Review on Effect of Steel Slag and Fly Ash in Road Construction

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ABSTRACT— *Recycling and environmental sustainability goals can be pursued through the reuse of waste generated from different industries such as plastic, glass, iron, etc. in road pavements. The handling of industrial wastes such as fly ash, glass powder, and steel slag has grown to be a major issue in developing nations. The disposal issue will be resolved if fly ash, glass powder, and steel slag can be used for road construction. The current study examines the impact of coarse steel slag aggregate (instead of coarse natural stone aggregate) and fly ash (FA) as fillers on the performance of asphalt mixes for road construction. The reuse of metallurgical slags in road pavement is an important concern. Mostly the by-products produced during the separation of molten steel from impurities in steel-making furnaces include steel slag is generally used in our study on road pavements. Its manufacturing procedures, and chemical, morphological, and physical features have an impact on its contribution to asphalt mixture when slag partially or fully replaces virgin aggregate. This study reviews physical, chemical, and mechanical properties and developments in several areas related to using steel slag aggregate and fly ash in hot-mix asphalt. Road performance can be considerably impacted by the characteristics of steel slag. By-product of burning pulverized coal i.e., fly ash. It can be utilized as a mineral filler in hot mix asphalt (HMA) paving applications at a reasonable cost. Based on the Marshall parameter specific percentage of filler i.e., Fly Ash used in HMA is fixed. Compared to other filler materials, the FA performs better. Additionally, a cost study shows that asphalt mixes containing FA and steel slag aggregate have lower construction and life cycle costs than the control mix. FA and steel slag aggregate both can be utilized as substitute components in asphalt mixes for the construction of roads.*

Keywords: Steel Slag Aggregate (SSA), Fly Ash (FA), Hot Mix Asphalt (HMA), Recycling, Bitumen, Marshall Parameter.

1. INTRODUCTION

A growing worry across the globe is the lack of raw resources for construction projects [1]. As a result, using sustainable materials and conserving natural resources are now developing research areas [2]. Steel slag waste, recycled construction waste, reclaimed pavement trash, overburnt brick waste, and so forth are employed most frequently in various construction projects [3][4]. A by-product of steel manufacture, steel slag accounts for 15% of total steel production [1]. In China, fewer than 22% of steel slag is utilized, and an extra 60 million tonnes of steel slag are discharged annually [3][4]. The steel slag dumps take up a lot of space and have a negative impact on the environment in numerous ways [5]. Calcium oxide (CaO), silicon dioxide (SiO2), aluminum oxide (Al2O3), iron sesquioxide (Fe2O3), magnesium oxide (MgO), and others are the primary chemical components of steel slag. Dicalcium silicate (C2S), tricalcium silicate (C3S), dicalcium ferrite (C2F), RO phase (CaOFeO- MnO- MgO solid solution), and free CaO are the most prevalent minerals in steel slag [6]. Table.1 shows the typical chemical composition of steel slag in different percentages [7]. In many countries, using steel slag as an aggregate is considered to be best practice. It can be used for granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement, among other things **(FHAR&T)**. Therefore, it is crucial to look for innovative, effective uses for steel slag in order to raise utilization rates [8].

Table 1 Chemical composition of Steel Slag

Constituents	**Composition (%)**
CaO	40-52 %
SiO_2	10 – 19 %
FeO	10 – 40 % (70-80% FeO, 20-30% Fe_2O_3)
MnO	5 – 8 %
MgO	5– 10 %
Al_2O_3	1 – 3 %
P_2O_5	0.5-1 %
S	<0.1 %
Metallic Fe	0.5-10 %

Material

In the current investigation, steel slag materials and NTPC fly ash were gathered. Using steel slag as a coarse aggregate in bitumen mixtures can provide a sustainable and cost-effective solution for pavement construction [9]. The use of SS can help to reduce the amount of natural aggregate required for construction, conserve natural resources, and reduce the amount of waste sent to landfills. In steel-making furnaces, the process of separating the molten steel from impurities results in the production of steel slag, a by-product. The slag is a complex mixture of silicates and oxides that forms as a molten liquid melt and solidifies after cooling [5].

1. Steel Slag

Slag is a molten waste or co-product of various metallurgical processes that is then cooled (by air, pelletization, foaming, or granulation) for use or, regrettably, in too many instances, disposal. This disposal is now problematic. Because of this, we are attempting to use this industrial waste as a structural paving material [10]. Steel slag is a substance with a black colour that is tough, dense, and abrasion-resistant. It has a high density and high hardness because it includes a substantial amount of free iron [11]. Steel slag is frequently used in industrial roadways, junctions, and parking lots where strong wear resistance is required due to its great frictional and abrasion resistance. It can be used to substitute aggregate in HMA, road base, and subbase [12]. Additionally, steel slag has great bitumen binding properties, a low flakiness index, strong mechanical qualities, and good antiskid resistance. It is also chemically stable [11]. Numerous studies have revealed that adding steel slag to HMA improves the pavement's performance properties [13],[14]. Steel slag, a dark-colored material, is hard, dense, and abrasion resistant. It contains a significant amount of free iron, giving the material high density and hardness. It can be used as an aggregate replacement for HMA, road base, and subbase [12].

1.1 Utilization of Steel Slag

Steel slag is a recycled material obtained from milled or molten by plants in pavements. Its utilization in flexible pavements can significantly reduce costs by minimizing the need for new materials and reducing waste disposal expenses [15] investigated the economic benefits of incorporating steel slag in asphalt mixtures. One of the main benefits of employing steel slag is that it can increase the quality of asphalt mixes made with locally accessible, cheap, or low-quality elements [16]. Environmental benefits of steel slag when used in flexible pavements. It is consistent with sustainable practices and can benefit the environment, which indirectly lowers costs [8]. These practices can assist the economy in addition to protecting the environment by offering long-term fixes that will enable the steel sector to soon reach its goals of "zero-waste" emissions. It is now well known that processed slag can be used as a safe alternative to natural aggregates for roads and civil construction after various studies on the durability and long-term impact of slag usage in roads and building were published recently [17].

The central Government established the Indian Road Congress. In IRC SP.121-2018 guidance for the use of iron, steel, and copper slag in the construction of rural roads . Fig. 1 Signifies the slag reuse in different countries in different areas [18].

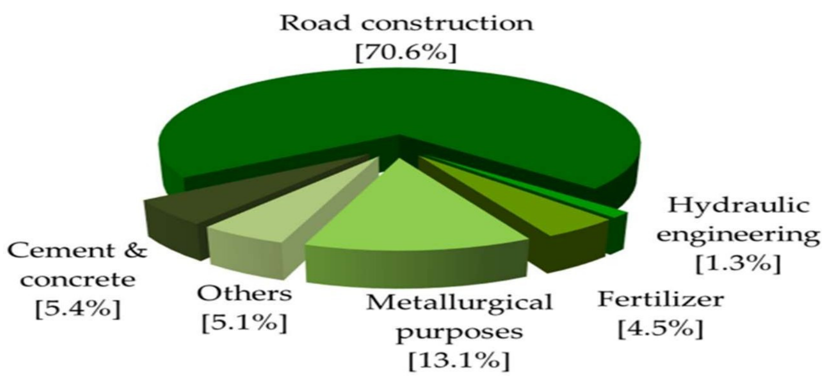

Fig.1 Use of Steel Slag in different areas

Steel can be made in a variety of grades, and each grade might have drastically different steel slag characteristics. Depending on the amount of carbon in the steel, grades can be categorized as high, medium, or low. High-grade steels contain a lot of carbon. A higher oxygen content is needed during the steel-making process to lower the amount of carbon in the steel [19]. Furnace slag or tap slag are two terms used to describe the steel slag created during the initial step of steel manufacture. For steel slag aggregate, this is the main source. After being removed from the furnace, the molten steel is placed in a ladle for extra refining to get rid of any remaining impurities. Due to the fact that this process is finished inside the transfer ladle, it is known as ladle refining. By again melting fluxes in the ladle during ladle refining, more steel slags are produced. Fig. 2 shows the slag production process in plants [7].

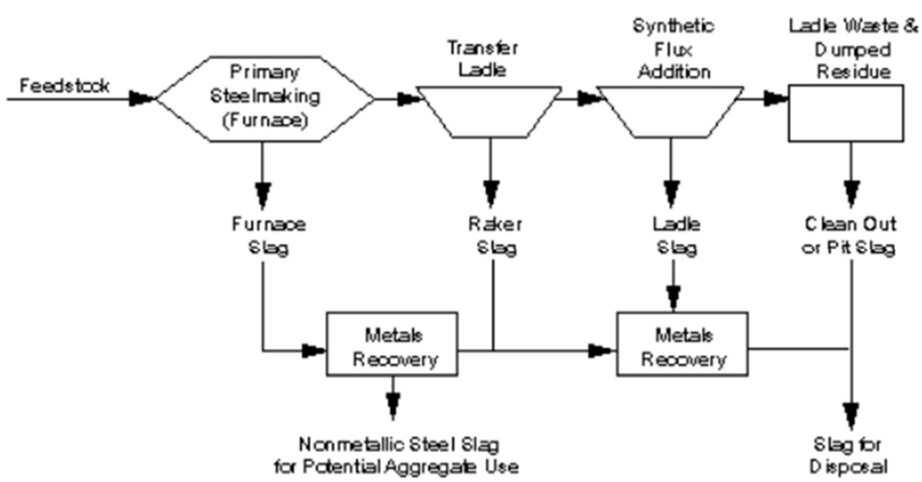

Fig. 2 Slag production process in steel plant

Steel slag aggregates are highly angular in shape and have a rough surface texture. They have high bulk-specific gravity and moderate water absorption (less than 3 percent) [20]. The physical properties of Steel Slag like specific gravity, moisture content, and gradation are shown in Table.2 [21]. Slag gradation is comparable to that of a crushed natural aggregate while having a larger fines concentration. The material's deterioration during the milling and crushing processes led to the high fine concentration. Utilizing L.A. abrasion, crushing, and impact tests is a common way to quantify aggregate degradation brought on by construction and traffic loads [22]. A general overview of the usual physical and mechanical Properties of Steel slag is shown in Table 2 [22],[23].

Table 2. Physical Properties of Steel Slag

Unit Weight	1600-1920 kg/m^2
Water absorption	Standard to 3% Maximum up to 7-8%
Specific Gravity	3.2-3.6
LA abrasion	11-13.2%
Crushing Value	12.1-14.2%

2. Fly Ash

The term fly ash signifies all the categories or groups of coal or lignite ash generated at the thermal power plant and collected by electrostatic precipitator (ESP) or bag filters, bottom ash, pond ash, and mound ash [24]**.** Fly ash is a fine powder consisting of mainly silica, alumina, and iron oxide, among other components. The specific composition of fly ash can vary depending on the type of coal burned and the combustion process. Fly Ash possesses good pozzolanic properties [25]. The country's utilization of fly ash increased from 13.51 to 57.63 percent from 1999 to 2014, according to the **Ministry of Environment, Forest, and Climate Change**. By utilizing fly ash efficiently in India, it is possible to save approximately 20,000 hectares of land annually [24].

2.1. Characteristics of Fly Ash

Indian coal belongs to sub-bituminous, bituminous, or lignite quality. Fly Ash particles are very fine, light in weight, and have a pozzolanic ability. Its colour vary from grey to blackish grey depends on the type of coal and combustion process [26]. Fly ash is classified into two type C and F. C signifies the amount of lime present in it which signifies amount of CaO > 10% and Class F signifies the amount of CaO < 10% ASTM C-618 [27]. Fly Ash is recently being used in the road constructions, bridges, flyovers. CEA report signifies that production of fly ash is increasing as the need of electricity is increasing due to increasing growth of population [28].

Depending on the increasing production 60.81 Million Tonnes of fly ash is used in Pavement construction [29]. Fig. 3 indicates the increasing usage of fly ash in road construction in year 2021-2022.

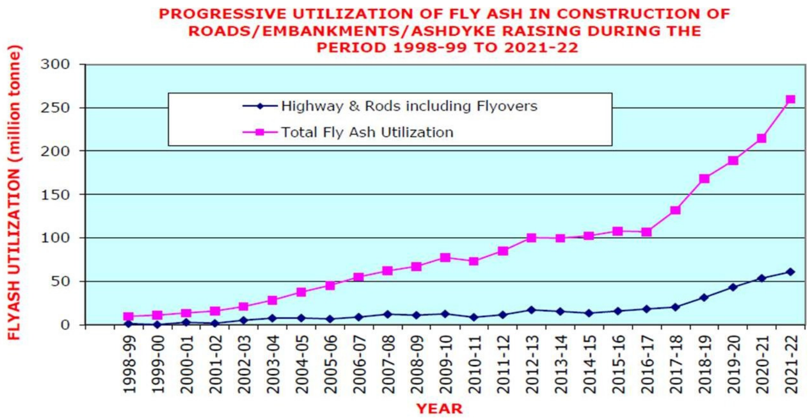

Fig. 3 Utilization of FA in Pavement

2.2. Utilization of Fly Ash in different area

The characteristics of fly ash are dependent on the type of Coal. Utilisation of fly ash, a byproduct of coal combustion, can take the form of a replacement for another industrial resource, method, or use [30]. Table. 3 and Fig. 3 shows the different countries produce different percentage of fly ash annually and it was also used in huge quantities [26].

Table 3. Fly Ash Generation in different countries

Country	Annual ash Production, MT	Ash Utilization %
India	112 MT	38%
China	100 MT	45%
USA	75	65%
Germany	40	85%
UK	15	50%
Australia	10	85%
Canada	6	75%
France	3	85%
Denmark	2	100%
Italy	2	100%
Netherlands	2	100%

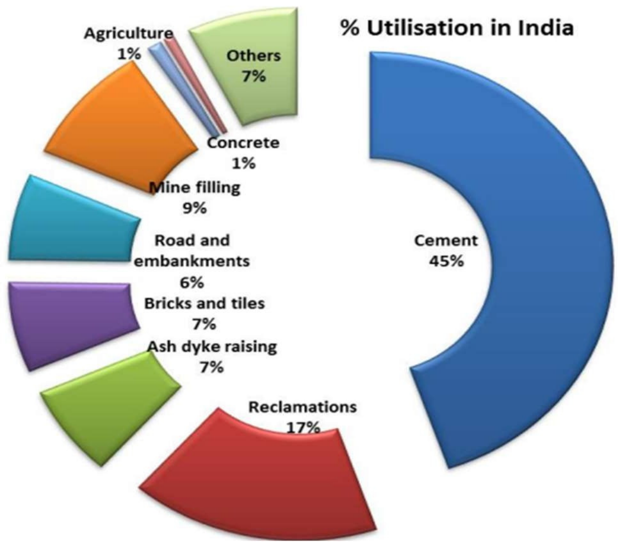

Fig. 4 Fly Ash utilization in India

Fly Ash generally used in many different from but recently some studies signify that fly ash usage as a filler replacing other material in asphalt mixture varies comparison with other filler materials like cement, lime stone etc. and improve the economics of overall fly ash disposal. Fly Ash composes of some chemical i.e. CaO, SiO_2, Al_2O_3, Fe_2O3, SO_3, MgO, TiO_2, NaO_2, K_2O and other alkaline [31].

2.2.1 Fly ash utilization as eco-friendly source material

Important initiatives must be done towards fly ash management because of the large-scale generation of fly ash and the growing environmental problems that result from it. Fly ash has excellent properties and the ability to be used as a starting material, most critically. Numerous Government and Non-Government Organisations are engaged in the use of fly ash and its safe disposal in light of its versatility. In order to preserve it, it is being used as a source material and has been substituting diverse natural resources in a variety of applications [30]. When we discuss about some practical uses of fly ash, such as incorporating it into the production of environmentally friendly bricks and concrete, and utilizing it as a soil treatment agent in agriculture. [32].

2.2.2 Comparison of properties of fly ash with other filler material

In India according to Ministry of Road Transport and Highways (MoRTH) requirements, fillers used in bituminous mix are sieved via 75 µm IS sieve to meet the desired properties of filler material [33]. Due to their fineness, fillers produce bituminous mastic, which serves two main purposes in the mixture; they fill the spaces between the mineral aggregates. The mastic result can have a big impact on physical and mechanical properties of mixture. Additionally, fillers with a large surface area take up more bitumen [34]. The ideal use of fly ash will benefit the environment and the economy. First off, it will reduce the additional expenses the power plant has to pay to deposit the fly ash trash. Fly ash also has the ability to replace the use of some natural resources. Therefore, new industrial technologies should be created for the best possible use of fly ash. It can be utilised for a variety of things, such producing building materials and in road construction [35],[36]. Table. 4 shows the properties of fly ash with other materials like hydrated lime, cement, granite powder, marble powder etc.

Table.4 Properties of fly ash and other filler material

Properties	**Fly Ash**	**Other Filler Materials**
Specific Gravity	**1.6-2.6**	**2.7-3.2**
Density (g/cc)	**1.97-2.8 g/cc**	**2.40 g/cc**
Colour	**Greyish**	**White**
Plasticity	**Low or higher**	**Low or higher**

3. Effect of steel slag and fly ash in HMA mixtures

Fly ash improves the characteristics of the asphalt mix and modernises the waste management system when used as a filler material [32]. Numerous studies have revealed that adding steel slag to HMA improves the performance properties of pavement [37]. Steel slag increases the skid resistance of pavement since it is a rough material. Additionally, due of crushed steel slag's high specific gravity and angular, interlocking characteristics, the resulting HMA concrete is more stable and rut-resistant [38] [39] . By combining steel slag and fly ash in the hot mix asphalt, engineers and researchers aim to create a more sustainable and durable pavement material that can withstand heavy traffic loads, resist deterioration, and have a lower impact on the environment compared to conventional HMA mixtures [40].

In its lifetime, a high-speed road is subjected to alternate stress and recycling, which causes fatigue. Steel slag aids in improving the stability and fatigue life of asphalt mixes [41]. Mixtures using steel slag as coarse particles are less rutting-prone and more resistant to permanent deformation [42]. Steel Slag has emerged as a popular replacement for enhancing the performance and durability of asphalt mixtures [43].

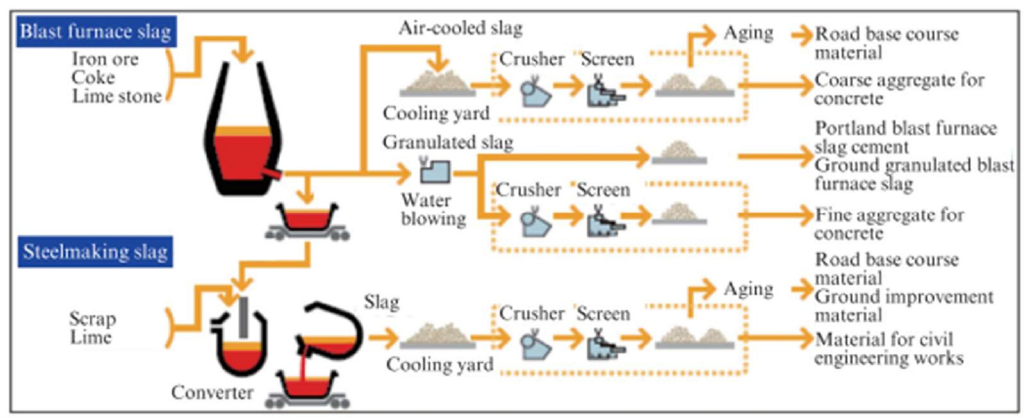

Fig. 5. Steel Slag Recycling in road construction

For transportation organisations, the expense for construction and maintenance of flexible pavements can be a heavy financial burden. It is observed that by combining the steel slag and fly ash in the hot mix asphalt it is more sustainable and durable pavement material that can withstand heavy traffic loads [44]. Based on findings from numerous research publications and scholarly journals, this section of the literature review seeks to assess the potential of Steel Slag in lowering the cost of flexible pavements [7].

An extensive overview of the impact of fly ash and steel slag on asphalt mixtures has been provided by this literature review. Numerous important conclusions and patterns have been discovered through an examination of numerous research papers and scholarly journals. This paper analyse that the particle density of steel slag aggregate is approximately 25% greater than the nature coarse aggregate.

4. CONCLUSION

A primary purpose of this review is to provide complete conformation regarding the steel slag and fly ash characteristics and utilization in asphalt pavement. The various properties of both materials like rheological, physical, and mechanical properties. Comparison have been discussed in this paper. Some of the key findings that have been drawn from these studies are:

1. According to most of the studies, steel slag blends exhibit reduced moisture susceptibility than the corresponding conventional mixes [22].
2. On the basis of the indirect tensile strength ratios, it can be said that adding steel slag as a coarse aggregate to asphalt mixtures increases resistance to both moisture damage and moisture-induced rutting damage [10].

3. The steel slag SMA combination had a greater optimal asphalt binder content (OAC) than the control mix.
4. All of the mechanical qualities of the asphalt mix were improved when steel slag aggregate was used to replace up to 75% of the natural coarse aggregate [1].
5. Dry Density of road base material increase with the increase in the ratio of steel slag and fly ash [40].

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