Steel Slag Waste Applied to Modify Road Pavement

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Abstract. Steel slag is a waste material that generated during the process of steel making as a byproduct. It is the major industrials waste that generated from electric arc furnaces that accumulation with huge quantities which causes environmental problems for industrial and agricultural sectors. Therefore, it is very important to minimize waste disposal to reduce landfill area and disposal cost as well as their environmental effects. Lately, sustainable engineering has been applied to minimize waste disposal by using byproducts and waste materials to produce useful products. Therefore, in this research, steel slag has been applied as aggregate concrete asphalt to improve the properties of road pavement. It is used with the percentage of 10-40% of the weight of concrete asphalt mix. The results show that there is an improvement in the mechanical properties of the pavement. Marshal stability was increased from 8 to 15 KN by added slag with the percentage of 30-40%. For that reason, steel slag has widely accepted as aggregate in the pavement application as a road surface for heavy duty work.

Keywords. Steel, slag, pavement, waste, recycling, disposal, sustainability.

1. Introduction
Road pavement consists from four layers including sub–base, road base, binder course and surface course. Blue limestone and sharp sand or natural gravel utilized for the base and sub-base layer. However, bitumen binder and aggregates materials are used as a binder course layer which can be called as a load-bearing and strengthening layer and the final surface course comprises Hot Mix Asphalt [1].

Rutting is the major distress in flexible pavement which can be considered as permanent deformation of pavement which is leading to failure the pavements. The pavement is rutting due to uncontrolled large and heavy axle loads, increased traffic levels, increased tire pressures, pavement materials and climatic conditions. Asphalt binder becomes viscous and plastically flow when it subjected to loads higher than its viscosity at high temperature. This is due to the viscoelastic properties of asphalt cement which is very much temperature-dependent. Therefore, longitudinal cracking, transverse cracking, block cracking, alligator cracking, potholes and rutting will appeared in the pavement as defects [1-3].

The good compacting road should have low air voids which lead in the range of 3 and 5% to be durable and resist the ingress of water. Additionally, roads would deform minimally under heavy loads and thus resist raveling and fatigue. However, pavement too rich in asphaltic binder with air void content lower than 3% becomes subject to bleeding as there are insufficient voids to tolerate the
expansion of the binder on very hot days. Therefore, too low an air void content results in rutting leads to reduce the service life of the pavement. For that reasons, filler materials are used as binder materials to improve the temperature susceptibility of asphalt by increasing asphalt binder stiffness at high service temperatures enhances the service properties over wide range of temperature which undergoes deformation when the pavement is stressed during service [1, 3].

Aggregates are obtained from natural rocks and their mining leads to reduce natural resources. The countries having limited resources of natural aggregate are thinking to save their natural resources for their future generation. Therefore, scientist thinking to investment the large quantity of solid waste produced by industrial sector and disposed in the landfills area. As a result of that, they have explored variety of recycled materials which can be used as an aggregate. Moreover, adopting of aggregate gradation procedure of super pave method of pavement mix design for Marshall Method of asphalt concrete mix design can reduce the pavement rutting by about 50%. It is environmental and economic process that can be considered as sustainable manufacturing process for construction material to improve the properties of pavement [2, 4, 5].

The technique of recycling asphalt pavement for road construction is widely used as the most recycled material in the world. It is commonly used as an aggregate substitute in asphalt mix and as granular sub-base or base aggregate as well as embankment or fills material. The previous studies show that using of reclaimed asphalt pavement saving up to 39% of total pavement cost comparing with conventional flexible pavement in Iraq. Most of highways and roads in the World are constructed with Hot Mix Asphalt which must be maintained and rehabilitated. Over 80% of reclaimed asphalt pavement was recycled, making asphalt the most frequently recycled material [6].

To increase the durability of highway pavement need to control the quality of pavement materials. Therefore, different percentages of polymer are used to modify mixes were designed in accordance with Marshall Method. The engineering properties of polymer modified mixes meet the requirements of general specific for road and bridge of asphalt mix that used for the construction of surface course. The Marshall stability for modified mixes is higher than of control mixes. Although, the using of polymers in asphalt is still an emerging market, the polymer-modified binder can be considered as one of the main solution that applied to mitigate the damaging effect of increasing traffic stresses [7, 8].

Steel slag is a byproduct that generated as waste from steelmaking industry which has been recycled in many countries around the world for decades. Approximately 160 kg of steel slag is generated per ton of steel produced. The common chemical compounds in steel slag are SiO₂, CaO, Fe₂O₃, Al₂O₃, and MnO. Therefore, the recovery of these metals may make it economic to clean the slags to the point where they are not only safe for disposal [9]. Steel slag is recycling as aggregate material for asphalt pavement to reduce the landfills area that reserved for disposal slag and reduce the cost of waste disposal as waste as well as for saving the natural resources. Steel slag is a valuable resource to replace natural rocks and reduce the environmental impact of excavating virgin resources[1, 4, 10-14].

Germany is one of the main countries that recycling steel slag for pavement application which used 97% of the total generated steel slag for the construction of high trafficked roads. It is utilized as aggregate for surface layer, road base, sub base, earthworks and hydraulic structures because steel slag becomes hard and dense which provide high abrasion resistance. Concrete with steel slag by-products is a cost effective and advantageous material for pavement construction. The low cement content of the proposed concrete reduces cost significantly, while the use of high volumes of industrial by-products is a step towards preserving natural resources and producing concrete of reduced environmental impact [15-17].

2. Experimental Work
Since the effect of mineral fillers is more prominent in gap graded asphalt mixtures, such as the stone matrix asphalt that contains large amounts of fines, it is important to understand the changes that occur in the properties of the mixture due to the fines. Therefore, the primary objective of this study was to determine the impact of different percentage and particle size of steel slag that used as filler material on the stiffness and deformation properties of stone mastic asphalt mixture. Many
experimental works have been done to improve the properties of pavement and get suitable concrete asphalt mix for Iraqi weather

2.1. Materials
The main materials that used in this research are including asphalt, aggregates, steel slag, Portland cement and sand. Asphalt type (50 – 60) with physical specification that shown in table 1 has been used. The aggregates that used in this study are mixing from crushed aggregates and crashing steel slag which divided into coarse aggregate in the range of (4.75 - 19) mm and fine ranges of (0.0075 - 4.75) mm according to the specification of road and bridge as shown in table 2 [11, 12]. The specification of crashed aggregates that used in this research showed in table 3. Moreover, steel slag of electric arc furnaces with chemical analysis shown in table 4 are used to modified asphalt mix. In addition the specification of Portland cement that used as filler showed in table 5 that mixing with commercial sand of 0.070 to 2.36 mm size.

| Property                     | ASTM Designation No | Test Condition | Results | SCRB limits |
|------------------------------|---------------------|----------------|---------|-------------|
| Penetration                  | D – 5               | 25 °C, 100 gm 5 Sec, 0.1 mm | 56 | 50 – 60 | 50 – 60 |
| Softening Point              | D – 36              | Ring & Ball | 47 | 50 – 60 | 50 – 60 |
| Ductility                    | D – 113             | 25 °C, 5 cm/min Relationship Between P&S | 150 | >100 | >100 |
| Penetration Index            | -                   | -             | -1.6 | 2± | 2± |

| Property                     | ASTM Designation No | Coarse Aggregate | Fine Aggregate | ASTM limits |
|------------------------------|---------------------|------------------|----------------|-------------|
| Bulk Specific gravity        | D - 127             | 2.646            | 2.63           | -           |
| Apparent Specific gravity    | D – 128             | 2.656            | 2.667          | -           |
| Percent water absorption     | -                   | 0.140            | 0.523          | 4.00 Max    |

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| Percent water absorption     | -                   | 0.140            | 0.523          | 4.00 Max    |
| Grain size mm                | 4.75-19             | 0.075-4.75       |                |             |

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| Percent water absorption     | -                   | 0.140            | 0.523          | 4.00 Max    |
| Grain size mm                | 4.75-19             | 0.075-4.75       |                |             |
Table 5. Specification of Portland cement

| Property                        | ASTM Designation N0 | Result |
|--------------------------------|---------------------|--------|
| Apparent Specific gravity      | D – 128             | 3.04   |

2.2. Mixing Procedure

2 kg of aggregates was prepared in the suitable size that meet the standard of surface stage of bridges and road without and with using steel slag as shown in table 6 and 7 respectively. Mixing aggregate was prepared according to surface level of surface of road and bridge as shown in table 8 to mix with asphalt according to the following equation:

\[ \text{Equation mix} = 0.15 \times A + 0.20 \times B + 0.15 \times C + 0.45 \times D + 0.05 \times F \]

Table 6. Gradients the aggregates for surface level without using slag

| Grading mm | Coarse | Middle | Fine | Sand | Filler |
|------------|--------|--------|------|------|--------|
| 19         | 0      | 0      | 0    | 0    | 0      |
| 12.5       | 0      | 0      | 0    | 0    | 0      |
| 9.5        | 0      | 12     | 964  | 0    | 0      |
| 4.75       | 0      | 1697   | 989.5| 0    | 0      |
| 2.36       | 0      | 232    | 288  | 0    | 0      |
| 0.30       | 0      | 1486   | 0    | 0    | 0      |
| 0.075      | 0      | 274    | 0    | 0    | 0      |

Table 7. Gradients the aggregates for surface level with using slag

| Grading mm | Coarse | Middle | Fine | Sand | Filler |
|------------|--------|--------|------|------|--------|
| 19         | 0      | 0      | 0    | 0    | 0      |
| 12.5       | 0      | 0      | 0    | 0    | 0      |
| 9.5        | 0      | 12     | 964  | 0    | 0      |
| 4.75       | 0      | 1697   | 989.5| 0    | 0      |
| 2.36       | 0      | 232    | 288  | 0    | 0      |
| 0.30       | 0      | 1486   | 0    | 0    | 0      |
| 0.075      | 0      | 274    | 0    | 0    | 0      |

Table 8. Aggregate mixing according to equation mix for surface level (SORB)

| Standard grain size (ASTM1559) | Theoretical Equation Mix | Filler % | Sand % | Fine % | Middle % | Coarse % | Grading mm |
|--------------------------------|--------------------------|----------|--------|--------|----------|----------|------------|
| 100                            | 100                      | 100      | 100    | 100    | 100      | 100      | 19         |
| 95 – 66                         | 98                       | 100      | 100    | 100    | 98       | 94       | 12.5       |
| 88 – 54                         | 77.9                     | 100      | 100    | 99     | 50       | 20       | 9.5        |
| 70 – 37                         | 52.5                     | 100      | 100    | 15     | 0        | 1.6      | 4.75       |
| 51 – 26                         | 45.56                    | 100      | 89.4   | 1      | 0        | 1.2      | 2.36       |
| 22 – 8                          | 11.2                     | 97.3     | 14     | 0      | 0        | 0        | 0.30       |
| 10 – 4                          | 5                        | 91       | 0.40   | 0      | 0        | 0        | 0.075      |

2.3. Optimum Asphalt Content

To obtain the optimum asphalt content according the surface of road and bridge for surface level, asphalt mixing by using the numerical average of higher stability and higher apparent density with air voids of...
5% as shown in figures 1-5. The closeness of the values of bulk density and the values of the specific gravity indicate the air void content is low as formulated below [1]:

\[
\text{Air Void \%} = \frac{\text{Theoretical specific gravity} - \text{Bulk specific gravity}}{\text{Theoretical specific gravity}} \times 100
\]

Figure 1. Apparent density with weighing percent of asphalt

Figure 2. Marshall Stability with weighing percent of asphalt

Figure 3. Marshall Flow with weighing percent of asphalt
3. Results and Discussions

The result shows that when steel slag percentage that used with hot asphalt mixing mix according the (ASTM D 1559 – 82) increased the Marshal stability and Marshal Index were increased too. The Marshal stability increased from 8 to 12.2 KN for samples prepared by using hot asphalt mix with 10 % of steel slag due to increase its bulk density from 2.23 to 2.40 and Marshal Index increased from 2.93 to 4.42. On the other hand, when the steel slag increase to 20%, marshal stability and marshal index were increased to be 13.65 KN and 5.42, respectively. Furthermore, marshal stability and index increased to be 15.85 KN and 5.82 when the percentage of steel slag increased to be 30%. However, when steel slag increased to be 40 %, Marshall Stability and Marshall Index were decreased to be15.25 and 5.62, respectively as shown in table 9. Therefore, the optimum percentage of steel slag that suitable for Iraqi weather with high temperature reach to 50 °C or more in summer is 30%.

| Specification Marshall for hot asphalt mix at 10, 20, 30 and 40 % |
|---------------------------------------------------------------|
| **AC (40 – 50)** | **Bulk Density** | **Max Sp. Gr.** | **V.T.M % (3 – 5)** | **V.F.M % (65 – 85)** | **Stability 8 KN Min** | **Flow (2 – 4) mm** | **Marshall Index KN/mm** | **V.M.A % 14 Min** |
| Standard | 2.28 | 2.34 | 3.30 | 87.50 | 8.40 | 3.20 | 2.93 | 17.26 |
Iraq has very hot weather in summer and cold weather in winter which leads to deterioration the specification of asphalt and pavement of the roads. The higher temperature in summer which reach to 50 °C or more made the pavement and their asphalt very soft which affected the mechanical properties of them. On the other hand, the cold temperature in winter that reaches to 0 °C or less in some case leads to decreases the elasticity of road. However, increasing the numeric of trucks that passing over the road will destroyed it and make a lot of waves in the street. Therefore, the road pavement needs to be developed and improved. Steel slag is the best and cheaper material that used to overcome this problem as aggregate materials that mixing with hot asphalt mix with percentage up to 30%. The results show that the mechanical properties of pavement and asphalt were improved with percentage of 190 % when the steel slag used instead of gravels. This is because the cohesion and adhesion of aggregates were increased due to their porosity and structural properties of pavement mix and high density of steel slag. Moreover, using steel slag as aggregate will reduce solid waste materials from the landfill.

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| Modified With 10% | 2.40 | 2.40 | 4.20 | 96.10 | 12.20 | 2.60 | 4.42 | 17.50 |
|-------------------|------|------|------|-------|-------|------|------|-------|
| Modified With 20%| 2.431| 2.44 | 3.40 | 96.10 | 13.85 | 2.60 | 5.42 | 17.50 |
| Modified With 30%| 2.570| 2.54 | 3.90 | 84.03 | 15.85 | 3.10 | 5.82 | 14.45 |
| Modified With 40%| 2.631| 2.64 | 4.60 | 95.10 | 15.25 | 2.70 | 5.62 | 16.40 |
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