Performance Evaluation of Asphalt Pavements Mixed with Steel Slag

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Abstract: Lack of natural stone and expensive cost of purchasing high-quality aggregate promote the utilization of steel slag. The asphalt mixtures incorporating basic oxygen furnace steel slag (BOF) as coarse aggregate were prepared and subsequently subjected to various laboratory tests to determine the engineering properties of asphalt concrete. Results show that BOF provides higher stability value compared to natural-aggregate-based asphalt mixtures. Steel slag would include angular and rough textured particles that could enhance the interlocking mechanism. Test sections were constructed by using three different types of asphalt mixtures as follows: stone mastic asphalt with BOF, dense-graded asphalt concrete with BOF, and dense-graded asphalt concrete with natural aggregate. Pavement performance including rutting, ride quality and friction was collected and analyzed. Field data indicated that the use of BOF steel slag as aggregate present a viable solution for asphalt pavements, which could ensure a satisfactory level of performance.

Keywords: Hot-Mix Asphalt, Pavement Performance, Basic Oxygen Furnace Steel Slag

1. INTRODUCTION

The properties of the aggregates used in asphalt mixtures have a direct influence on pavement performance. When an asphalt mixture is designed, it is normally recommended that angular and rough-surfaced aggregates are selected, once they tend to promote better resistance to permanent deformation for the mixtures. Aggregates for asphalt mixtures should also be resistant enough to bear production, transportation and construction processes, as well as traffic loads and climate effects. Lack of good quality of natural crushed aggregate promotes the recycling of steel slags (Krayushkina et al., 2012; Bessaa et al., 2014). At the same time, environmental and technical problems have led to increasing attention being paid to the subjects of secondary solid materials in the construction and maintenance of road infrastructure. The industrial by-products from the metallurgical industry have been frequently applied to base and surface courses in the road structure. These by-products are primarily constituted of electric arc furnace (EAF) slag and basic oxygen furnace (BOF) slag (Noureldin and MacDaniel, 1990; Motz and Geiseler, 2001; Maslehuddin et al., 2003).

BOF steel slag is a by-product of the conversion of pig iron to steel in a basic oxygen furnace using an LD (Linz-Donawitz) type converter. This by-product has existed since the development of the oxygen converter in the 1950s. Recycling of BOF is an important issue world widely. Researchers have been trying to search its value added applications (Motz and Geiseler, 2001; Asi 2007; Krayushkina et al., 2012). Literature reports that it can be used as aggregate in asphalt or cement concrete (Xue et al., 2006; Bessaa et al., 2014). It was first used in agriculture as a soil amendment to neutralize soil acidity, stabilize soil structure, and increase plant resistance, but its main valorization has concerned road works for many years (Rex 2005). Due to lack of superior natural aggregate for road construction such as limestone,
authorities in some countries have made legislation and government programs on the BOF valorization. On the other hand, increased spending on highway construction also promotes its application. According to its mechanical characteristics, this material has been used for embankment or as an aggregate in road construction (Xue et al., 2006; Asi 2007).

The moisture sensitivity of steel slag including BOF- and EAF-based asphalt mixtures were investigated by highway engineers and researchers. Airey et al. (2004) conducted research on stone mastic asphalt mixture (SMA-13) and dense graded asphalt mixture with EAF and BOF. The involvement of steel slag provided benefits on the moisture sensitivity of asphalt mixture, as well as the stiffness and fatigue life. All the improvement of performance attributes to the vesicular and pitted structure of steel slag. The study conducted by Noureldin and MacDaniel (1990) shows that after freeze–thaw treatment, steel slag based asphalt mixtures exhibited larger indirect tensile strengths, compared to the limestone based asphalt mixtures. Also their volume expansions were lower than 1%. Xue et al. (2006) carried out an investigation of BOF as coarse aggregate in SMA asphalt mixture. The BOF based mixtures showed superior moisture sensitivity to the controlled mixtures composed by basalt or limestone. Marco analyzed the performances of asphalt concretes with EAF. Their results show that the mixtures with EAF slag have been characterized by a low water damage so demonstrating a good durability. Shen et al. (2009) prepared mixtures with different percentages of BOF by volume as a coarse aggregate substitution. Results show that the tensile strength ratios for all of the mixtures exceed the minimum values of 70% requirement. It is indicated that the mixtures may have sufficient resistance against moisture induced damage.

This study was motivated by concerns that stone mastic asphalt (SMA) mixed with BOF steel slag might not perform well under the environmental and traffic conditions (Dunford and Roe 2010). SMA is designed to be a tough, stable, rut-resistance mixture that relies on stone-to-stone contact to provide strength; however, it was feared that the rut resistance, friction, durability and environmental benefits of SMA with BOF would be lost due to heavy trafficking. The primary objective of this study is to evaluate the use of BOF in hot-mix asphalt mixtures. All aspects of using BOF in asphalt pavements will be evaluated, including:

- Engineering properties,
- Constructability, and
- Performance characteristics.

2. MATERIALS AND PROPERTIES

2.1 Aggregate

Natural aggregate used in this study was a limestone obtained from the Kao-Ping River, and BOF was supplied by the CHC Resources Corporation, as shown in Figure 1. BOF steel slag consists of crushed angular particles and has a rougher surface texture than natural aggregate. The basic properties of BOF and natural aggregates were listed in Table 1. Both materials meet the specification requirements stipulated by the roadway agency.

The LA abrasion test provides an indication of the relative quality of competence of various sources of aggregate. In general, the LA abrasion test can be used as an indication of aggregate wear resistance. BOF seems to possess better LA abrasion value than natural aggregate. Both aggregates meet the requirement of flat and elongated particles, although the shape of BOF aggregate is more cubic. Flat and elongated particles tend to break during
mixing, compaction, and under traffic. The specific gravity of BOF is about 30% higher than that of natural aggregate.

Because of the porous structure on the aggregate surface of BOF, the absorption value of BOF is slightly higher than that of natural aggregate. The sodium sulfate test measures the soundness of aggregates subject to weathering action, by immersing samples in either sodium sulfate. The test results indicate that both samples are resistant to weathering; however, steel slag has a better soundness value as compared to natural aggregate. BOF and natural aggregate have a high content of crushed particles that should provide the interlocking mechanism.

Figure 1. Comparison of natural aggregate and BOF

Table 1. Basic properties of BOF and natural aggregate

<table>
<thead>
<tr>
<th>Test</th>
<th>BOF</th>
<th>Natural Aggregate</th>
<th>Spec.</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA Abrasion (%)</td>
<td>10.26</td>
<td>17.75</td>
<td>&lt; 30</td>
<td>AASHTO T96</td>
</tr>
<tr>
<td>Flat and Elongated (%)</td>
<td>3.12</td>
<td>12.54</td>
<td>&lt; 15</td>
<td>ASTM D4791</td>
</tr>
<tr>
<td>1 : 3</td>
<td>0.52</td>
<td>3.95</td>
<td>&lt; 5</td>
<td></td>
</tr>
<tr>
<td>Bulk Gravity</td>
<td>3.41</td>
<td>2.62</td>
<td>-</td>
<td>AASHTO T85</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>2</td>
<td>1.28</td>
<td>&lt; 2</td>
<td>AASHTO T85</td>
</tr>
<tr>
<td>Soundness (%)</td>
<td>0.65</td>
<td>0.73</td>
<td>&lt; 12</td>
<td>AASHTO T104</td>
</tr>
<tr>
<td>Crushed Content (%)</td>
<td>One face</td>
<td>100</td>
<td>100</td>
<td>ASTM D5821</td>
</tr>
<tr>
<td>Two face</td>
<td>100</td>
<td>95</td>
<td>&gt;90</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Binder

Bitumen used in this study was polymer-modified binder (PMB). All properties listed in Table 2 achieve the requirements set by the roadway agency.

Table 2. Basic properties of asphalt binder

<table>
<thead>
<tr>
<th>Test</th>
<th>PMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Penetration (25°C, 0.1mm)</td>
<td>25</td>
</tr>
<tr>
<td>Viscosity (60°C, poise)</td>
<td>10,753</td>
</tr>
<tr>
<td></td>
<td>1658</td>
</tr>
<tr>
<td>Flash point(°C)</td>
<td>&gt;232</td>
</tr>
<tr>
<td>Solubility (%)</td>
<td>99.7</td>
</tr>
<tr>
<td>TFOT residue</td>
<td>0.05</td>
</tr>
<tr>
<td>Weight loss(%)</td>
<td>76</td>
</tr>
<tr>
<td>Retained penetration (%)</td>
<td></td>
</tr>
<tr>
<td>Viscosity (60°C, poise)</td>
<td>23,521</td>
</tr>
</tbody>
</table>
2.3 Gradation and Engineering Properties of Asphalt Mixtures

A total of three mix designs were performed as follows: the stone mastic asphalt with BOF (BOF-SMA), dense-graded asphalt concrete with BOF (BOF-DGAC), and dense-graded asphalt concrete with natural aggregate (NA-DGAC). The master aggregate gradation bands listed in Table 3 were based on the field test road selected. The 19-mm maximum aggregate size gradation is gapped on the 4.75-mm sieve for SMA mixtures. The percentage of mineral fillers used for SMA mixtures was 9.3 percent. Both the control mix (i.e., NA-DGAC) and the slag-modified mix (i.e., BOF-DGAC and BOF-SMA) were fabricated by the Marshall mix design procedure according to ASTM D1559. The Marshall compactor was used to compact the DGAC samples 75 times each side, but 50 times each side for the SMA samples. The optimum binder content was determined to be 5.1%, 4.3% and 5.2% for NA-DGAC, BOF-DGAC and BOF-SMA mixtures, respectively. The mixing and compaction temperatures for bitumen were selected corresponding to 0.17 and 0.28 Pa.s viscosities, respectively.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>NA-DGAC</th>
<th>BOF-DGAC</th>
<th>BOF-SMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot;(25)</td>
<td>100</td>
<td>100</td>
<td>100.0</td>
</tr>
<tr>
<td>3/4&quot;(19)</td>
<td>95</td>
<td>97.4</td>
<td>94.9</td>
</tr>
<tr>
<td>1/2&quot;(12.7)</td>
<td>82</td>
<td>78.3</td>
<td>57.9</td>
</tr>
<tr>
<td>3/8&quot;(9.5)</td>
<td>74</td>
<td>70.6</td>
<td>45.4</td>
</tr>
<tr>
<td>#4(4.75)</td>
<td>51</td>
<td>47.0</td>
<td>24.9</td>
</tr>
<tr>
<td>#8(2.36)</td>
<td>37</td>
<td>31.5</td>
<td>18.6</td>
</tr>
<tr>
<td>#16(1.18)</td>
<td>31</td>
<td>25.4</td>
<td>16.6</td>
</tr>
<tr>
<td>#30(0.6)</td>
<td>22</td>
<td>18.7</td>
<td>14.7</td>
</tr>
<tr>
<td>#50(0.3)</td>
<td>12</td>
<td>11.7</td>
<td>12.5</td>
</tr>
<tr>
<td>#100(0.15)</td>
<td>7</td>
<td>7.3</td>
<td>11.0</td>
</tr>
<tr>
<td>#200(0.075)</td>
<td>5</td>
<td>4.9</td>
<td>9.3</td>
</tr>
<tr>
<td>Binder content (%)</td>
<td>5.1</td>
<td>4.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Bulk gravity</td>
<td>2.36</td>
<td>2.81</td>
<td>2.88</td>
</tr>
<tr>
<td>Stability (kgf)</td>
<td>1111</td>
<td>1822</td>
<td>931</td>
</tr>
<tr>
<td>Flow value (mm)</td>
<td>2.2</td>
<td>3.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Voids (%)</td>
<td>4.3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>VMA (%)</td>
<td>17.6</td>
<td>11.3</td>
<td>15.9</td>
</tr>
<tr>
<td>VFA (%)</td>
<td>70</td>
<td>69.7</td>
<td>75.6</td>
</tr>
<tr>
<td>Tensile strength ratio (%)</td>
<td>80.2</td>
<td>84.3</td>
<td>84</td>
</tr>
</tbody>
</table>

Note that the bulk specific gravity of BOF mixtures is much higher than that of natural-aggregate-based mixtures. This is due to the fact that BOF possesses higher density. An increase in stability is observed for the BOF-DGAC mix as compared to the NA-DGAC mix. The SMA-BOF mix had the highest asphalt content among three mixtures because of its high bulk gravity after the bulk specific gravity was taken into consideration. BOF mixes may provide higher stability values because steel slag would include angular and rough textured particles that could increase the interlocking friction. The tensile strength ratio shows the superior moisture sensitivity of BOF-based asphalt mixtures to natural-aggregate-based mixtures.
2.3 Strength of Asphalt Mixtures

The resilient modulus and the indirect tensile tests were conducted to evaluate the strength of the porous asphalt mixtures. The repeated-load indirect tension test for determining the resilient modulus was conducted by applying compressive loads with a haversine waveform according to ASTM D 4123. The load was applied vertically in the vertical diameter plane of a cylindrical specimen of asphalt concrete through a curved loading strip. The resulting horizontal deformation was measured and used to calculate the total resilient modulus (Mr) and the indirect tensile strength (IDT). The indirect tensile strength is defined as the maximum stress from a diametric vertical force that a Marshall sample can withstand.

Figure 2 shows that BOF-DGAC mixes exhibit higher indirect strength and resilient modulus than NA-DGAC. As listed in Table 3, the stability value of BOF-DGAC mix is about 2 times higher than that of the NA-DGAC mixes. Test results indicate that BOF could help provide better adhesion between steel slag and bitumen. It appears that the addition of BOF contributes to the increase in the indirect tensile strength and the resilient modulus of dense-graded asphalt mixtures than that of nature aggregate. Since SMA a gap-graded bituminous concrete, the resilient modulus and the indirect tensile tests cannot properly represent the engineering properties of SMA.

2.5 Permanent Deformation of Asphalt Mixtures

A wheel-tracking test was performed to evaluate the rutting characteristics of porous asphalt concrete. The porous asphalt slab was rigidly restrained in a 300mm×300mm×50mm steel mold. The wheel driven by a motor and a reciprocating device loaded the slab bi-directionally. At a rate of 42 cycles/min., the wheel covered a loading distance of 230±10mm. The vertical deformation at the middle of the slab was recorded. For the standard test condition, loading pressure was 700kPa at temperature 60°C under dry conditions. The dynamic stability (DS) used to characterize the rutting resistance of each mix is calculated as follows:
\[ DS = \frac{t_2 - t_1}{d_2 - d_1} \times N \]  

(1)

where,
\[ d_1 \]: deformation at \( t_1 \) minutes (mm),
\[ d_2 \]: deformation at \( t_2 \) minutes (mm), and
\[ N \]: speed of the wheel, 42 cycle/mm in this study.

Default values of \( t_1 \) and \( t_2 \) were used in this study, which are at 45 and 60 minutes, respectively. Figure 3 represents the average rut depth curve of each mix from the wheel-tracking test. The rut depth of the porous asphalt mix appears to be sensitive to gradation and aggregate type as shown in Figure 3. The rut depths at 6,000 cycles were less than 5 mm for all mixes, and were considered acceptable. With the use of BOF, there is greater resistance to permanent deformation than the mix fabricated with natural aggregate, because BOF steel slag has a rougher surface texture than natural aggregate. Figure 3 shows that NA-DGAC has a rut depth curve similar to that of BOF-DGAC, indicating that the dense gradation did not significantly improve the resistance of asphalt mixtures to rutting. The most significant reduction on rutting occurs at the use of the SMA gradation. The dynamic stability (DS) value is 1635, 2263 and 3568 cycle/mm for NA-DGAC, BOF-DGAC and BOF-SMA mixtures, respectively. The dynamic stability greater than 1500 cycle/mm is recommended for a hot-mix asphalt mixture. Rough surfaced angular particles of BOF steel slag help develop high internal friction and good particle interlock, which contribute to high stability when used as aggregate for bituminous mixes. This observation corresponds well with the test results obtained from the indirect tensile strength and resilient modulus.

![Figure 3. Rut depth changing with load repetitions](image-url)
3. CONSTRUCTION OF TEST SECTIONS

3.1 Pavement Structures

All three test sections investigated in this study are located in the southern region of Taiwan. The stone mastic asphalt with BOF (BOF-SMA), dense-graded asphalt concrete with BOF (BOF-DGAC), and dense-graded asphalt concrete with natural aggregate (NA-DGAC) test sections are located adjacent to each other on an urban roadway. These three mixtures were used to build test pavements about 750 m long with each section of about 250 m. The researchers and the field engineers design the test scheme to only compare the effect of mixture types on pavement performance. Therefore, the pavement thickness has to be kept constant throughout the test road. All other variables (i.e., geometric and structural design) were held constant. Each section was consisted of a 10-cm asphalt surface course over a 30-cm coarse aggregate base course as shown Figure 4. The surface course was constructed with two 5-cm lifts thickness including tack coat and prime coat sprayed in between to achieve smooth requirements.

![Figure 4. Pavement structure of test sections](image)

3.2 Constructability

Quality control of hot-mix asphalt mixture begins with the stockpiles of aggregate that were to be processed through the asphalt plant and incorporated into the mix. To reduce the amount of moisture that accumulates in BOF, especially from rain, a roof or a shed should be provided to cover the BOF stockpiles. The moisture content inside BOF will directly affect the quality of asphalt concrete as well as field performance.

The mixing plant was a 2,000-kg batch plant that produced mix at 120 ton/hr. The BOF steel slag was added to the mix like the natural aggregate, substituted for the 4.75- to 19-mm aggregate. The mix was dropped into end-dump semi-trucks and hauled to the paving site, about 30 minutes away.

End-dump semi-trucks laid the mix in a hopper in front of a paving machine. For the NA-DGAC and BOF-DGAC test sections, compaction was provided with a 12-ton pneumatic-tired roller making six passes, and a 10-ton vibratory roller making two passes in vibratory mode and two passes in static mode. The finish roller was an 8-ton steel wheel roller which made at least two passes. During construction, it was observed that the mix containing the steel slag aggregate held the temperature longer than the conventional mix.

Only steel rollers were used to compact the BOF-SMA section. Breakdown rolling
began immediately behind the paver, and the roller stayed close behind the paver at all times. Six passes in static mode were needed to seat the BOF-SMA test section because over-rolling could lead to aggregate breakdown. Due to the gap-graded nature of the SMA mix, there is extensive stone-to-stone contact between the coarse aggregate particles, with very few fine materials to cushion the coarse aggregates. Pneumatic-tired rollers are not allowed for use on SMA. The rubber tires tend to pick up the mortar causing surface deficiencies.

4. PERFORMANCE CHARACTERISTICS

All test sections were completed in March 2012 with typical construction equipment and operations. This urban road has four lanes and an average traffic volume of 36,000 vehicles per day with about 15% truck traffic. The test sections are heavily trafficked, and the terrains are essentially straight and level. The relative humidity during testing also varies from 50 to 90% with annual average rainfall of about 2000 mm. Following construction, distress surveys have been conducted on a regular basis on each section during trafficking. The surveys of pavement performance included friction, rutting and ride quality.

4.1 Friction

Pavement skid resistance was measured by the British Pendulum Tester according to ASTM E303 and expressed by a British Pendulum number (BPN) as shown in Figure 5. The tests were all adjusted by the exact pavement temperature at measurement to an equivalent BPN value at 20°C, as shown in Figure 5. BOF-SMA1 and BOF-SMA2 are two different locations subject to high stress induced by braking and turning vehicles at the intersection, respectively. BOF-SMA2, BOF-DGAC, and BOF-NA are located adjacent to each other on the same segment of a street.

![Figure 5. Measurement of pavement friction](image-url)
The measurement of the friction showed an initial BPN of 6.5 to 6.8. Skid resistance was relatively low just after construction because of asphalt binder film coating the aggregate at the pavement surface. As a consequence of the disappearance of the binder film covering the surface of the aggregate, skid resistance was improved after test sections open to traffic. A BPN value higher than 45 is considered sufficient and safe for roadway pavements. According to test results in Figure 6, all three test sections provide good wet weather friction. The BPN value of test sections built with BOF appear to provide good skid resistance after one year in service. Because of the significant amount of macrotexture produced within BOF-SMA pavement surfaces, BOF-SMA layers maintained adequate frictional characteristics even after pavements become condensed. There was no significant difference in friction characteristics among these three mixtures.

![Figure 6. Test results of pavement friction](image)

4.2 Rutting

A rut is a surface depression in the wheel path. The mean rut depth is calculated by laying a straightedge across the rut, measuring its depth, then using measurements taken along the length of the rut to compute its mean depth in millimeters, as shown in Figure 7.
The test results of permanent deformation on pavement surfaces are shown in Figure 8. Pavements exhibited significantly higher rut depth before construction. Rutting slowly increases with increasing service time after construction. Rutting of these test sections stems from the permanent deformation of the pavement surface, primarily caused by consolidated movement of asphalt mixtures due to traffic load. The severity level is considered to be low when the mean rut depth is less than 12.5 mm, moderate when rutting is between 12.5 and 25 mm, and high when rutting is higher than 25 mm.

With the rut depth lower than 12.5 mm, test results indicate that all test sections possesses good resistance to plastic deformation. In particular, the BOF-SMA section has a coarse gradation that results in stone-on-stone contact. Rutting ranged from 4 mm for the BOF-SMA section to 8 mm for the NA-DGAC section after one year in service. The rut depth of the NA-DGAC section was highest among the three sections, that of BOF-SMA the lowest, and that of BOF-DGAC in between. In the BOF-SMA section, the angularity and toughness of BOF was shown to improve the rutting resistance of SMA mixtures.

Asphalt cement is a highly hydrophobic substance and is capable of forming an immobilizing barrier that can prevent any pollutant from leaching out from BOF into the environment. The use of BOF steel slag as aggregate is shown to present appropriate technical solutions for road applications, which could ensure both an excellent level of performance together with a harmless environmental impact.
4.3 Ride Quality

Roughness is an important index of pavement performance evaluation, which affects the comfortableness of drivers and passengers. It is an index involving human-vehicle-road interaction, and often evaluated by the International Roughness Index (IRI), as shown in Figure 10. The ICC Surface Profiler used in this study is a multi-wheeled inclinometer-based system that is pushed by an operator at a walking speed of 1.2 km/h.

For these sections, the IRI value expressed by m/km increased with time as shown in Figure 11. It is required that the IRI value of a roadway after construction be lower than 3.5 m/km. All test sections meet the specification requirement. The IRI value of BOF-SMA was the lowest, while the roughness of NA-DGAC was larger than that of BOF-DGAC. The
increase in the international roughness index (IRI) corresponds well with the increase in rut depth. No raveling, cracking or other failures have been observed on the BOF-SMA section to any significant extent since open to traffic. Test results suggest that BOF-SMA be a viable pavement surface type for use on roads to provide good performance, including good friction, reduced rutting, and improved durability.

Figure 11. Test results of ride quality on pavement surface

4.4 Overall Performance

A comparison of rutting, skid and ride quality testing reveals differences in performance between control and steel slag pavements. No raveling, cracking or other failures have been observed on the BOF-SMA section to any significant extent since open to traffic. Test results indicate that BOF-SMA is a viable pavement surface type for use on roads to provide good performance, including good friction, reduced rutting, and improved durability. According to field observations, BOF is well encapsulated by a rich mortar binder in SMA.

5. CONCLUSIONS AND RECOMMENDATIONS

This paper is to evaluate the engineering properties of hot-mix asphalt mixtures in laboratory, and compare field performance of flexible pavements constructed using two types of aggregate. These two aggregate types were limestone as natural aggregate, and basic oxygen furnace steel slag (BOF). Test sections made of dense-graded asphalt concrete (DGAC) and stone asphalt mastic (SMA) were produced and constructed when BOF steel slag was used to replace coarse aggregate in asphalt pavements. On the basis of the test results and the performance survey conducted in this work, the following conclusions and recommendations appeared warranted.
• BOF steel slag could meet the specification requirements set by the highway agency as aggregate for road construction. The BOF-DGACE mix had the highest indirect tensile strength and the highest resilient modulus since the BOF steel slag could help provide better adhesion between aggregate and asphalt binder.
• The BOF-SMA mix had the best resistance to permanent deformation because BOF steel slag has a rougher surface texture than natural aggregate. Using conventional paving techniques, test sections were successfully constructed with steel slag replacing coarse aggregate in hot-mix asphalt mixtures.
• The BOF-SMA section exhibited superior performance compared with the control section built with natural aggregate. Field data indicated that the use of BOF as aggregate is a viable option for hot-mix asphalt mixtures.
• The gradation of the steel slag should be monitored to assure that a uniform mixture of hot-mix asphalt concrete is produced. To reduce the amount of moisture that may accumulate in BOF, especially from rain, a roof or a shed needs to be provided to cover the BOF stockpiles at an asphalt plant.
• The specific gravity of the produced slag aggregate should be monitored. Care should be taken to unit weights of asphalt concrete mixed with BOF when calculating bid quantities for overlay construction.
• Due to limited period of survey time, more field data should be collected to address the long-term performance of steel slag as aggregate for asphalt pavements.

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