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# Mechanical Performance of Bituminous Concrete in Incorporating Steel Slag with Natural Aggregate

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**ABSTRACT:** India has world's second largest road network in terms of length with a total road length of 4.24 million km. Hot mix bituminous pavement contributes around 50% road length to this vast road network. Large scale highway construction in India, emanating from rapid development, has caused massive depletion of scarce natural aggregate. This paper addresses this problem by investigating the influences of the utilization of steel slag as a coarse aggregate on the properties of hot mix bituminous concrete. Physical characteristics of bituminous mix ingredients i.e. natural aggregate, steel slag aggregate and bituminous binder were determined to find out their compliance with Ministry of Road Transport and Highway Specification for Road and Bridge Works in India. Mechanical characteristics of bituminous mixes i.e. Unmodified (having natural aggregate) and Modified (having steel slag as coarse aggregate) were determined using Marshall Method of mix design.

Unmodified and Modified mixes were subjected to an array of performance tests to check out the suitability of steel slag aggregates for the preparation of high performance bituminous concrete mix. The performance tests includes, retained Marshall Stability, indirect tensile strength, static creep test, wheel-tracking test and resilient modulus test. The laboratory study confirmed the improvement in various mechanical properties of steel slag modified mixes besides reduction in temperature and moisture susceptibility.

**KEYWORDS:** Steel Slag Aggregate, Natural aggregate, Bituminous Mix, Bituminous Pavement.

## I.INTRODUCTION

The development of the highway construction industry in India under the aegis of National Highway Development Program (NHDP), has posed great demand of natural aggregates for road construction. As the resources for naturally occurring aggregates diminished at an ever increasing rate, road industries are keen to utilize recycled and waste materials in road construction in harmony with sustainable development. Steel slag, a waste product from the steel making industry, is one of the recycled materials reported to exhibit great potential to replace naturally occurring aggregates in bituminous mixes.

Metallurgical waste particularly steel slag, generated in India is mostly collected by the waste producers themselves and partly by the companies doing separate collection of waste as their primary activity. The generated steel slag waste is partly recovered and returned to the production process (reuse) and part of the waste is sometimes used by other industries as secondary raw material (recycling), whereas the largest part still ends on often non-regulated landfills as industrial waste in adjoining areas. Disposal of steel slag as landfills are particularly hazardous for the environment. Steel slag, a by-product from the steel making process had been reported to exhibit great potential as a replacement for natural aggregates in road construction.

### Design proposals for a new road section

In planning and carrying out the construction work, the development fee is the element which can have important effect on many-sided selection makings. The comments of the systematic creation cost facts is important in assessing the financial system based totally at the efficiency in opposition to investment at the early degree of the mission while the commercial enterprise is deliberate or evaluating the alternatives derived from the assessment of

economy or advancing the design. In this connection, it is necessary to take note of the fact that the influence of the result of decision-making on the construction cost rather gets larger as it reaches the early stage of project such as planning and design, etc.

Nevertheless, in the case of public production project in Korea, as compared with the manner of predicting the construction fee based totally at the targeted portions statistics after the drawings and specs are completed, the system of predicting the construction price approximately on the early level is simply too low in objectivity and transparency, which require an development. Such low accuracy of the construction cost predicted on the early level inevitably comes from the distinction in quantity and degree of the information that may be used in production cost prediction, however its improvement is urgently wanted from the component that it's far inclined in phrases of consistency in addition to objectivity and transparency of approximate estimate prediction on the early degree. The development inside the method of predicting the construction fee at early degree is also a crucial mission that is the first step to efficaciously execute the finance of the authorities in spite of everything.

### Objectives

Most projects in India involving steel slag aggregates as construction material are using this recycled aggregate in lower quality applications such as road bases rather than wearing course. The aim of this research is to study the performance of steel slag as road pavement aggregates compared to the conventional use of siliceous aggregates for the same purpose. The detailed objectives are outlined below:

- (1) To assess the physical and mechanical characteristics of steel slag aggregate to find out its suitability in high performance bituminous concrete mix.
- (2) To assess the performance of bituminous concrete mix prepared using steel slag aggregate with siliceous natural aggregate and bituminous concrete mix having 100 % natural siliceous aggregates.
- (3) To evaluate the effect of moisture and temperature on the performance of mixes incorporating steel slag.
- (4) To compare the performance of Steel slag modified mix and Unmodified mix having natural aggregates.

## II. LITERATURE REVIEW

The ductility of bitumen containing steel slag aggregates firstly increases and then decreases with increase in percentage of steel slag aggregates in the mix. The test results showed a significant scope of use of steel slag, along with the bitumen as a binder. Around 8%-12% of steel slag is mixed to attain the ideal properties of the binder material.

[1] **Sagar P. Parajuli, Mussie (2014)** Buildings and similar structures use huge amount of concrete and their effective disposal after the life span is getting increasing attention as the older structures are being dismantled and newer structures are being constructed to adjust with the modern environment. With the development of technology, availability of recycling facilities for such dismantled materials is also spreading. Moreover, landfills are becoming increasingly difficult to find, are too remote from the demolition site, or are too costly to maintain increasing the necessity for recycling. As the dismantled concrete after crushing can yield good aggregates with acceptable strength, they are being considered as one of the viable material in road base construction. In fact, it has been proved by different tests that the strength of recycled aggregates is comparable to that of crushed aggregate or natural gravel

[2] **E.K. Anastasioua, A. LiapisaM.Papachristoforou (2013)** Global sustainable development will require using every resource to its maximum potential. The potential of construction and demolition waste's inert fraction can be maximized if it is reused as recycled aggregates (RA) for concrete production. However, there are technical risks involved in this technique, particularly due to lack of knowledge in terms of the long-term behaviour of concrete made with these aggregates. Abrasion resistance is one of the least known properties of hardened concrete but nevertheless one of the most important for certain applications (hydraulic structures and floors/pavements). It is concluded that there is no loss of abrasion resistance with the incorporation of RAs and that there are reasons to believe that it even improves, even though the quantification of that improvement needs further investigation to be accurate.

[3] **Flyvberg, B., M.K.S. Holm, and S.L. Buhl (2003)** presented the choice of the appropriate economical and advantageous pavement type was made by carrying out life cycle cost analysis, which takes into account the initial cost and the maintenance cost. They also presented the cost of construction for both rigid and flexible pavements. They also estimated an economical cost analysis, which showed us that the life cycle cost of concrete pavement is about twenty to twenty five percent lower than bituminous pavement. The needs of other road users including pedestrians, cyclists, and rickshaw riders were largely ignored – as were the needs of bus drivers and their passengers, and people who needed vehicle access to roadside property. This was shortsighted because the congestion and other problems caused by failing

to provide for all road users meant that the benefits of constructing a good road pavement were partly lost. Designers are now taking a wider view but there is still not enough attention being given to how everyone will use the road.

[4] Gransberg, D. D., and K.R. Molenaar (2004), "In this process, all participants must be treated equally in order to prevent the decision-makers from taking only one side's arguments into account. Availability of information is therefore a central part of environmental democracy as it encourages concerned members of the public to become active participants in the decision making processes related to environmental issues. The terms "public" and "concerned public" are defined by the Convention itself: The term "public" stands for one or more natural or legal persons and their associations, organizations and groups as defined by local law. The public can be any person, regardless of their citizenship, residence or headquarters (for legal persons). Discrimination on the basis of citizenship, nationality, residence or location of headquarters (for legal persons) is forbidden. The term "concerned public" stands for segments of the public that are or could be affected by environmental decision-making, or that are interested in the issue; non-governmental organizations whose work is in the field of environmental protection and that meet all the criteria set by local law will be considered members of the concerned public.

[5] Chan, A., G. Keoleian, and E. Gabler (2008) there are a number of different approaches organizations use to relate to the public opinion. Some of them try to create their own atmosphere in the public opinion in an aggressive manner, while most organizations see public opinion as an extremely important area, where daily acting and activity adapting are required.

The primary goal of public relations is the adaptation of conducting business and communication of the organization to the characteristics and expectations of the public and the public opinion, more so than manipulating public opinion. Systematic adjustment to the public and public opinion implies a constant gathering of information among members of the public who are important for the organization, and the submitting of the said information to the management, which ultimately makes the final decision in the organization and manages it. The component of socially responsible behavior of investors is important in the processes of environmental impact studies. An environmental approach is the fundamental role the organizations have to play to adapt to changes in their environment. In order to successfully operate and survive, all organizations must: accept public responsibility as imposed by society, communicate with the various publics, and get integrated into the community because of which they exist in the first place.

### III. MATERIALS AND METHODOLOGY

The study is divided into three main phases. The first is related to the physicochemical characterization of the steel slag aggregate, natural aggregate and bitumen. The second phase deals with bitumen mix designs which were two mixes; One with an integrated slag-natural aggregate matrix (Steel slag modified mix) and one with only natural aggregates (Unmodified Mix) used as a control mix. Third phase covers the various performance tests carried out to assess mechanical characteristics of steel slag modified and unmodified mix.

#### Material Used

The processed steel slag aggregates used in the study was supplied by HARSCO India Private Limited. Steel Slag was generated as a melt at about 1650°C during steelmaking from hot metal, direct reduced iron or scrap. It consisted of oxidized co-elements of the hot metal and other metallic charges which reacted with the added limestone and dolomite. Depending on the process technology, one could distinguish Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slag. The chemical composition of EAF steel slag used in the study is given in Table 1. Calcium oxide (CaO), iron oxide (FeO) and silica (SiO<sub>2</sub>) are the three major chemical constituents of both EAF and BOF slags. Due to the presence of unstable phases in its mineralogy, steel slag can show volumetric instability, caused mainly by the presence of free CaO. In the presence of water, free lime hydrates and forms Portland (Ca (OH)<sub>2</sub>). Portland has a lower density than CaO and hence, hydration of free CaO results in volume increase.

In order to reduce the expansibility of steel slag aggregate, several aging methods can be used like air aging, hotwater aging and steam aging; under first method steel slag is left out in the open for 1 month for weathering through air (air aging), in the second method i.e hot water aging steel slag is immersed in hot water at 80 ± 3 °C temperature for 1 day or 3 days and the last method exposes steel slag aggregate to steam at 100°C for over 3 days (steam aging). The geotechnical characteristics of Steel Slag Locally Available Soil and their mixtures were investigated to study their feasibility in different layers of road pavement. Construction of road embankment using slag alone would not be feasible as it is cohesion less material. Such embankments would be highly erodible. Therefore, it was blended with local soil in the range of 25-75 % and their geotechnical characteristics were investigated.



**ENGINEERING PROPERTIES OF SLAG**

- a) **Gradation:** Steel slag should be crushed and screened to produce a material that satisfies the grading requirements of granular base and sub base specifications, such as AASHTO M147.
- b) **Compacted Density:** The compacted density varies with size and grading of the slag, method of measuring, and bulk specific gravity of the slag. The compacted density of Slag aggregates ranges from 1120 kg/m<sup>3</sup> to 1940 kg/m<sup>3</sup>, which is somewhat lower than that of conventional granular materials. Allowance for this differential should be considered during design and in specifications in order to ensure equal volume irrespective of the type of aggregate used.
- c) **Stability:** Slag aggregate angularity and high friction angle (40° to 45°) contribute to high bearing capacity (California Bearing Ratio (CBR) greater than 100).
- d) **Freeze-Thaw Resistance:** Slag aggregates display good durability with resistance to freeze-thaw weathering and erosion.
- e) **Hardness and Impact Resistance:** The hardness of slag as measured by Moh’s scale is between 5 and 6, corresponding to durable igneous rock. However, Slag aggregate is quite brittle and prone to breakdown when subjected to impact loading.
- f) **Abrasion:** AASHTO M147 requirements for Los Angeles Abrasion loss for granular base aggregates are typically waived for Slag aggregate since no correlation between the Los Angeles Abrasion test loss for slag in laboratory tests and degradation in field applications has reportedly been observed. For this reason ASTM has deleted this test for slag in its specifications and major slag-using states, such as Michigan, Ohio and Indiana, do not use this test procedure with ACBFS.

**Table 1: Engineering Properties of slag**

Maximum Dry Density (Standard)	12.30-16.9
Optimum Moisture	9-11%
Fractured Faces	100%
Dry Strength	200 -220kN/m <sup>2</sup>
Wet Strength	180 - 200kN/m <sup>2</sup>
Liquid Limit	Not obtainable
Plastic Limit	Not obtainable
Plasticity Index	Non-plastic
Linear Shrinkage	0%

**Construction Procedures:**

**a) Material Handling and Storage:**

The same equipment and procedures used for conventional aggregate may be used to stockpile and handle conventional aggregates as appropriate for slag aggregates. However, greater care is required when handling and stockpiling blast furnace slag aggregates to avoid brittle fracture that can result in excessive fines generation.

b) **Placing and Compacting:** Procedures should be employed to ensure uniform gradation and layer thickness. Good uniformity is obtained by combining the coarse and fine aggregates with optimum water for compaction at the blending plant just prior to placing. The material should be graded and placed in a manner that allows free drainage and prevents ponding within or adjacent to the material.

c) **Quality Control:** The same test procedures used for conventional aggregate are appropriate for Slag aggregates. Standard field and laboratory tests for compacted density and field measurement of compaction are given by AASHTO T191(9), T205(10), T238(11), and T239(12) test methods.

**Table 2: Physical properties of bitumen**

Properties	Test value	Standard
Penetration at 25°C, 1/10 mm	87	ASTM D 36 - 06
Ductility at 25°C (cm)	> 100	ASTM D 113 - 07
Softening point	49	ASTM D 36 - 06
Specific gravity at (25°C) (g/cm <sup>3</sup> )	1.02	ASTM D 70 - 09
Viscosity @ 135 °C (cP)	487	ASTMD44
Viscosity @ 165 °C (cP)	144	
Mixing temperature	160 °C	ASTM D4402
Compaction temperature	150 °C	



IV. RESULTS

This study investigates use of plastic waste with bitumen to replace it to a limited extent and also the steel slag of a particular type in the form of aggregates along with conventional stone aggregates, its effects and an economical method for its implementation. Marshall Specimens were prepared at bitumen contents of 4.0, 4.5, 5.0% by weight to find optimum bitumen content, with P.E.T content of 0%, 4%, 6%, 8%, 10% by weight of bitumen and with steel slag aggregate content of 5%, 10%, 15% and 20% to find out respective limits and their properties.

S.No	Properties	4.0%	4.5%	5%
1	Marshall Stability ,KN	11.2	13.8	12.4
2	Flow Value ,mm	4.9	3.8	4.4
3	Marshall Quotient, Kn/mm	2.28	3.63	2.81
4	Theoretical Max Density (Gt) ,gm /cc	2.48	2.45	2.45
5	Average Height Of Specimen ,cm	6.8	6.8	6.8
6	Weight Of Sample In Air ,gm	1254	1257	1266
7	Volume Of Sample ,cc	534.004	534.004	534.004
8	Bulk Density (Gb) ,gm/cc	2.348	2.353	2.370
9	Volume Of Air Voids (V <sub>v</sub> ) %	5.645	4.081	3.673
10	VOLUME OF BITUMEN (V <sub>b</sub> ) %	12.425	13.587	14.824
11	VOIDS IN MINERAL AGGEREGATE (VMA) ,%	18.070	17.668	18.498
12	Voids filled with bitumen (VFB) ,%	68.759	76.898	80.141

The above table shows the results of various properties like Flow value, Stability value, Marshall Quotient, VFB, VMA etc. for the specimens of conventional bituminous mix with varying percentages of bitumen like 4%, 4.5% and 5.0%. Also the optimum bitumen content is found out from above. Optimum bitumen content is the bitumen content at which properties like stability and flow show the better results.

**Table: Properties of 4.5% bituminous mix with various plastic and steel slag %**

S.no	Properties	4 & 5 %	6 & 10%	8 & 15 %	10 & 20 %
1	Marshall stability ,KN	14.1	15.4	16.8	14.7
2	Flow value ,mm	2.6	2.7	2.5	2.38
3	Marshall quotient, kN/mm	5.42	5.70	6.72	6.17
4	Theoretical max density (Gt) ,gm /cc	2.48	2.47	2.47	2.47
5	Average height of specimen ,cm	6.8	6.8	6.8	6.8
6	Weight of sample in air ,gm	1258	1260	1259	1263
7	Volume of sample ,cc	534.004	534.004	534.004	534.004
8	Bulk density (Gb) ,gm/cc	2.355	2.359	2.357	2.365
9	Volume of air voids (V <sub>v</sub> ) %	5.241	4.453	4.858	4.453
10	Volume of bitumen (V <sub>b</sub> ) %	12.124	12.686	17.223	16.844
11	Voids in mineral aggregate (VMA) ,%	17.622	16.840	17.223	16.844
12	Voids filled with bitumen (VFB) ,%	70.252	71.554	72.791	73.559

The above table shows the results of various properties like Flow value, Stability value, Marshall quotient, VFB, VMA etc. for the specimens of modified bituminous mix with percentage of bitumen being constant i.e. 4.5% (optimum bitumen content) and varying percentages of plastic and steel slag. For example- 4% P.E.T and 5% steel slag, 6% P.E.T and 10% steel slag and so on.

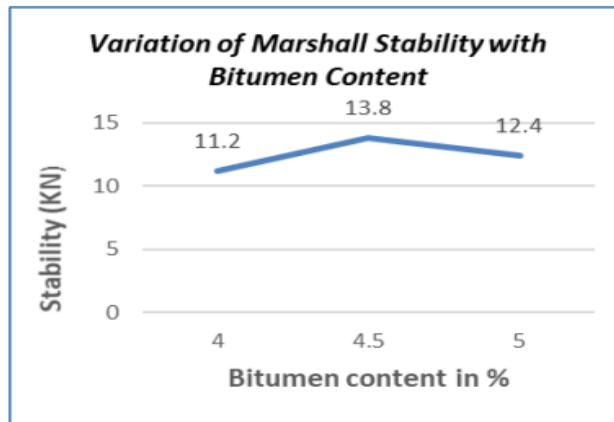


Figure: Marshall Stability Vs Bit. Content (Optimum bitumen content found out to be 4.5%)

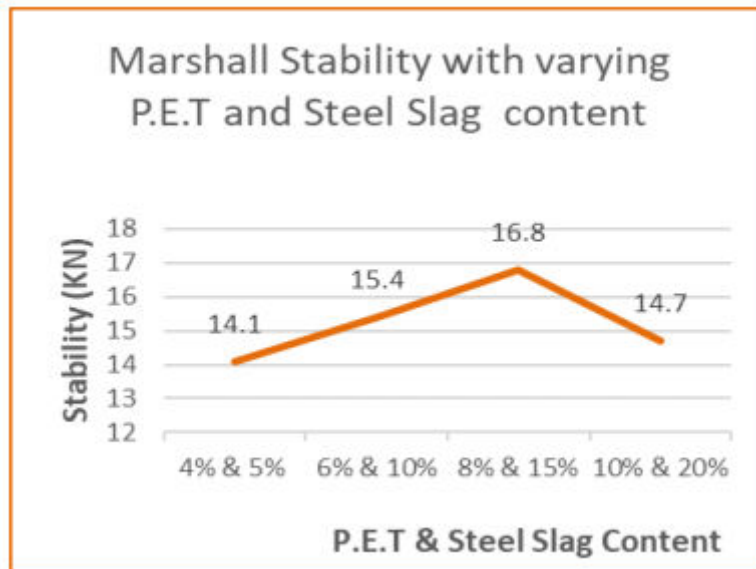


Figure: Marshall Stability variation for various P.E.T and steel slag contents.

The above Figure shows the Marshall Stability values in KN for various P.E.T and steel slag combinations. For example- 4% P.E.T as a replacement to bitumen and 8% steel slag as a replacement to aggregates by total weights.

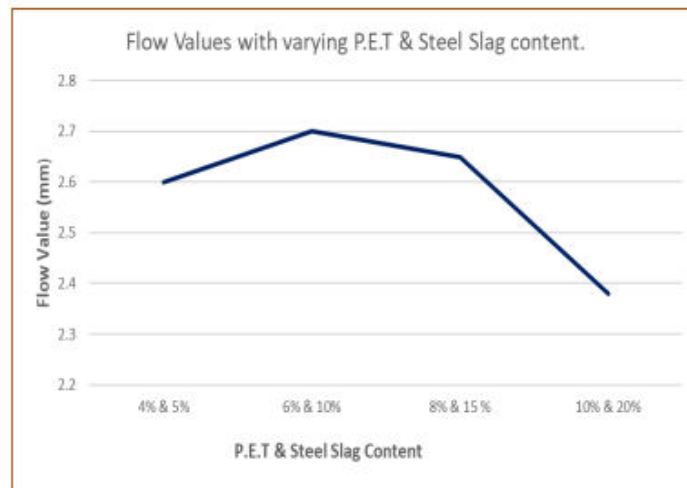
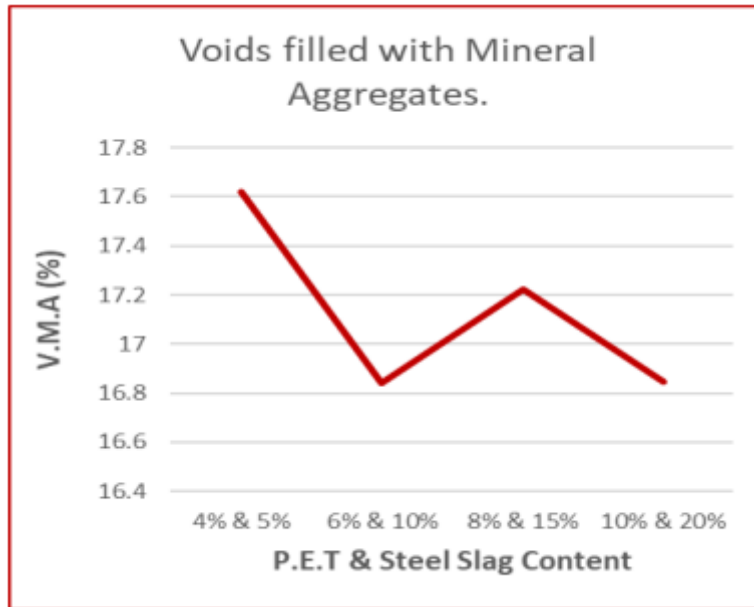


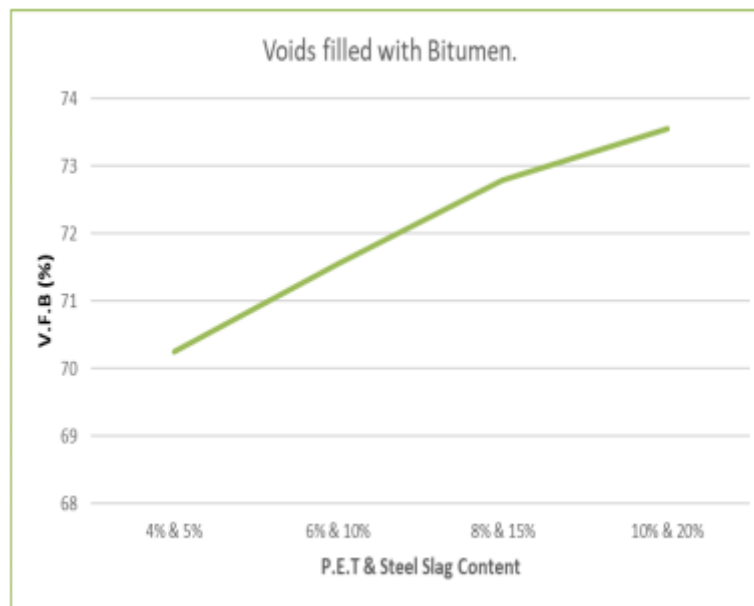
Figure: Marshall Flow in mm for various P.E.T and steel slag contents



The above Fig shows the Marshall Flow values in mm for various P.E.T and steel slag combinations. It is observed that result starts falling down (negative) after point of 8% P.E.T and 15% steel slag addition. IRC specification for Marshall Flow ranges between 2mm-5mm.



A graph of Voids in Mineral Aggregates Vs P.E.T and steel slag content



A graph of Voids Filled with Bitumen (VBF) Vs P.E.T and steel slag content

The optimum bitumen content was found out to be 4.5% It is seen that up to 8% use of plastic and 15% of steel slag improved results can be achieved.

This study suggests a reliable alternative to the conventional materials used in construction of bituminous roads. It is seen that use of plastic and steel slag as a modifier is a good choice which also enhances the performance of the roads. Since plastic is a hazardous waste which has difficulties in disposal, its utilization in construction of road proves as an approach in safeguarding the environment and this work provides a scope for further studies of steel slag as an ingredient in flexible pavements.

- Use of steel slag increases the strength parameters. It provides resistance to rutting, stripping, permanent deformation etc.



- Modified mixes shows low permeability and seepage of water which would prevent formation of potholes and also increase durability.
- Cost of steel slag is very less approximately Rs 600 per tonne and is as affordable as stone aggregates. (market survey)
- Marshall Stability and flow values show improved results for modified mix.
- Mostly costly ingredient in road construction is bitumen or asphalt, Since P.E.T would replace this bitumen there would surely be cost saving up to some extent making the process economic.
- The results obtained by laboratory testing of aggregates shows that EAF steel slag aggregate meets the Indian specifications for the use in bituminous mixes. Steel slag aggregates possess requisite physical and mechanical properties which are comparable with the natural aggregate produce from igneous rocks of silicate composition.
- Mix design results are quite satisfactory for bituminous mix containing steel slag aggregates with good values of Marshall Stability and Retained Marshall Stability. Steel slag mix shows significant improvement in resistance to moisture damage and high resistance to permanent deformation. Improved resilient modulus at higher temperature and reduced susceptibility for rutting in steel slag modified mix pave the way for thinner bituminous layer as wearing course.
- In conclusion the study found that the use of EAF steel slag in bituminous mixes may be a technically satisfactory option which can preserve rapidly depleting natural aggregate. Further the laboratory study reported in the paper is required to be complemented by field trial of steel slag aggregate bituminous mixes to establish beneficial effects for formulation of national specification.

## V. CONCLUSION

As the world's largest solid waste, the re-utilization of the most solid waste should become one of the important research focuses in the country. Especially in road with high quality aggregate become scarce, steel slag as an alternative set of used asphalt concrete is of great research and the social significance. In this paper, the physical and chemical properties of steel slag are tested, and the steel slag is a porous material.

- The expansion of slag is very less so we can replace the expansive soil by utilizing this industrial slag rather than utilizing natural aggregates. The industrial slag which is wasted anywhere that can be utilized, very well, so soil pollution can be prohibited. We can replace the top layered metal by replacing the slag with bituminous cementing material enhancing the resistance against skidding due to this property slag can also be utilized on the sloping gradients of roads.
- In many cases, the use of reactive cost management reduced maintenance costs, yet in other cases, it resulted in impaired maintenance standards and quality. This impairment is mainly due to the focusing on reducing personnel, recurring rate of maintenance activities as well as prioritizing some maintenance measures before others. In almost all efforts towards efficient maintenance, road authorities have ignored improvement potentials that exist during the planning and design phase.

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