

# Application of Steel Slag Asphalt Mixture in Road Engineering

Wangyiling Yang \*

Chang'an University, Xi'an City, Shaanxi Province, China

\* Corresponding author Email: 741283603@qq.com

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**Abstract:** As a by-product of the steelmaking process, steel slag has gained increasing attention and application in road engineering due to its excellent physical properties and abundant resources. This paper systematically analyzes the physical characteristics, chemical composition, and environmental impact of steel slag, explores the preparation process of steel slag asphalt mixtures, and investigates their mechanical properties and durability. Through actual engineering cases, the superior performance of steel slag asphalt mixtures in road base and surface applications is verified. The paper also comprehensively evaluates the economic, environmental, and social benefits of steel slag asphalt mixtures, highlighting their development trends and future research directions in road engineering. Finally, it identifies potential issues in the application of steel slag asphalt mixtures and proposes corresponding countermeasures, aiming to provide theoretical support and practical guidance for their promotion in road engineering.

**Keywords:** Steel Slag; Asphalt Mixture; Road Engineering; Mechanical Properties; Durability; Economic Benefits; Environmental Benefits.

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## 1. Introduction

Globally, the demand for road engineering is continuously increasing. Although traditional asphalt mixtures can meet these demands, they have significant drawbacks such as high energy consumption, pollution, and resource depletion [1]. The steel industry produces a large number of by-products—steel slag—annually. If not properly treated, steel slag can occupy large land areas and cause environmental pollution. However, steel slag possesses high strength and wear resistance, making it a potential high-quality material for road construction. Therefore, studying the application of steel slag in road engineering is of great significance for promoting resource recycling and reducing environmental pollution. This study aims to explore the feasibility and advantages of using steel slag as aggregate in asphalt mixtures for road engineering. The specific objectives include analyzing the physical and chemical properties of steel slag, studying the preparation process and performance of steel slag asphalt mixtures, evaluating their application effects in actual road engineering, and comprehensively assessing their economic and environmental benefits. Through this study, we aim to provide scientific basis and technical support for the application of steel slag in road engineering, promoting its practical application to achieve efficient resource utilization and environmental protection.

## 2. Performance Analysis of Steel Slag Asphalt Mixtures

### 2.1. Advantages and Disadvantages of Steel Slag as Aggregate

Steel slag, when used as aggregate in asphalt mixtures, has significant advantages and disadvantages, affecting the quality and durability of road engineering. Firstly, steel slag has high strength and hardness, which allows it to maintain good stability and durability under heavy traffic loads.

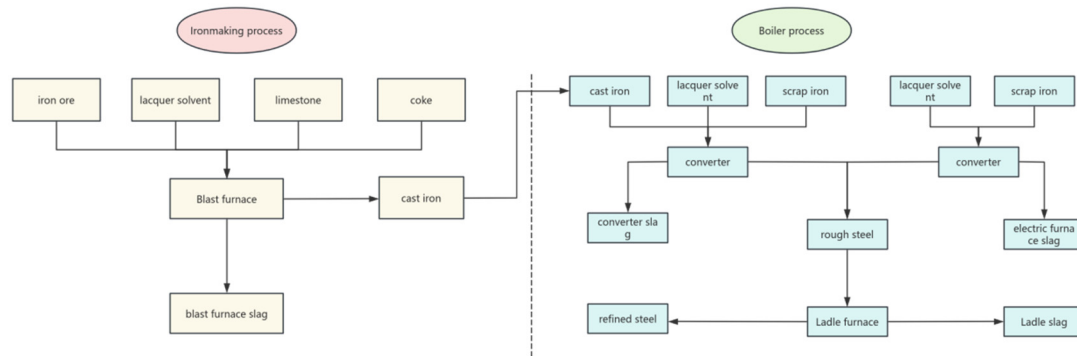
Asphalt mixtures with steel slag aggregates exhibit excellent compressive, tensile, and shear strength, helping to extend the service life of roads. Additionally, the wear resistance of steel slag is superior to traditional aggregates, making steel slag asphalt mixtures perform exceptionally well on high-traffic and heavy-load roads by reducing surface wear and pothole formation, thus improving the overall quality and user experience of roads. The porous structure and rough surface of steel slag enhance its bonding with asphalt, ensuring the mixture's integrity and stability. Good bonding properties also improve the road's fatigue resistance, reducing crack formation. Using steel slag as a road material can also reduce the extraction and use of natural aggregates, protecting natural resources and achieving resource recycling and sustainable development by minimizing the negative environmental impact of steel slag accumulation [2].

However, steel slag as an aggregate also has certain disadvantages. Its high alkalinity, if not adequately treated, can react with water and air in the environment, leading to alkali-silica reaction (ASR), causing aggregate expansion and asphalt mixture damage. Therefore, appropriate pretreatment is required to reduce its alkalinity before use. The high density of steel slag increases costs and difficulties during transportation and construction, and the overall weight of the mixture may increase, necessitating corresponding adjustments in design and construction. Certain components in steel slag (such as phosphorus and sulfur) may trigger chemical reactions under specific conditions, affecting the long-term performance and stability of the mixture. Therefore, strict quality control and chemical composition analysis of steel slag are necessary to ensure its stability in engineering applications. Additionally, the porous structure of steel slag results in high water absorption, which may degrade the mixture's performance in wet environments, such as reduced freeze-thaw resistance and increased susceptibility to water damage. Measures must be taken to reduce its water absorption to ensure road durability when using steel slag asphalt mixtures. In summary, steel slag as aggregate in

asphalt mixtures has significant advantages, such as high strength, excellent wear resistance, and good bonding properties, but also presents challenges, such as alkalinity, high density, and high water absorption. Through scientific pretreatment and strict quality control, the advantages of steel slag can be maximized, and its disadvantages mitigated, achieving widespread application in road engineering.

## 2.2. Preparation Process of Steel Slag Asphalt Mixtures

The preparation process of steel slag asphalt mixtures involves multiple key steps, from the selection and treatment of raw materials to the formulation and construction of the mixture, each step significantly impacting the performance and quality of the final product. <Figure 1> illustrates the source and production process of steel slag, providing a foundation for preparing high-quality steel slag asphalt mixtures.



**Figure 1.** Source and Production Process of Steel Slag

Firstly, the selection and treatment of raw materials are crucial steps in preparing steel slag asphalt mixtures. Steel slag is a by-product of the steelmaking process, mainly derived from converter slag and electric furnace slag (as shown in Figure 1). The selected steel slag must meet the requirements of road engineering, with its physical and chemical properties strictly tested to ensure it meets usage standards. After selecting the steel slag, it requires pretreatment, including crushing, screening, and cleaning, to remove dust and impurities and enhance its bonding with asphalt. Secondly, the design of the mixture is a key step in the preparation process. The design must consider the characteristics of steel slag aggregates, the type of asphalt, and the performance requirements of the mixture. Through tests such as the Marshall test, rutting test, and fatigue test, the mixture ratio is optimized to ensure its mechanical properties and durability meet design requirements. The preparation process of the mixture includes heating, mixing, and transportation. First, steel slag and other aggregates are heated to the predetermined temperature according to the design ratio. Then, the heated aggregates and asphalt are thoroughly mixed in a mixer to ensure the asphalt evenly coats the aggregate surface. During mixing, the temperature and mixing time must be controlled to prevent asphalt aging and mixture segregation. After uniform mixing, the mixture is promptly loaded and transported to the construction site. Construction and compaction are crucial steps to ensure the performance of steel slag asphalt mixtures. Upon arrival at the construction site, the mixture should be promptly laid at the predetermined location, ensuring thickness and uniformity to avoid segregation and unevenness. After laying, a roller is used for staged compaction, ensuring optimal density and structural performance. After construction, the mixture requires appropriate curing to stabilize performance. During the curing process, early traffic load and environmental impacts should be prevented, and quality inspection and evaluation should be conducted to ensure it meets design and regulatory requirements[3].

In conclusion, the preparation process of steel slag asphalt

mixtures is complex and meticulous, with each step requiring strict control to ensure the high quality and excellent performance of the final product. Through scientific design and standardized construction, the advantages of steel slag asphalt mixtures can be fully utilized, achieving widespread application in road engineering. The steel slag production process illustrated in Figure 1 provides essential raw material support for preparing high-performance steel slag asphalt mixtures.

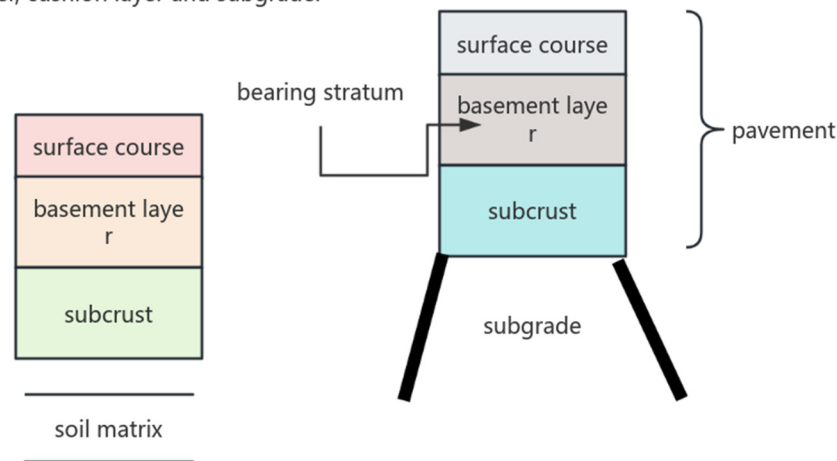
## 3. Application of Steel Slag Asphalt Mixture in Road Engineering

### 3.1. Application of Steel Slag Asphalt Mixture in Road Base and Surface Layers

The application of steel slag asphalt mixture in both road base and surface layers demonstrates superior engineering performance and environmental benefits. According to the road structure diagram in Figure 2, a road consists of the surface layer, base layer, and subbase layer, each of which must have high strength, good load-bearing capacity, and durability to ensure the stability and service life of the road. Due to its excellent physical and mechanical properties, the steel slag asphalt mixture has become an ideal material choice.

As shown in <Figure2>, In road base layers, the steel slag asphalt mixture significantly improves the load-bearing capacity. The high strength and density of steel slag give the mixture high compressive strength, enabling it to effectively bear the pressure of the upper structure and traffic loads, preventing deformation and damage to the base layer and ensuring the long-term stability and durability of the road. Additionally, the rough surface and porous structure of steel slag enhance its bonding with asphalt, ensuring the integrity and stability of the mixture.

Asphalt pavement is composed of surface layer, base layer, cushion layer and subgrade.



**Figure 2.** Road structure composition diagram

The wear resistance of steel slag surpasses that of traditional aggregates, reducing long-term wear in the base layer, extending the road's service life, and lowering maintenance costs. Using steel slag as a base material also reduces the extraction and use of natural aggregates, protecting natural resources and promoting resource recycling and sustainable development. In road surface layers, the steel slag asphalt mixture also exhibits outstanding engineering performance. The high strength and hardness of steel slag provide the mixture with excellent compressive performance, allowing it to withstand repeated heavy traffic loads without deformation or damage, significantly extending the service life of the road surface and reducing maintenance frequency and costs. The high hardness and wear resistance of steel slag result in less wear under long-term traffic loads, maintaining good surface smoothness and structural integrity. The rough surface of steel slag increases the friction coefficient of the road, enhancing skid resistance and improving driving safety, especially in rain and snow conditions. Additionally, the porous structure of steel slag allows for rapid water drainage, reducing water retention in the mixture, decreasing the erosion and damage to the asphalt membrane caused by water, and significantly improving the fatigue resistance and water damage resistance of the surface layer. In practical applications, the construction process of steel slag asphalt mixture in road base and surface layers is similar to that of traditional asphalt mixtures but requires special attention to the pretreatment of steel slag and the design of the mixture ratio. The steel slag should be crushed, screened, and cleaned to ensure proper particle size distribution and surface cleanliness. Based on road usage conditions and performance requirements, a reasonable mixture ratio of steel slag and other aggregates should be designed to ensure that the mechanical properties and durability of the mixture meet engineering requirements. During construction, strict control of temperature and compaction is necessary to ensure the uniformity and density of the mixture, preventing segregation and loose areas [5].

In conclusion, the application of steel slag asphalt mixture in road base and surface layers not only significantly enhances the load-bearing capacity, wear resistance, and

fatigue resistance of roads but also offers important environmental benefits. Through scientific design and strict construction control, the advantages of steel slag asphalt mixture can be fully utilized, achieving widespread application in road engineering and improving overall road quality and sustainability. The road structure diagram in Figure 2 provides a reference for the application of steel slag asphalt mixture in practical engineering [6].

### 3.2. Analysis of Actual Engineering Cases

The practical application of steel slag asphalt mixture in road engineering has achieved significant results. The following actual engineering cases analyze its application effects and advantages.

#### Case 1: Highway Pavement Rehabilitation Project

In a highway pavement rehabilitation project, steel slag asphalt mixture was used as the surface material. This highway has high traffic volume with frequent heavy vehicles, demanding high compressive strength and wear resistance from the pavement materials. During construction, high-quality converter steel slag was selected as aggregate, and it was crushed, screened, and cleaned to meet design specifications. Optimizing the mixture ratio ensured the mechanical properties and durability of the steel slag asphalt mixture. After two years of use, inspections showed that the pavement maintained good smoothness and structural integrity, with minimal surface wear and excellent skid resistance, and no significant cracks or potholes, verifying the superior performance of steel slag asphalt mixture in terms of high strength and durability.

#### Case 2: Urban Main Road Construction Project

In an urban main road construction project, steel slag asphalt mixture was applied to both the road base and surface layers. Urban roads require high load-bearing capacity and water damage resistance. Electric furnace steel slag was selected as the main aggregate for this project. Through scientific pretreatment and mixture ratio design, the steel slag asphalt mixture exhibited excellent compressive strength and water stripping resistance. During construction, strict temperature and compaction controls ensured the uniformity and density of the mixture. Post-construction monitoring

revealed that the pavement maintained good stability and durability even in wet and rainy conditions, demonstrating excellent water damage resistance and durability.

### Case 3: Industrial Area Logistics Road Construction Project

In a logistics road construction project within an industrial area, the road needed to withstand heavy transport vehicles, requiring high wear resistance and fatigue resistance from the pavement materials. Steel slag asphalt mixture was chosen as the main paving material. High-quality steel slag was carefully crushed and screened, and the mixture ratio was optimized through Marshall and fatigue tests. Post-construction, dynamic load tests and long-term observations indicated that the steel slag asphalt mixture showed no significant wear or fatigue cracks under repeated heavy vehicle loads, maintaining stable road structure and significantly extending the road's service life and service level. These actual engineering cases fully demonstrate the superior performance of steel slag asphalt mixture in various types of road engineering. Through scientific design, strict construction control, and optimized material treatment, steel slag asphalt mixture can significantly enhance the compressive strength, wear resistance, fatigue resistance, and water damage resistance of roads. Promoting the application of steel slag asphalt mixture in more road engineering projects in the future will help improve road quality, extend service life, achieve efficient resource utilization, and protect the environment.

In summary, the application of steel slag asphalt mixtures in road engineering offers significant environmental benefits. By reducing natural resource consumption, decreasing industrial waste accumulation, minimizing environmental impact during construction and use, and lowering carbon emissions and energy consumption, steel slag asphalt mixtures provide essential support for green road construction and sustainable development. As technology continues to advance and the scope of application expands, the environmental benefits of steel slag asphalt mixtures will become increasingly significant, contributing more to building an ecological civilization and a beautiful China.

## 4. Engineering Practice and Construction Technology

The successful application of steel slag asphalt mixtures in road engineering relies not only on the excellent performance of the material itself but also on scientific construction techniques and rigorous engineering practices. First, the construction process of steel slag asphalt mixtures begins with the preparation of raw materials. As the primary aggregate in asphalt mixtures, steel slag must undergo strict quality control and processing. Before use, steel slag needs to be crushed and screened to achieve the desired particle size distribution and cleaned to remove surface dust and impurities, ensuring its cleanliness. Additionally, to reduce the alkalinity of steel slag and improve its bonding with asphalt, pretreatment is typically necessary. The preparation process of the mixture includes aggregate heating, asphalt heating, and mixing. First, the aggregate is heated to an appropriate temperature, followed by the heated asphalt and aggregate being uniformly mixed in a mixer to ensure the asphalt evenly coats the aggregate surface. The mixing process requires strict control of temperature and mixing time to prevent asphalt aging and mixture segregation. Secondly, construction and paving are

critical steps to ensure the performance of steel slag asphalt mixtures. Once transported to the construction site, the mixture should be quickly paved at the designated location, ensuring the mixture's thickness and uniformity to avoid segregation and unevenness. After paving, a roller is used to compact the mixture in stages, including initial rolling, intermediate rolling, and final rolling, with the number of passes and methods adjusted according to site conditions to ensure the density and smoothness of the pavement. Temperature control is crucial during compaction, ensuring the mixture is compacted within the appropriate temperature range to achieve optimal density and structural performance. Lastly, curing and quality control are essential steps to ensure the long-term performance of the road. After construction, the steel slag asphalt mixture should be adequately cured to stabilize its performance. During the cooling and solidification process, early traffic loads and environmental impacts should be prevented, with barriers or warning signs set up to prevent vehicle and pedestrian access. Quality testing and evaluation, such as checking pavement smoothness, density, and strength, are necessary to ensure the mixture meets design and regulatory requirements. Regular inspections and maintenance can promptly identify and repair early-stage road issues, extending the service life of the road. In conclusion, the application of steel slag asphalt mixtures in road engineering requires scientific construction techniques and rigorous engineering practices. Through proper raw material processing, precise mixture preparation, standardized paving and compaction processes, and effective curing and quality control, the superior performance of steel slag asphalt mixtures can be fully realized, enhancing the overall quality and service life of roads while achieving both economic and environmental benefits [7].

## 5. Future Development and Research Directions

Steel slag asphalt mixture, as a high-performance and environmentally friendly road engineering material, shows broad application prospects. However, to further enhance its performance and promote its application, in-depth research and development in several areas are needed. Future research should focus on further optimizing the mixture design and material modification of steel slag asphalt mixtures. By adding various modifiers, such as fibers, polymers, and nanomaterials, the mechanical properties and durability can be improved. Additionally, adjusting the pretreatment processes of steel slag, such as surface activation and chemical modification, can enhance its bonding performance with asphalt, further improving the overall performance of the mixture. Currently, the application of steel slag asphalt mixtures lacks unified technical standards and construction specifications. In the future, it will be necessary to develop and refine relevant standards and specifications at national and industry levels, clearly defining performance requirements, testing methods, and construction processes. This will provide technical support and assurance for large-scale application, along with establishing comprehensive quality control systems to ensure stable performance under various engineering conditions. Further, conducting environmental impact assessments and life cycle analyses of steel slag asphalt mixtures is essential[8]. By systematically studying its environmental impact during production, construction, use, and recycling phases, and quantifying its

carbon emissions, energy consumption, and resource use, scientific bases for policy formulation and technical improvements can be provided. Additionally, exploring the recycling and regeneration technologies for steel slag asphalt mixtures will enable sustainable use of materials and maximize resource utilization. Beyond road engineering, future research can explore the application of steel slag asphalt mixtures in other infrastructure projects, such as airport runways, port terminals, and bridge pavements. These areas have higher performance requirements, and through innovative research, the application scope of steel slag asphalt mixtures can be expanded, enhancing its market value and application benefits. Comprehensive analyses of the economic benefits and social impacts of steel slag asphalt mixtures should also be conducted, evaluating their cost-benefit ratios and social benefits in different application scenarios. Case studies and data analyses can demonstrate its advantages in reducing engineering costs, minimizing environmental pollution, and promoting social sustainable development, providing decision-making support for governments and enterprises and driving its wider application. In summary, the future development of steel slag asphalt mixtures should focus on performance optimization and material modification, standardization and regulation, environmental impact assessment and life cycle analysis, exploration of new application areas, and analysis of economic benefits and social impacts. Through multifaceted research and practice, the technical level and application value of steel slag asphalt mixtures can be further enhanced, contributing significantly to green road construction and sustainable development [9].

## 6. Conclusion

Steel slag asphalt mixture, as a high-performance and environmentally friendly road engineering material, demonstrates significant application advantages and broad prospects. Through in-depth analysis of the physical properties and chemical composition of steel slag, its high strength, hardness, and good bonding properties can be fully utilized to significantly enhance the load-bearing capacity and durability of road engineering. Results from practical engineering cases show that steel slag asphalt mixtures perform better than traditional materials in both road base and surface layers, particularly in terms of compressive strength, wear resistance, fatigue resistance, and water damage resistance. This effectively extends the service life of roads and reduces maintenance costs. From an economic perspective, steel slag asphalt mixtures achieve significant cost savings by reducing material costs, maintenance expenses, and improving construction efficiency. Additionally, promoting the resource utilization of by-products from the steel industry reduces waste accumulation and disposal costs, enhancing overall economic benefits. Environmentally, the application of steel slag asphalt mixtures reduces natural resource consumption, lowers carbon emissions and energy use, mitigates environmental pollution, and achieves resource recycling and sustainable

development. Moreover, steel slag asphalt mixtures contribute to raising public environmental awareness, driving the development of related industries, and improving public service levels in road construction. However, to further promote and optimize the application of steel slag asphalt mixtures, ongoing research is needed in performance optimization, standardization, environmental impact assessment, exploration of new application areas, and analysis of economic and social benefits. Through continuous technological innovation and scientific research, construction techniques and quality control systems can be perfected, unified technical standards and specifications can be established, and the application effect and market acceptance of steel slag asphalt mixtures can be further improved. In conclusion, as an efficient, environmentally friendly, and economical road engineering material, steel slag asphalt mixtures have significant application value and development potential. In the future, continuous technical development and scientific management will allow the full utilization of their advantages, contributing more significantly to green road construction and sustainable development.

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