Performance of Steel Slag in Highway Surface Course

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Graphical abstract

Property	Value
Los Angeles Abrasion (ASTM C131), %	20 - 25
Sodium Sulfate Soundness Loss (ASTM C88), %	<12
Angle of Internal Friction (ASTM D3080)	40° - 50°
Hardness (measured by Moh's scale of mineral hardness) (ASTM D3080)	6 - 7
California Bearing Ratio (CBR), % top size 19 mm (3/4 inch) (ASTM D1883)	up to 300

* Hardness of dolomite measured on same scale is 3 to 4.
** Typical CBR value for crushed limestone is 100%.

Abstract

As the quantity of disposing waste material is increasing in road construction, researchers are exploring the use of alternative materials which could preserve natural sources and save the environment. One of these sustainable materials is steel-furnace slag which is a synthetic aggregate produced as a consequence of the electric arc furnace (EAF). Steel slag was selected due to its characteristics, which are almost similar to conventional aggregates, and the fact that it is easily obtainable as a by-product from the steel industry. The same gradations of mixtures were produced using normal crushed aggregate as control samples. The experimental research has been articulated in a preliminary study of the chemical, leaching, physical, and mechanical properties of the electric arc furnace (EAF) steel slag. In addition, the outstanding benefits of steel slag were highlighted. All the mixtures with EAF steel slag have satisfied the requisites for acceptance in the road sector technical standards, thus resulting as suitable for use in the construction of road infrastructures.

Keywords: Steel slag; environment; resilient modulus; rut depth; rutting, industrial waste material, sustainability

■1.0 INTRODUCTION

Nowadays, the topic of steel slag is one of the most important issues especially in transportation and highway. The molten slag flows from the furnace into a pit area where it solidifies. The slag consists principally of a fused mixture of oxides of calcium, silica, iron, alumina and magnesia. Other benefits of using steel slag in asphalt concrete include the recycling of a waste product, thus reducing the volume of material placed in Oregon landfills. Steel slag, as waste material of steel production, has been used widely in road construction because it has high density and hardness similar to those of coarse aggregates [1].

In general conditions, steel slag aggregates can replace natural aggregates in approximately every situation. The exemption to this is where the density of the aggregate is a crucial design consideration as in cement [1].

Hot mix asphalt (HMA) concrete is a combination of aggregate and asphalt cement. The aggregate acts as the structural frame of the pavement and the asphalt cement as the glue of the mixture[2]. The mineral aggregate, including coarse and fine particles in asphalt paving mixtures, encompasses approximately 90% of volume of HMA [3]. Somehow the properties of the aggregate have straight and considerable effect on the performance of asphalt pavements [4].

The HMA industry has been pressured in recent years to add in a wide variety of waste materials into HMA pavements [5]. The resulting large quantities of slags produced and their potential impact on the environment have encouraged materials scientists and civil engineers to explore technically sound, cost-effective and environmentally acceptable use of this material in civil and highway construction. Steel slag is industrially-produced artificial aggregate which, after suitable treatment, constitute an excellent material for manufacture of wearing course in the road construction industry. The manufacture and its employ are friendly to the environment while contributing to the safer highway. Somehow the most destructive effects on construction of road especially wearing course can be to consist fatigue, rutting, skid resistance, and texture depth.

Steel-slag is a by-product of the steel industry, and is reported to exhibit great potential as a replacement for natural aggregates in road construction. Steel-slag is a waste material that can be recycled as a road construction material. Steel-slag aggregates have been reported to retain heat considerably longer than natural aggregates. In other hand, the heat retention characteristics of steel-slag aggregates can be advantageous for HMA construction, as less gas (energy) is used throughout the execution of asphaltic concrete works. Based on high frictional and abrasion resistance, steel-slag is used commonly in industrial roads, intersections, and parking areas where high wear resistance is required[3].

2.0 INTRODUCTION OF STEEL SLAG

Electric arc furnace (EAF) slag is an industry-produced artificial aggregate which, after appropriate behavior, constitutes an excellent material for the manufacture of wearing course in road construction industry. The production of its use of friendly to the environment, while contributing in the produce of safer highway [6]. In September 1994, steel slag test and control sections were constructed in Oregon to evaluate the use of steel slag in HMA [7]. Steel slag is a by-product of the steel making process. Previous studies have shown that the global amount of steel slag has been increasing rapidly [8]. Production of steel, calls for the removal of surplus silicon and carbon from iron by oxidation. In the production of steel, the furnace is charged with iron ore or piece metal, fluxing agents, usually limestone and dolomite, and coke as both fuel and reducing agent [2].

3.0 PRODUCTION OF STEEL SLAG

Iron and steel making slag is classified as BF (Blast Furnace) slag or steelmaking slag, .It obviously consists of silicates, alumina silicates, calcium aluminum silicates, iron oxides and crystalline compounds [9]. BF slag is generated during the process of reducing iron ore with coke in a blast furnace. Its sources are the gangue content of iron ore, that is, constituents of iron ore other than iron, and lime content added to adjust the composition of molten slag. Steelmaking slag is generated in the process of refining hot metal produced by a blast furnace into steel, and has been mostly used as road material [10].

EAF mills produce steel generally by remelting piece steel. In each of these processes, input materials (iron ore, scrap metal, fluxing agents such as lime are charged into a furnace, refined, and halted further than their melting points [11]. Two or more liquids have been formed when these materials arrive at a state of complete fusion. The liquid with the lowest specific gravity forms a layer on the surface of the melt that is called slag [12]. The presence of steel scraps in the basic-oxygen furnace charge plays an important role in cooling down the furnace and maintaining the temperature at approximately 1600°C–1650°C for the required chemical reactions to take place. Slag resulting from the steelmaking process floats on top of the molten steel [11].

4.0 BENEFITS OF STEEL SLAG

Many researchers found that those benefits of steel slag are numerous, the following are the major benefits for using steel slag:-

1. Improved deformation characteristics i.e. strength and stability.
2. Improved durability e.g. rough surface texture, improved stripping resistance. This is very important in the prevention of stripping of the binder and moisture damage. Steel slag, with a pH between 8 and 10, has a strong affinity to bitumen and therefore displays a greater degree of binder retention.
3. Improved Skid resistance i.e. polished stone value. A Polished Stone Value (PSV) of 63 for the steel slag aggregate indicates a high resistance to the surface of the aggregate polishing under the action of traffic.

4. Specific gravity and water absorption
Particle density of the steel slag aggregate compared to natural aggregates (dolerite & quartzite) is denser and heavier

material by approximately 20%, Steel Slag typically has a higher water absorption than dolerite and quartzite
5. Its heavy weight provides a high resistance to lateral movement on curves and washout protection in area subjects to flooding.
6. Steel slag provides better drainage because it's high percentage of void space, its cleanliness and high resistance to degradation.
7. It is rough, angular pieces provide an interlocking, stable roadbed. Its sharp concern and rough pitted surface grip the ties firmly and prevent shifting of the track on curves.
8. It contains no organic substance and is an exceptionally clean ballasting material that will not support the growth unwanted vegetation.
9. Steel slag has high resistance to wear and abrasion, minimizing degradation from heavy traffic.
10. Steel slag is highly resistant to change by wetting and drying, freezing and thawing, extreme changes in temperature and chemical attract.

5.0 PROPERTIES OF STEEL SLAG

5.1 Physical And Chemical Properties

Steel slag aggregates consist extremely angular in shape and have rough surface texture. They considered high bulk specific gravity and reasonable water absorption (less than 3 percent). The chemical composition of slag is frequently expressed in terms of simple oxides calculated from elemental analysis determined by x-ray fluorescence. One more importance is the mineralogical form of the slag, which is highly dependent on the rate of slag cooling in the steel-making process. Table 1 shows the physical and chemical properties of steel slag.

Table 1 Typical physical and chemical properties of steel slag [13-16]

Property	Value
CaO	40 – 52%
SiO_2	10 – 19%
FeO	10 - 40 (70 - 80% FeO, 20 - 30% Fe2O3)%
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%
Specific Gravity >	3.2 - 3.6
Unit Weight, kg/m³ (lb/ft³)	1600 - 1920 (100 - 120)
Absorption	up to 3%

5.2 Mechanical Properties

Processed steel slag has favorable mechanical properties for aggregate use, including good abrasion resistance, good soundness characteristics, and high bearing strength. Table 2 shows the mechanical properties of steel slag.

Table 2 Typical mechanical properties of steel slag (According to US. Department of Transportation, Federal Highway Administration) [1]

Property	Value
Los Angeles Abrasion (ASTM C131), %	20 - 25
Sodium Sulfate Soundness Loss (ASTM C88), %	<12
Angle of Internal Friction (ASTM D3080)	40° - 50°
Hardness (measured by Moh's scale of mineral hardness) (ASTM D3080)	6 - 7
California Bearing Ratio (CBR), % top size 19 mm (3/4 inch) (ASTM D1883)	up to 300
* Hardness of dolomite measured on same scale is 3 to 4. ** Typical CBR value for crushed limestone is 100%.	

■6.0 EFFECT OF STEEL SLAG ON PAVEMENT INDUSTRY

6.1 Application Of Steel Slag In Asphaltic Concrete For Road Works

Replacing the coarse portion of limestone aggregate with steel slag has the better function compares to mixtures which contain steel slag as the fine portion [8]. Steel slag could be used on different types of mix designs; e.g. porous asphalt, dense graded, stone-mastic asphalts and etc . Steel slag increases Marshal Stability and decreases flow values [3, 8]. Mixtures with steel slag coarse aggregates have higher Marshal Quotient (MQ) values, which is an indicator of high stiffness and resistance to permanent deformation [3, 8]. According to result obtained from past studies mixtures with steel slag have better result than mixtures with limestone. Stiffness modulus values of the mixtures contain steel slag course aggregate where higher than mixtures with limestone course aggregate [3]. Creep stiffness values of steel slag mixtures are substantially higher than mixtures containing limestone. Therefore, steel slag mixtures have higher rutting resistance[3]. Steel slag mixtures have better cohesive strength than mixture with limestone coarse aggregates [3]. The resilient modules of samples with 100% steel slag and samples containing 50% steel slag and 50% granite, increases after short-term oven aging due to oxidation of the asphalt binder. However the resilient modules of mixture containing 100 % steel slag, after aging is higher than 50-50% mixtures. Resilient modulus of both samples decreases around 90% when temperature increases from 10˚C to 40˚C [17].

Tests performed on bituminous mixture samples for the base course (steel slag percentage of 30 and 40%), provided acceptable results as well. The stability and stiffness values, obtained by the Marshall test, were significantly higher than the limits of acceptance, indicated by the CNR Bulletin n. 178/95 and by the Technical Specifications [2], and even better than the values obtained from the tests completed on the natural aggregate mixture. The remaining voids resulted high and the apparent density of the Marshall test specimens were 6–8% higher than mixtures with natural aggregates [18].

States in the midwest and the eastern United States have extensive experience about of steel slag to HMA. Their experiences indicate that the addition of steel slag may enhance the performance characteristics of the pavement. Since the slag is rough, the material improves the skid resistance of the pavement. Also, because of the high specific gravity and angular, interlocking features of the crushed steel slag, the resulting HMA is more stable and resistant to rutting [19-22].

In the most type of asphaltic concrete pavement failure is rutting, which is manifested at the surface [23-26]. Mixtures containing steel slag as the coarse portion are more resistant to permanent deformation and have lower rut depths [27-29]. Using steel-slag as an aggregate replacement could cater for a higher volume of traffic due to its greater adhesion ability, also using from steel slag in flexible pavement shows that the dimension of rut in steel slag is lower than conventional flexible pavement [18].

■7.0 CONCLUSION

Using from artificial or resource material can be an exceptional phenomenon in highway construction. Accomplishments by using steel slag in surface course are preventing road damage such as, rutting, fatigue and texture depth. The most ideal mixtures between steel slag mixture and conventional mixture, is when both of them be blended. Although steel slag can have perfect influence of Marshall mix design, nevertheless select the percentage of steel slag is so important. A mix of 50% steel slag and 50% natural aggregates can be the best mixture for the marshal mix design as per this study. Less rut depth and fatigue cracking are obtained from using steel slag in asphalt mix design in comparison with conventional surface course. In addition, steel slag mixtures have more resilient modules compare with natural aggregate asphalt mix designed in wearing course. Furthermore, more texture depth of steel slag asphalt mix designed is gaining against conventional mix designed in wearing course. Steel slag can be one of the best replaces artificial aggregates for road construction, this issue causes us save the environment and have artificial material with higher resistance.

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