistance, Marshall stability, Resilient modulus, fatigue life of slag and conventional asphalt mixture containing different percentage (0,25, 50, 75 wt. %age) of RAP or SS were compared to evaluate the mechanical performance of recycled asphalt the mechanical performance of recycled asphalt with slag aggregate.

(Mojtaba Alinezhad, Ali Sahaf, 2019), Investigation of the fatigue characteristics of Warm Stone Matrix Asphalt containing ERF steel slag as CA and Sarobit as Warm mix additive. The Marshall stability and quotient for mixture contains EAF slag compared to other mixture. Fatigue test indicated the similar performance of SMA contains EAF slag to the control mix contains natural aggregate. The higher stiffness and less flexibility of the mixture contains slag in comparison to the control mix containing natural aggregate. The fatigue life of all SMA & WSMA specimens in the recommended strain level of AASTHO-7-321 fatigue test standards is more than 10,000 cycles.

(Yu Liu, Peifeng Su, Miaomiao Li, Zhanping You, Mohan Zhao, 2020), The wide range literatures on asphalt pavement, explore the evolution of the road pavement. In the past 100 years, asphalt pavement materials and structures had been becoming more and more strong. Asphalt layer thickness were varying from 5 to 60cm and the overall pavement thickness were varying from 28 to 160cm. The long-life pavement in the other countries become shorter life pavement according to prediction based on Chinese specification.

(Mohd Rosil Mohd Hasan, J-Wei Chew, Ali Jamshidi, Xu Yang, 2019), Review of sustainability, pretreatment and engineering consideration of asphalt modifiers from industrial solid waste. While empowering solid waste application as an alternative to solid waste application as an alternative to soild waste management. For addressing both engineering limitation and environment concerns will be a significant stimulus to the future development of having ecofriendly and sustainable asphalt pavement while providing industry with a greater alternative in disposable methods.

(Jens Groeniger, Augusto Cannone Falchetto, Ivan Isailovic, Di Wang, 2017), Investigation on the performance properties of different types of asphalt mixture prepared with 100% LD steel slag and a conventional asphalt mixture contains natural Gabbro aggregate. Use of LD steel slag in mastic asphalt leads to an advantageous deformation resistance compared to mastic asphalt with natural Gabbro aggregate. Due to higher binder needs to LD slag, the mixture with LD slag showed slightly higher air void content result in disadvantageous resistance to deformation.

(Ahmed Ebrahim, Abu Maaty Behiry, 2012), To estimate the resistance for failure factor such as vertical and radial stress and vertical strains of sub-base under overweight truck loads. Increasing SS %age to limestone in the blended mix increase the mechanical properties like Max. Dry density, CBR, Resilient modulus. With increase the depth of sub-base layer vertical stress decrease the deflection is almost constant while the radial stress changes from –ve to +ve through layer depth.

(Marco Pasetto, Nicola Baldo, 2017), The lab study was conducted on bituminous mix made with RAP, EAF, up to 100% by weight of aggregate. In order to evaluate statistically the influence of recycled aggregate on stiffness ofmixes, ANOVA has been performed. The 4-point load test fatigue data recorded at 10Hz have been elaborated according to the energy-based methodology. In order to maximize the environmental sustainability of the road pavement, the use of the highest RAP content (40%) can be recommended. Although the best fatigue life performance achieved at 20% RAP.

(Nayeem Ahmed Mir, O.P. Mittal, 2016), Bituminous can be prepared and used in pavement section for a bituminous binder course using different types of additives. The flow criteria for DBM-1 are satisfied only if bitumen is replaced by 8% plastic waste. Although stability value lies within range. The data obtained that on replacing OBC with 8%, 12%, 16% waste stability value decreases. Stability value increases for 65 replacements of OBC by Rice Husk ash & reduced for 10% and 14% replacement level, but the 6% replacement level only does notsatisfy flow criteria.

(Mansour Fakhri, Amin Ahmadi, 2017), Evaluation of fracture resistance of asphalt mixes without steel slag and RAP. Susceptibility to aging level & freeze and Thow cycle. A set of 576 semicircular bending specimen with different ratios of these two marginal materials with and without WMA additive were prepared in 2 aging levels and underwent up to five freeze and Thow cycle. FT cycles decrease the fracture resistance of asphalt mix. LT agingreduces the fracture resistance of asphalt mixes in term of both Jc and FI indices.

(Marco Pasetto, Nicola Baldo, 2020), This paper shows the use of two types of EAF steel slag as substitute for natural aggregate, in the composition of base course & road base asphalt concrete. The results are extremely satisfactory for all the BBAC mix design with the slag with good value of Marshall stability and Quotient without penalization in term of densification and workability of mix.

(S.H. Mousavinezhad, G.H. Shafabakhsh, O. Jafari Ani, 2019), Nanoparticle have exhibited a promising potential in enhancing the bituminous material performance. The enhancement of Nano polymer composite %age in the modified binder will cause a decline and enhancement in the penetration and softening point of the mixture.

(Lizasoain Arteaga, Lastra Gonzalae, 2020), The environmental impact of replacing high quality CA by EAF steel slag. A life cycle assessment was performed on three asphalt mixture containing different aggregate namely ophite, slag1 and slag2. The absorption rate of slags strongly affects the LCA results increase the binder content of the mixture as well as aggregate humidity.

Conclusion

The following conclusion are drawn based on above literature review.

- From this literature review study that the performance of Dense Bituminous Macadam using steel slag adding in bituminous as per weight of bitumen. And checkout the property of aggregate and bitumen. As from the recent tests in above literatures, steel slag in bituminous mix improves the Marshall stability, flow, OBC, strength.
- The properties of steel slag are found to be in compliance as per the specification which is same as for the crushed aggregate.
- The stability, bulk density increases in percentage of steel slag in the mix irrespective of the steel slah proportion and size.
- The air voids are reduced as the percentage of steel slag increased.

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