IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

# Replacement Of Steel Slag As Aggregate And Its Stabilization In Flexible Pavement

[1]Mohd Abdul Rehman, [2]Pavan V. Kaware, [3]Vishal S. Pande
[1]Assistant Professor, [2]Student, [3]Student,

[4]Rahul R. Rathod, [5]Nilay Lokhande, [6]Vaishnavi P. Manwar
[4] Student, [5]Student , [6]Student

[1]Department of Civil Engineering
[1]P. R. Pote Patil College of Engineering and Management, Amravati, India

***Abstract:*** Natural aggregates are the most widely used constituent in the construction industry, forming a significant portion of materials used in concrete, road construction, and railway ballast. In concrete works, aggregates constitute approximately 50–60% of the total volume, while in road construction, this figure rises to about 75–80%. However, natural aggregates are finite resources, and their continued extraction poses environmental and sustainability concerns, especially in a rapidly developing country like India, where construction demands are ever-increasing. To address this issue, alternative materials are being explored, with steel slag emerging as a promising candidate. Steel slag is a byproduct of the steel manufacturing process, produced in molten form and cooled to form a strong, porous material. It exhibits favorable mechanical properties, such as high impact resistance, abrasion resistance, and crushing strength, making it a potential substitute for natural aggregates.

However, its porous structure leads to excessive water absorption, causing volume instability and limiting its direct application in construction. To overcome this limitation, surface treatment is essential. Among the available techniques, applying coatings of cement paste or oil paint has been found to be both effective and economical. This research project aims to determine the optimum replacement level of natural aggregates with steel slag in concrete and other construction materials. Additionally, the study will evaluate the performance of chemically treated steel slag, with a focus on mechanical properties and durability, to establish its viability as a sustainable aggregate alternative.

***Index Terms* - Material used, Theoretical framework, Outline of Project, Design Mix**

## I. INTRODUCTION

Steel slag is a byproduct obtained from steel industry. It is generated as a residue during the production of steel. Because of the high disposal cost as a waste material and the overall positive features of steel slag, it has been declared a useful construction material, not an industrial waste by most of the developed countries. Successively, it is recycled as an aggregate for the construction of roads, soil stabilization, and base and for the surfacing of flexible pavement.

Fig.1. Removal of steel slag while steel manufacturing

Despite this, a large amount of steel slag generated from steel industries is disposed of in stockpiles to date. As a result, a large area of land is being sacrificed for the disposal of this useful resource. Many researchers have investigated the use of steel slag as an aggregate in the design of asphalt concrete for the road construction. The best management option for this by product is its recycling. This leads to reduction of landfills reserved for its disposal, saving the natural resources and attaining a potential environment. The purpose of this paper is to review the engineering properties of steel slag and its utilization for road construction in different ways.

Aggregate is obtained from natural rocks. Mining of the aggregate leads to the reduction of natural resources. The countries having limited resources of natural aggregate are thinking to save their natural resources for their future generation. A large area of land is utilized for the disposal of such solid wastes, producing by industries. Factors like environmental, economic, technical and deficiency of proper construction material have diverted the attention of researchers to other alternatives. As a result, they have explored variety of recycled materials which can be used as an aggregate. during the purification of iron, a byproduct is generated like a stone called iron slag. It has number of advantages but very effective for drying the injuries. The byproduct generates from the melting of scrape to produce steel by an electric arc furnace (EAF), and through the conversion of iron to steel by a basic oxygen furnace (BOF). The steel slag obtained from these furnace looks like similar but the properties may differ based on the grade of steel produced and the furnace, while the chemical composition remains within the range. As compare to electric arc furnace, the main problem with basic oxygen furnace is the excess quantity of its free lime and free magnesia contents. Particular expertise are needed to handle it in a proper way to avoid the volumetric expansion otherwise it may result pavement failure. According to National Slag Association iron and steel slags have been used in engineering constructions for more than 150 years. It is being used as aggregate in replacement of natural aggregate, for bounding applications (BFS) instead of Portland cement, fill material, rail road ballast and sub grade soil staIt is utilized as aggregate for surface layer, road base and sub base. It is also utilized in earthworks and hydraulic structures as well. Because of significant amount of free iron, steel slag becomes hard and dense to provide high abrasion resistance. It is a rough textured, sufficient angular, vesicular and porous material. After compaction it provides a satisfactory particle interlock and high stability. There is not any standard for the proportioning of steel slag with natural aggregate but if partially replaced at the percentage of about 20% to 100% provides satisfactory results. Previous experimental studies show that the use of steel slag may improve the performance pavement. The rough textured surface of steel slag provides high skid resistance. The high specific gravity and the proper interlocking due to angularity of steel slag result better stability and resistance against rutting as well.

During the production of three tons stainless steel around one ton of steel slag is generated. It has been noticed that per year fifty million tons of steel slag is generated from different steel industries throughout the world. Only in Europe, around twelve millions of steel slag is generated every year. Steel slag is a residual material that generates during the production of stainless steel by different resources either from the melting of scrape to produce steel in electric arc furnace (EAF), or by converting iron to steel in basic oxygen furnace (BOF). Hot liquid metal, scrape and fluxes together with lime and dolomite lime processed in basic oxygen furnace. The impurities like carbon monoxide and silicon, manganese, phosphorous and iron in liquid state combines with lime is and dolomite lime are separated by injecting oxygen with high pressure to form steel slag. Electric arc furnace is a kettle shaped arrangement used to process cold steel scrape instead of hot liquid metal. The scrap is melted through high electric current passing through graphite electrodes by forming an arc. Some other metals like Ferro, alloys are added to balance the required chemical composition of steel and oxygen is blown to purify the steel. At the end, the floating steel slag is separated from the surface of molten steel. The residual steel slag is then crushed into 8 inches with the help of a large steel ball or a solid steel cylinder by dropping it to the slags. The process for crushing and grading is repeated until to get the required grade of aggregates. Recovery of metallic particles is carried out through conveyer belts electromagnetically in the same plant. Then supplied in the form of construction aggregate to the construction agencies. It is competing with natural aggregate, where high performance aggregate is limited. This indicates the importance of alternative aggregates like steel slag are valuable products not the wastes, also providing environmental benefit.

Steel slag is a by-product of the steelmaking process, and its production accounts for 8%, 15% of the raw steel. The comprehensive utilization rate of steel slag in Europe and the United States is as high as 84.4~98.4%, and the utilization rate of steel slag for road construction is 32.4~49.7%, with a perfect quality control system and production process. The annual production of steel slag in China is about 70 million tons, with an accumulated stockpile of more than 1 billion tons, and the utilization rate of steel slag is about 30%, of which only 7.6% is used for highway construction. The use of steel slag as asphalt pavement aggregate can reduce the increase in pavement cost due to the use of high quality aggregates, and effectively solve the problem of inadequate utilization of steel slag resources and environmental pollution [4]. In addition, the density of steel slag is higher than that of natural aggregates, and its mechanical properties are better than those of ordinary aggregates. Asphalt pavements are undoubtedly an ideal way for the application of steel slag due to its characteristics such as high consumption of aggregates and aggregate high strength requirements. However, there are still problems in the actual use of steel slag in asphalt pavements. On the one hand, steel slag undergoes hydration reaction with free calcium oxide (f-CaO) and free magnesium oxide (f-MgO) in contact with water, causing volume expansion, which leads to cracking and bulging of asphalt pavement and other damage. On the other hand, steel slag has a rich porous macrostructure, which makes the amount of asphalt used in steel slag asphalt mixtures significantly higher and increases the cost of highway construction.

## II. LITERATURE REVIEW

**Mohd. Rosli Hainina et al. (2015)** Steel slag has a number of advantages with high engineering properties. It has been declared a useful construction material not an industrial waste. steel slag mixture requires higher value of bitumen content, which does not meet the guidelines of optimum bitumen content for natural aggregate. There is not any guideline or specification in general for steel slag to be followed, for the different proportions of steel slag blended with natural aggregate to obtain adequate mix design It is concluded based on chemical and mineralogical composition, the properties of steel slag are different compared to the natural aggregate. So, the guidelines of natural aggregate are being followed for steel slag is not appropriate.

**Magdi M. E. Zumrawi et al. (2015)** The physical properties of SSA basically satisfy the requirements of Marshall Specification for the design of HMA. Based on laboratory test results, SSA appears to be especially beneficial for the use in Sudan to reduce the dependent on naturally occurring aggregate. Thus, it is recommended that the producers and the users of AHM in Sudan consider the use of SSA. From the economic point of view, utilization of steel slag as road construction aggregate may reduce the cost of extracting and processing naturally occurring aggregates. The steel producing industry may also reduce their cost of treating and disposing the huge number of steel slag stockpiles. The use of natural aggregate in the HMA layer of road pavement is seen as a wasteful use of a finite natural resource. Therefore, the use of waste (secondary) materials is recognized as being of benefit to both environment and society. Of the various waste materials, the steel slag can be considered reasonable alternative sources of aggregate for concrete asphalt mixture productions. Further research is still required to obtain new specifications for the use of SSA in different fields of application to conserve Sudan natural resources and preserve the environment.

**Manoj Kumar Tiwari et al. (2016)** it identified from the past researches that the steel slag is heavier than conventional aggregate, having improved friction asphalt mixtures, providing high stability (less rutting) and high angle of internal friction. Thus steel slag, instead of being disposed-off on valuable land, is suggested for use as a low-cost construction material in quality construction. Usage of steel slag in India needs to proceed cautiously, because of possible environmental, health and safety concerns. Thus, further research is needed before any specific utilization and also a final approval will be required from the government as an alternative construction material. It is anticipated that the availability of scientifically sound technology, legislation and appropriate knowledge amongst all advocates would augment the possibilities of using steel slag as an environmentally sustainable and a future substitute material for various activities.

**Sabapath et al. (2017)** modified the surface of steel slag with the ratio of cement:dust:slag at 1:6:14, and the results showed that the bulk stability of steel slag improved significantly after porous surface treatment, and the compressive strength of the asphalt mixture increased slightly, and the splitting and tensile strength peaked at 25% of aggregate replacement.

**Khaled E. Hassan et al. (2021)** The mineralogy of EAF steel slag aggregate is dominated by iron oxide and magnesium-iron oxides, accounting for high density and increased hardness, with potential expansive reactions due to the presence of unhydrated lime. The weathering trials and laboratory expansion tests confirmed the effectiveness of preconditioning EAF steel slag for one-year to produce compliant aggregate with low susceptibility to expansive reactions. The properties of EAF steel slag satisfied the aggregate requirements for use in hot mix asphalt mixtures, with higher binder content necessary for increased slag content to achieve similar voids content to the control. Coarse slag aggregate (5_20 mm) was found to be more effective than fine slag aggregate (0_5 mm) in satisfying the mix design requirements. Despite the similar results of in-situ voids content and IDT of the slag and gabbro asphalt immediately after construction, the slag asphalt exhibited lower reduction in voids and increased IDT after 3 years in service. The results confirm the benefits of slag aggregate in improving the bond characteristics with bitumen and resistance to pavement deformation. The properties of the recovered binder indicated significant aging after 3 years in service in a hot, arid climate. However, there is no evidence of adverse effect of the slag aggregate on the binder ageing compared to the gabbro.

**Ion Chiricuta et al. (2021)** Using BOF slag coarse aggregates will result in a significant increase in the percentage of air voids in asphalt mixture. The rough surface texture and higher sphericity of BOF slag will cause the increase of the air voids of asphalt mixture. Besides, if the BOF slag has excessively high angularity, it will have an adverse effect on the increase of air voids. Also, if BOF slag has excessive angularity value, the edge angle of BOF slag would be destroyed during the compaction of the asphalt mixture, which would result in the decrease of the air voids of the asphalt mixture.

**Giulio Dondi et al. (2021)** Regarding the cement bound mixture, static mechanical characterization tests (ITS,UCS) highlight that results are not far from those obtained with the virgin mixture and satisfy the principal requirement imposed by the technical specifications. Additionally, the ITSM results confirm what is found in the literature: there is a consistent difference in stiffness between the mixture analyzed. The mixture containing steel slag has a higher stiffness modulus even if compared to the reference virgin mixture. The asphalt mixture that contains a higher percentage of slugs in weight of aggregate is characterized by higher stability and stiffness. The optimum mixture was obtained using 4.5% bitumen and 30% slag.

**Huang Yi et al. (2022)** Compared to the developed countries, the utilization rate of steel slag is still very low in China. Therefore, large-scale utilization is a substantial resolution to the environmental problems arisen by steel slag dump. The author believes that there are two important routs for steel slag large-scale utilization in China where industrialization is accelerating: one is to produce cement and concrete using the steel slag fine powder after reclaiming waste steel; the second is direct application in road and hydraulic construction. When the technology of CO2 capture and flue gas desulfurization become reliable in the future, the two technologies will be selective before utilization in other ways. In addition, the database establishment of steel slag characteristics and applications is a substantial task for steel utilization.

**Youwei Gan et al. (2022**) Different surface treatment methods of steel slag were compared, and the optimum surface treatment process and modifier dosing Different surface treatment methods of steel slag were compared, and the optimum surface treatment process and modifier dosing The experimental sections were paved based on the test results. The following conclusions were obtained. According to the microscopic morphological characterization and Matlab software analysis, EAOR retains the height characteristics of the steel slag profile while making the slag surface smoother, but the adhesion grade is reduced by 1 level. The water absorption and crushing value of cement slurry modified steel slag (CPSS), polyvinyl alcohol modified steel slag (PVASS) and epoxy acrylic modified organosilicon resin steel slag (EAORSS) decreased significantly with the increase of modifier dosing. Among the four modifiers, EAOR had the best effect, with EAORSS having the best effect at EAOR:xylene = 2:1. EAOR enhanced the high-temperature rutting resistance of the steel slag asphalt mixture. Slightly reduced the water stability of steel slag asphalt mixture. Improve the durability of steel slag asphalt mixture against freeze-thaw damage. Significantly improves the volume expansion of steel slag mixes.

**Mohammed et al. (2021)** used the modifier to aggregate mass ratio of 0.3% polyvinyl alcohol, acrylic and polyester for the surface treatment of steel slag, and the results showed that the rutting resistance and cracking resistance of the surface modified steel slag asphalt mixes were significantly improved.

## III. RESEARCH METHODOLOGY

### 3.1 Material used

A] **Aggregate:** The natural aggregate used in this study is crushed stones of different sizes. This aggregate was collected from the road contractors at Amravati Maharashtra. The aggregate size we have selected is generally less than 20 mm. in this maximum amount is chippers and size of 16 mm. Aggregates plays a crucial role in flexible pavements particularly in asphalt concrete. It forms the load bearing skeleton providing the structural support and resisting stresses from traffic and environmental factors. The size, shape and texture of coarse aggregate significantly impact the pavements performance, including its density, stability and resistance to deformation.

B] **Bitumen:** The asphalt used in preparing all specimens of penetration grade 30-40. This asphalt was obtained from asphalt plants belong to road contractors at Amravati Maharashtra. These type of bitumen is suitable for hot weather climate due to softening of bitumen. Bitumen of 30/40 grade is a semi-hard penetration grade, meaning its penetration is 30-40 suitable for road construction and repair. Its commonly used in hot mix asphalt for bases and wearing courses. This grade is known for its ability to produce high quality asphalt pavements that meet stringent specifications and ensure durability.

C] **Steel Slag:** Steel slag was delivered from the by-product of steel manufacturing at Evonith Metallics limited (EML) in Wardha Maharashtra. After the steel slag has been crushed and graded to the desired sizes, it was stockpiled for delivery. The surface texture of the slag was observed to be quite variable, from very dense and solid like basalt, to vesicular like volcanic cinders. Steel Slag Aggregates samples were selected from three different stockpiles of coarse aggregates, fine aggregates, and mineral filler.

Fig.2. steel slag obtained from steel manufacturing industry

The samples of Steel Slag Aggregates were delivered to the Transportation laboratory at the P.R. Pote (Patil) College of Engineering and Management Affiliated with Sant Gadge Baba University Amravati Maharashtra.

D] **Cement:** Cement was collected from nearby hardware store at Amravati Maharashtra. Ordinary Portland cement of 33 grade used for cement paste. cement is used for coat steel slag.

E] **Paint:** Paint was collected from nearby hardware store at Amravati Maharashtra. Ordinary oil paint of normal consistency having yellow colour.

**3.2 Theoretical framework**

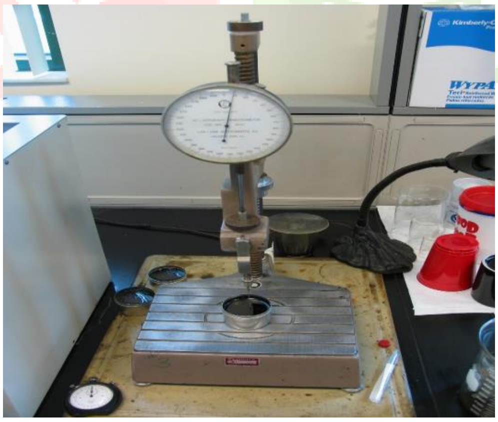
Tests conducted on Aggregate and steel slag are Impact test, Los Angeles abression test, water absorption test and crushing strength test. The 'Aggregate Impact Value' gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from its resistance to a slow compressive load. The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This Characteristic is measured by impact value test. This is one of the major mechanical properties required in a road stone. The test evaluates the ability of the aggregates used in road construction to withstand the stresses induced by moving vehicles in the form of crushing. With this, the aggregates should also provide sufficient resistance to crushing under the roller during construction and under rigid tyre rims of heavily loaded animal drawn vehicles. The crushing strength or aggregate crushing value of a given road aggregate is found out as per IS-2386 Part- 4.

Fig. Crushing strength test of aggregate on UTM

The principle of Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregates and steel balls used as abrasive charge pounding action of these balls also exist while conducting the test: Maximum Allowable Los Angeles Abrasion Values of Aggregates in Different types of pavement layers as per Indian Road Congress (IRC) are: - 1. For sub-base course a value of 60%. For base course such as WBM, Bituminous Macadam (B.M.), Built – Up spray grout base course and etc. value of 50%. 2. For surface course such as WBM, BM, Bituminous Penetration Macadam, Built-Up spray grout binder course and etc. a value of 40%. 3. If aggregates are used in surface course as bituminous carpet, bituminous surface dressing, single or two coats, cement concrete surface course and etc. a value of 35%. 4. If aggregates are used for bituminous concrete, Cement concrete pavement as surface coarse than aggregate abrasion value of 30% maximum.

Fig.2. Los Angeles Abression test on Steel Slag Aggregate

Water absorption gives an idea on the internal structure of aggregate. Aggregates having more absorption are more porous in nature and are generally considered unsuitable, unless found to be acceptable based on strength, impact and hardness tests.



Test conducted on the bitumen are penetration test, ductility test and softening point test. The penetration test determines the consistency of bituminous binders for the purpose of grading them and for the purpose of giving an indication of the expected performance. Penetration is determined by measuring the depth (in units of one tenth of a millimetre) to which a standard needle with the needle assembly weighing 100 gm will penetrate vertically at 25 ˚C standard temperature in 5 seconds of standard duration. The softer the bitumen, the larger will be the penetration. The penetration grades of bitumen are generally designated as 80/100, 60/70, or 30/40 grade bitumen. 80/100 bitumen indicates that the penetration value of binder ranges from 8 mm to 10 mm. In the flexible pavement construction where bitumen binders are used, it is of significance that the binders form ductile film around the aggregate.

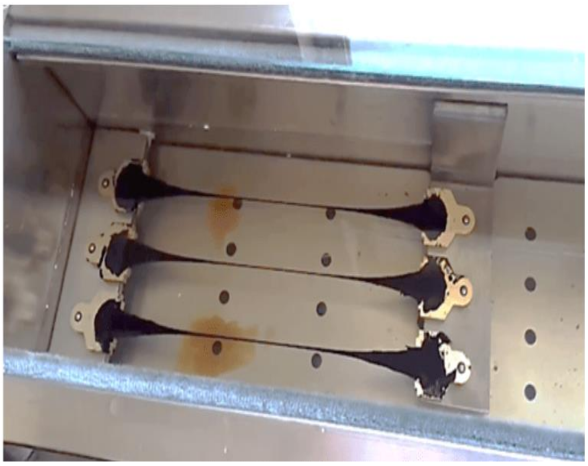


Fig.3 Penetration test of bitumen

The binder material which does not possess sufficient ductility would crack when flexed or elongated. Ductility is expressed as the distance in centimetres to which a standard briquette of bitumen can be stretched before the thread breaks. The test is conducted at 27 ° C +/- 0.5 ° C at a rate of pull of 50 +/- 2.5 mm per minute.

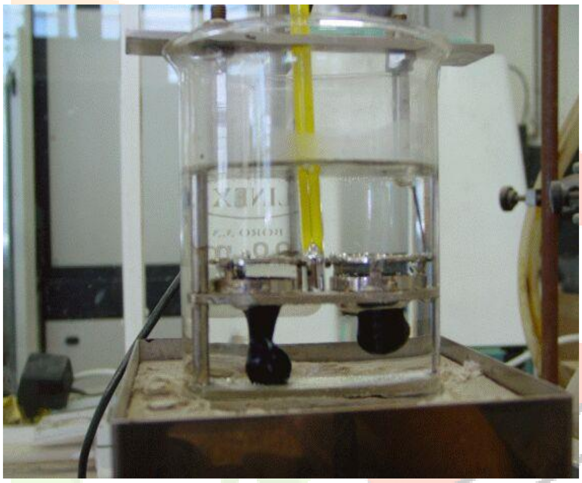


Fig.4. Ductility test on Bitumen and Assembling of sample

Softening point test: The Softening Point of bitumen or tar is the temperature at which the substance attains particular degree of softening. The binder should have sufficient fluidity before its applications in road uses. The determination of softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications. Softening point is determined by ring and ball apparatus.

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

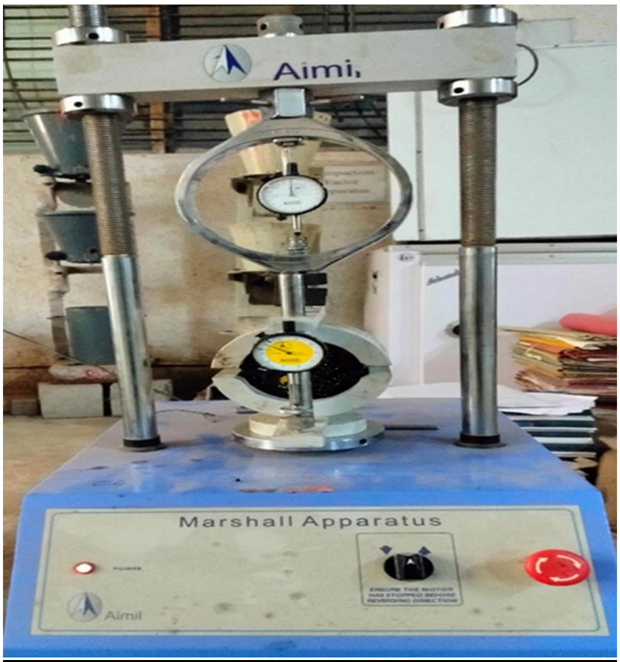



Fig.5. Marshall test apparatus of bitumen

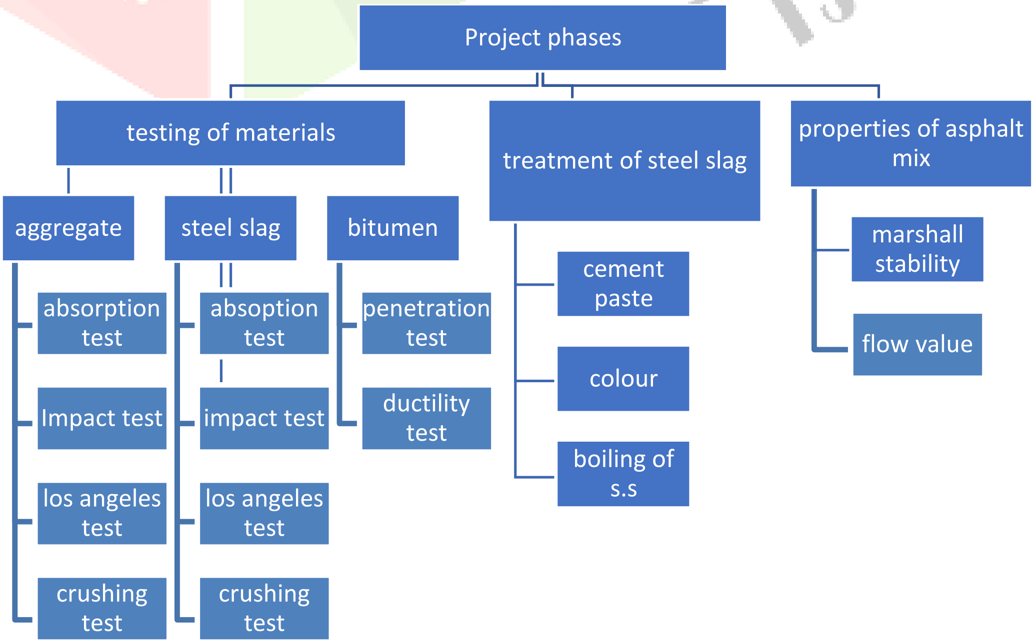
**3.3 Outline of Project work**

This project is doing to find the feasibility of steel slag as aggregate in flexible pavement and surface treatment which includes following steps:

1) To find out the basic properties of materials: aterials in this project includes Aggregate, Steel Slag and Bitumen and the basic properties such as hardness, strength, abrasion, crushing, absorption, etc. for aggregate and steel slag, for bitumen properties such as penetration, ductility and softening point test. On steel slag and aggregate are replace in various proportion and test performed are impact test, Los Angeles abrasion test, water absorption test.

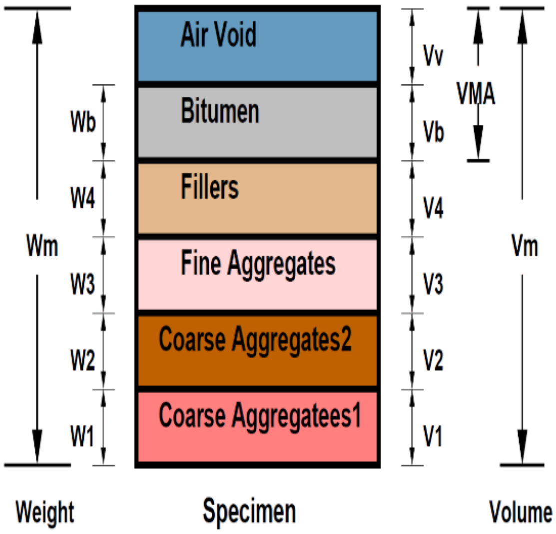
2) Treatment of steel slag by surface treatment: As steel slag having pores on its surface due to this the absorption gets increased. If this replace into asphalt mix it causes expansion of steel slag due to this cracks of flexible pavement happens. To avoid this surface coating is used of cement paste and oil paint. After that it will replace with aggregate and different basic properties are determined.

Chart.1. Classification of phases of project




3) Properties of asphalt mix and Comparison steel slag and natural Aggregate: Mixture of asphalt are created and the properties of asphalt mix to find its properties with respect to its stability and flow values, So that we can compare whether these material is suitable or not in the mixture of asphalt. Stability is the resistance of

bitumen mixture to deformation under load and thus it is a stress which causes specified strain depending upon the anticipated field conditions stability is the function of friction and cohesion frictional resistance is the function of both inner particle friction and friction imparted by bituminous material. Cohesion is mainly offered by the factors that influences the mass viscosity of bituminous binder.




### 3.4 Design Mix

*A) overview:* The mix design (wet-mix) determines the optimum bitumen content. This is preceded by the dry mix design. There are many methods available for mix design which vary in the size of the test specimen, compaction, and other test specifications. Marshall method of mix design is the most popular one and is discussed below.

*B) Marshall mix design:* The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. The important steps involved in marshal mix design are summarized next

Fig.6. Preperation of marshal mix of aggregate and steel slag

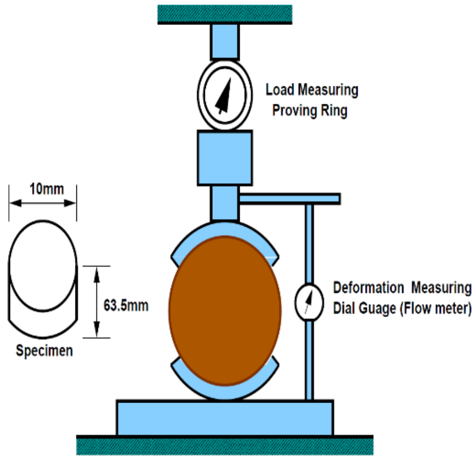



**Fig. 8. Marshall Mould**

<u>*C) Specimen preparation:*</u> Approximately 1200gm of aggregates and filler is heated to a temperature of 175˚C to 190˚C. Bitumen is heated to a temperature of 121˚C to 125˚C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the material aggregates) to the heated aggregates and thoroughly mixed at temperature of 154˚C to 160˚C. The mix is placed in a preheated mould and compacted by a rammer with 75 blows on either side at temperature of 138˚C to 149˚C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0:5% and repeat the above procedure. Number of trials are predetermined. The prepared mould is loaded in the Marshall test setup as shown in the figure below.

Fig.9. coating of oil paint and cement paste on the steel slag

<u>*D) Determine the properties of the mix:*</u> The properties that are of interest include the theoretical specific gravity Gt, the bulk specific gravity of the mix Gm, percent air voids Vv, percent volume of bitumen Vb, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. These calculations are discussed next. To understand these calculation a phase diagram is given in Figure

# IV. RESULTS AND DISCUSSION

## 4.1 Results of mechanical properties of steel slag and Aggregate

Table.1. Results of mechanical properties of steel slag and aggregate

| Sr. No | % replacement steel slag | Water absorption test | Los angeles abrasion test | Impact value test | Crushing strength test |
|---|---|---|---|---|---|
| 1 | 0 | 1.69 | 9.03 | 11.63 | 15.69 |
| 2 | 10 | 3.17 | 12.56 | 12.36 | 16.74 |
| 3 | 20 | 6.59 | 13.34 | 11.04 | 12.28 |
| 4 | 30 | 7.14 | 16.46 | 14.65 | 25.14 |
| 5 | 100 | 14.63 | 25.66 | - | - |
| 6 | 20 (Oil paint) | 4.13 | - | 10.46 | - |
| 7 | 20 (cement paste) | 4.53 | - | 10.75 | - |

The steel slag and natural aggregate samples were used to determine the physical and mechanical properties such as abrasion resistance, crushing strength, water absorption, flakiness and elongation, and Impact value test. The tests results on different properties are shown above. The abrasion test provides an indication of the relative quality of competence of various sources of aggregate with similar mineral compositions. The abrasion test is used as an indication of aggregate wear resistance. In this case, comparing the steel slag aggregate results to the natural aggregate results illustrate that Aggregate particles show high resistance to abrasion as given in Table 3.c.&3.i. and it found to be in case of 10% replacement is 3.17%, 20% replacement is 6.59% and 30% replacement is 7.14%. Also, the water absorption values of the slag are always more than the natural aggregate. It is found to be for no replacement 1.69% and for 100% replacement is 14.63%. Impact value is found out for 10% replacement is 12.36%, 20% replacement is 11.04% and 30% replacement is 14.65%. crushing strength test results for 10% replacement is 16.74%, 20% replacement is 12.28% and 30% replacement is 25.14%The results of the mix design for both the Steel Slag Aggregate mix and the conventional natural aggregate mix are presented in Table 3. Tests performed on bitumen such as penetration value, ductility and softening point as shown in table.3. shows all are as per required grade.

Table.2. Result of tests of Bitumen

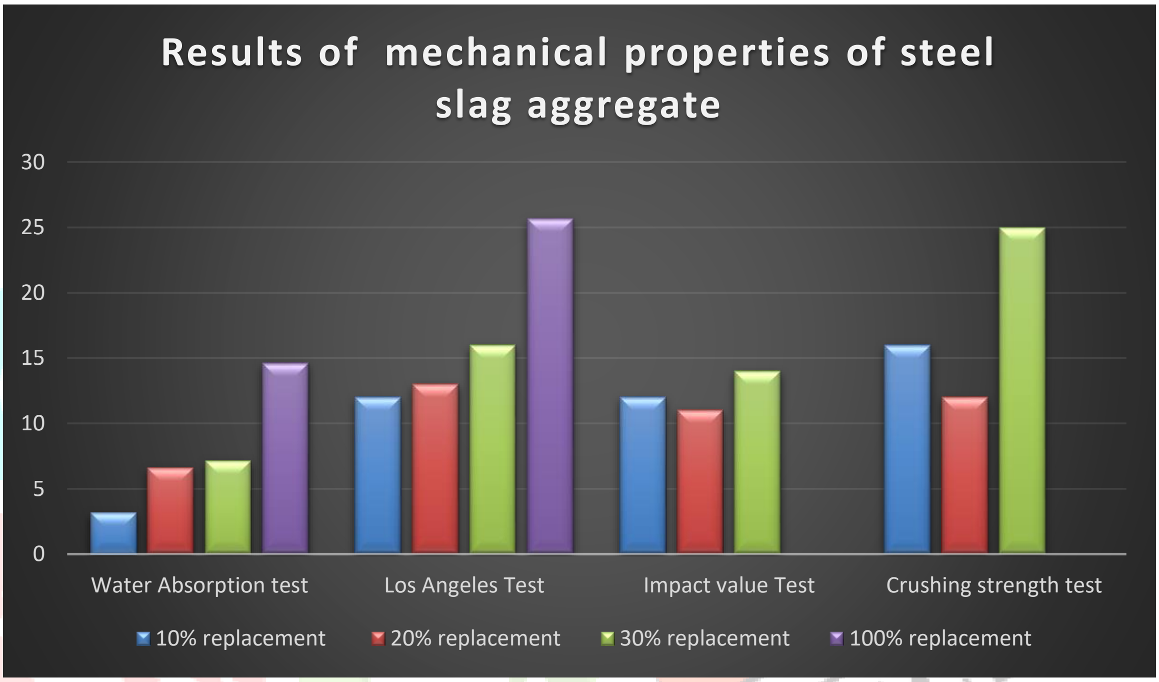
| Tests on bitumen | Value |
|---|---|
| Penetration Test | 48.33 mm |
| Ductility Test | 95.67 mm |
| Softening point Test | 58 ˚c |

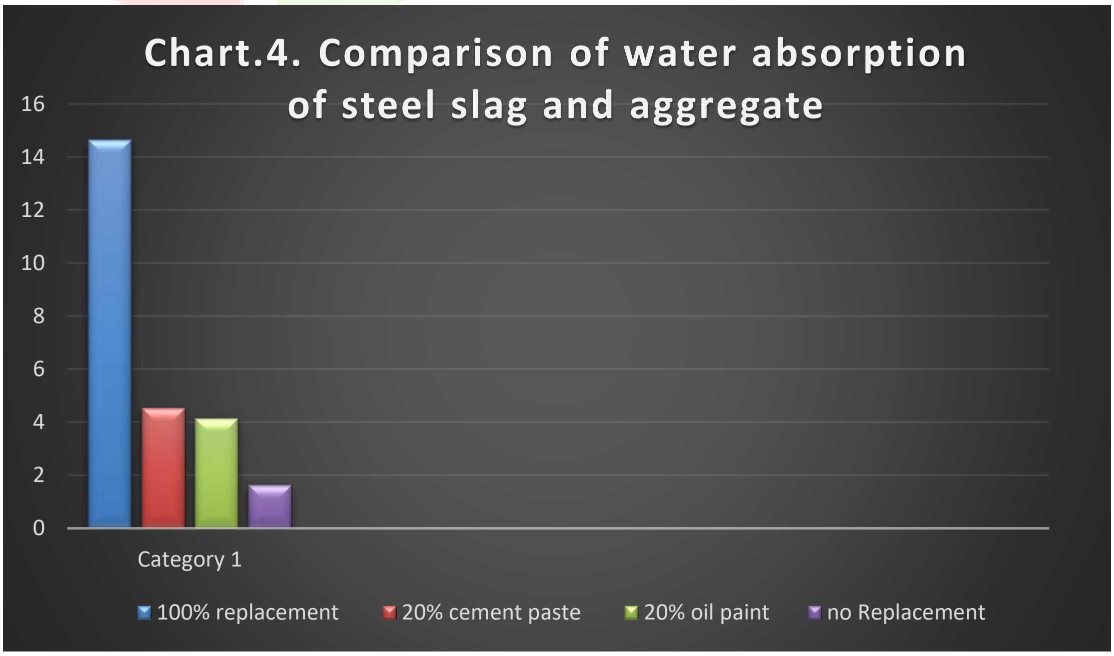
Table. 3. Result of marshal stability test of various type of mixes

| Sample No. | Bitumen content (%) | Height of specimen (cm) | Weight of specimen in air (gm) | Weight of specimen in water (gm) | Bulk volume (cm^3) | Bulk density (gm/cm^3) | Flow value (mm) | Stability value (kN) | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 52 | 1085.1 | 1093.1 | 408.3 | 2.65 | 10 | 48.3 | Nill |
| 2 | 5 | 51 | 1088.2 | 1098.5 | 400.55 | 2.71 | 10 | 40.2 | Nill |
| 3 | 5 | 52 | 1077.6 | 1086.5 | 408.3 | 2.639 | 10 | 34.60 | 10% |
| 4 | 5 | 50 | 1023.1 | 1045.3 | 392.69 | 2.605 | 10 | 33.06 | 10% |
| 5 | 5 | 52 | 1080 | 1099.1 | 431.75 | 2.501 | 10.5 | 52.355 | 20% |
| 6 | 5 | 51 | 1034.6 | 1055.3 | 400.55 | 2.582 | 11 | 48.22 | 20% |
| 7 | 5 | 55 | 1187.7 | 1202 | 431.75 | 2.75 | 12 | 46.84 | 30% |
| 8 | 5 | 52 | 1075.3 | 1099.6 | 408.3 | 2.63 | 13 | 44.33 | 30% |
| 9 | 5 | 50 | 1020 | 1030 | 416 | 2.45 | 8.75 | 46.84 | Cement paste |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 5 | 53 | 1093.4 | 1112.4 | 416.26 | 2.62 | 9 | 47.23 | Cement paste |
| 11 | 5 | 54 | 1144.7 | 1172.8 | 424.11 | 2.69 | 10 | 48.22 | Oil paint |
| 12 | 5 | 48 | 920 | 935.4 | 376.8 | 2.44 | 10 | 46.22 | Oil paint |

**Comparing the results**:
It can be observed that steel slag aggregate provide better properties and high values of density and stability, which resist permanent deformation. The Marshall tests results on the prepared specimens showed that the 20% replacement of steel slag resembles the stability as of natural aggregate.



## V. CONCLUSION

In this research, the natural aggregate was replaced by SSA, which is waste material derived from the steel industry, in different asphalt concrete mixes. The effectiveness of replacing natural aggregate by SSA was judged by the improvement in the physical and mechanical properties of the tested samples. The following conclusions can be drawn:

1. **Optimum Replacement Ratio:** Based on the study, replacing natural aggregates with **20% steel slag** yields optimal performance. This mix demonstrated **improved impact value, abrasion resistance, and crushing strength**, making it suitable for use in road construction applications.
2. **Asphalt Mixture Performance:** Asphalt mixtures incorporating **20% steel slag** showed favorable results. The **stability** was measured at **48.22 kN** and **flow value** at **10.5 mm**, closely resembling the performance of mixtures using 100% natural aggregates.
3. **Water Absorption Behavior:** Water absorption values varied with surface treatment:

    - **Untreated steel slag**: 7.635%
    - **Cement-coated slag**: 4.53%
    - **Paint-coated slag**: 4.13%

These results clearly indicate that surface treatment **reduces water absorption**, thereby enhancing the material's durability and making it more suitable for use in asphalt pavements.

4. **Conformance with Standards:** The **physical properties** of steel slag aggregates conform to **Marshall mix design specifications** for hot mix asphalt. Laboratory test results suggest that steel slag is a **viable alternative in the Indian context**, reducing dependence on scarce natural aggregates.
5. **Economic Advantages:** Utilizing steel slag as an aggregate in road construction can significantly **reduce costs** related to the **extraction and processing of natural aggregates**. Additionally, it offers steel manufacturers a cost-effective solution for managing and recycling slag stockpiles.
6. **Environmental and Social Benefits:** Relying solely on natural aggregates for hot mix asphalt is considered an **unsustainable practice**. Using steel slag, a **waste material**, not only helps conserve finite natural resources but also contributes positively to **environmental preservation and societal benefit**.
7. **Need for Further Research:** Ongoing research is essential to develop **new specifications** for steel slag applications across diverse construction fields. Future work should also focus on improving **treatment methods** to further reduce water absorption and expand the usability of steel slag aggregates.

## VI. ACKNOWLEDGMENT

It is our supreme duty and desire to express acknowledgement to the various torchbearers, who have rendered valuable guidance during the preparation of our project.

First of all, we extend our deepest gratitude to our revered Principal Dr. P. M. Jawandhiya without whose support; our project could not have been transformed into present form.

We are grateful to Dr. S. S. Saraf HOD, Civil Engineering Department; and guide Prof/Dr. M. A. Rehman for providing immense support and guidance. We are beholden for guiding us at every step in the project. His/her has most honestly guided us throughout; never leaving us unanswered for any of our doubts. It was his/her constant persuasion, encouragement, inspiration and able guidance that helped us in completing our project successfully.

## REFERENCES


**[1]** Mohd. Rosli Hainina, Md. Maniruzzaman A. Aziza, Zulfiqar Alia, Ramadhansyah Putra Jayaa , Moetaz M. El-Sergany c, Haryati Yaacoba (2015) Steel Slag as A Road Construction Material Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru UAE. Article in Jurnal Teknologi DOI: 10.11113/jt.v73.4282

**[2]** Magdi M. E. Zumrawi, Faiza O. A. Khalill, Experimental Study of Steel Slag Used as Aggregate in Asphalt Mixture (2015) World Academy of Science, Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:9, No:6,

**[3]** Manoj Kumar Tiwari1, Dr. Samir Bajpai Dr. Umesh Kumar Dewangan Steel Slag Utilization — Overview in Indian Perspective (2016). 1. Research Scholar, National Institute of Technology, Raipur, Chhattisgarh, India. 2. Professor, Department of Civil Engineering, NIT, Raipur, Chhattisgarh, India Copy Right, IJARISSN: 2320-5407

**[4]** Rondi, L.; Bregoli, G.; Sorlini, S.; Cominoli, L.; Collivignarelli, C.; Plizzari, G. Concrete with EAF steel slag as aggregate: A comprehensive technical and environmental characterisation. Compos. Part B Eng. 2016, 90, 195–202.

**[5]** Y.K. Sabapathy, V.B. Balasubramanian, N.S. Shankari, A.Y. Kumar, D. Ravichandar, Experimental investigation of surface modified EOF steel slag as coarse aggregate in concrete, J. King Saud. Univ. -Eng. Sci. 29 (2017) 388–393.

**[6]** Z. Chen, Z. Gong, Y. Jiao, Y. Wang, K. Shi, J. Wu, Moisture stability improvement of asphalt mixture considering the surface characteristics of steel slag coarse aggregate, Constr. Build. Mater. 251 (2020), 118987, https://doi.org/10.1016/j.conbuildmat.2020.118987.

**[7]** Khaled E. Hassana, Mohamed I.E. Attiab, Murray Reidc, Mohammed B.S. Al-Kuwarid, Performance of steel slag aggregate in asphalt mixtures in a hot desert climate (2021) IRD QSTP, Doha, Qatar Faculty of Engineering, Zagazig University, Zagazig, Egypt IRD, Glasgow, UK Ministry of Municipality & Environment, Doha, Qatar. Case Studies in Construction Materials 14 (2021) e00534

**[8]** Ion Chiricuță, Replacement of natural aggregates used in road structures with steel slag (2021), Technical University of Moldova, 168, Ștefan cel Mare Bd., MD-2004, Chișinău, Republic of Moldova.Journal of Engineering Science Vol. XXVIII, no. 2 (2021), pp. 120 – 124

**[9]** Giulio Dondi 1,Francesco Mazzotta et al. (2021), Use of Steel Slag as an Alternative to Aggregate and Filler in Road Pavements, Department of Civil, Chemical, Environmental and Material Engineering, University of Bologna, 40100 Bologna, Italy, F.I.S. Impianti Interrati S.R.L., Grumello del Monte, 24064 Bergamo, Italy.Materials (Basel) 2021 Jan 12;14(2):345. Doi: 10.3390/ma14020345.

**[10]** Mohammed et al., Hongling Liu a b c, Huanyu He a b c, Yang Li a b c, Taotao Hu a b c, Hongwei Ni a b c, Hua Zhang a b c, Coupling effect of steel slag in preparation of calcium-containing geopolymers with spent fluid catalytic cracking (FCC) catalyst (2021) Construction and Building Materials, volume 290, pages 123194

**[11]** Huang Yi, Guoping Xu, Huigao Cheng, Junshi Wang, Yinfeng Wan, Hui Chen, An overview of utilization of steel slag (2022), Sinosteel Wuhan Safety & Environmental Protection Research Institute, Wuhan 430081, PR China.Procedia Environmental Sciences 16 ( 2012 ) 791 – 801

**[12]** Youwei Gan a, Chuangmin Li a, Wang Ke b, Qinhao Deng a, Ting Yu c d, Study on pavement performance of steel slag asphalt mixture based on surface treatment. (2022).Article in Case Studies in Construction Materials · May DOI: 10.1016/j.cscm.e01131