Technical Effects of Air Cooled Blast Furnace Slag on Asphalt Mixtures

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Abstract
Air cooled blast furnace slag is a by product made of gradually air cooled molten blast furnace slag and is often stored in stockpiles near the iron mills and usually occupy a wide area around the iron mills. From this perspective the further use of these materials can have its own merits. Air cooled blast furnace slag can be used in asphalt mixtures because of their proper frictional properties. This research is conducted to investigate the effect of air cooled blast furnace slag on technical characteristics of asphalt mixtures and compare the results with the traditional asphalt mixtures. Two series of Marshal and Texas Boiling Tests were carried out in the laboratory. Three types of aggregates (air cooled blast furnace slag, siliceous gravel, lime gravel) with two types of dense graded and open graded were used. The frictional properties of the asphalt mixed with air cooled blast furnace slag materials were evaluated by using the British Pendulum, and the Sand Patch Method. Resistance to moisture was also determined in accordance to Texas Boiling Test. Results showed that by increasing percentage of air cooled blast furnace slag in asphalt mixtures, Marshall Stability, flexibility and skid resistance augmented. Also Texas Boiling Tests indicated that asphalt mixtures have a good resistance to stripping.

Keywords: Slag, air cooled blast furnace slag, asphalt mixtures, skid resistance

1. Introduction
Usage of industrial by-products and wastes is important from different points of view. It helps saving and sustaining the natural resources that are not replenished. It will reduce the pollution of the ecological surroundings. Also it helps saving and recycling the spent energies in production process. Air cooled blast furnace slag materials can be used as fine or coarse aggregates in asphalt mixtures. In spite of plentiful existence of this type of material, the mere problem with using this type of material is still the limiting distance from the storage deposits which is usually about 50 to 100 Km. [1]. Air cooled blast furnace slag has premium physical and mechanical properties. The main advantages of asphalt mixtures containing air cooled blast furnace slag materials are as follows:

a) The pH of air cooled blast furnace slag is between 8 to 10 and because of this high pH, it has good binding property when used with bituminous materials [1]. The chemical reaction of acidic bitumen and alkali aggregate will cause the mixture to be impermeable to humidity and contribute a high resistance to stripping [2].

b) The crushed and angular appearance and surface roughness of the air cooled blast furnace slag aggregates cause rutting resistance which is also advantageous for highways, industrial roads and parking areas subjected to heavy axial loads [3].

c) According to BS812, Part 3, the air cooled blast furnace slag aggregate has a high polished stone value (PSV) [4]. Therefore, the asphalt mixtures containing air cooled blast furnace slag has a high skid resistance. Most of aggregates used in asphalt mixtures show a good skid resistance at the beginning of the pavement services. However, heavy traffic makes them abrasive and causes lose their skid resistance. Marek reported that 50% of the initial skid resistance is lost during the first two years of pavement services and mentioned that the unique important factor that affects reduction of skid resistance is the polishing characteristics of aggregates used in the asphalt mix [5]. Therefore, usage of aggregates with high skid resistance and durability is vital for road safety.

2. The Laboratory Research Program

For evaluation of physical and mechanical characteristics of air cooled blast furnace slag and comparing the results with siliceous and lime gravels, several tests including specific gravity, shape, resistance to aggregate impact value, resistance to aggregate crushing value, Los Angeles abrasion and friction were conducted. To evaluate the asphalt mixtures characteristics containing air cooled blast furnace slag, Marshall specimens were made in accordance to ASTM D3515 and ASTM D1559 standards in two forms of open graded and dense graded with nominal maximum particle size of 12.7 mm [6]. For evaluation of resistance to stripping for similar mixtures, Texas Boiling Tests were performed in accordance to ASTM D3625. To compare frictional characteristics of the asphalt mixtures consisting of macro and micro textures, English Pendulum Method tests were carried out for micro textures in accordance to ASTM E303-93 and ASTM E965-87 for macro textures.

2.1 Types of Materials

2.1.1 Aggregate

Three types of aggregates have been used to carry out a series of tests. The first type was the air cooled blast furnace slag and the other two were siliceous and lime gravel aggregates. Air cooled blast furnace slag was obtained from Iron Mill Factory situated in Isfahan, central part of Iran. Due to lack of fine materials in air cooled blast furnace slag, Portland cement type II is used for asphalt mixture. The gradation of the test specimens were analyzed in accordance to ASTM D3515 standard and were open and dense graded. The results of sieve analysis of materials for making asphalt mixtures are given in Tables 1 and 2.

2.1.2 Bitumen

The bitumen used in this research was pure bitumen with penetration degrees of 60 to 70 and was obtained from Tehran refinery. The specifications of the pure bitumen used in this study are shown in Table 3.

3. Laboratory Tests Performed on Aggregates

To compare the specifications of air cooled blast furnace slag with siliceous and lime aggregates, laboratory tests including specific gravity, shape and resistance tests were performed on samples. The results of tests performed on three types of aggregates are shown in Tables 4 through 6. The results show that, the air cooled blast furnace slag has often cubic shape and a larger specific gravity compared to siliceous and lime aggregates. Meanwhile, the results indicate that the resistance of air cooled blast furnace slag is lower than siliceous aggregate and higher than lime.

4. Marshall Specimens

In order to find optimum bitumen for gradation specified in Tables 1 and 2, Marshall specimens were made and tested according to ASTM D1559 [6]. Aggregates and bitumen were heated at temperatures of 140 and 180 C° respectively and then were compacted with 75 blows of Marshall Hammer on each side. The bulk specific gravity of the specimens was measured according to ASTM D2726-88. The specimens were kept at ambient temperature for one day. To carry out the Marshall stability tests, the samples were kept in water bath at 60 C° for 30 minutes. Apparent specific gravity of the samples was measured according to ASTM D2041-90 and then the air voids were computed. The results of Marshall test specimens showed that they are satisfied by the design criteria of MS-2 publication of specifications [7]. The optimum bitumen content was determined according to the Marshall stability, percentage of void spaces of compacted specimens, specific gravity and Void Field Asphalt (VFA). The results of optimum bitumen content for different aggregates are shown in Tables 1 and 2.

Table 1. Dense Graded Aggregate Used for Asphalt Mixtures

Sieve Size	Percent passing							
	Air Cooled Blast Furnace Slag (A)	Siliceous Sand (S)	No.1 0.7A+0.3S	No.2 0.6A+0.4S	No.3 0.5A+0.5S	No.4 0.4A+0.6S	No.5 Natural Aggregate	Allowable Limit ASTM D3515
¾"	100	100	100	100	100	100	100	100
½"	95	100	96.5	97	97.5	98	95	90-100
⅜"	85	100	89.5	91	92.5	94	85	-
No.4	44	95	59.3	64.4	69.5	74.6	59	44-74
No.8	6	85	29.7	37.6	45.5	53.4	43	28-58
No.16	6	70	25.2	31.6	38	44.4	27	-
No.30	6	50	19.2	23.6	28	32.4	13	-
No.50	6	11	7.5	8	8.5	9	13	5-21
No.100	6	1	4.5	4	3.5	3	8	-
Mineral filler	6	0	4.2	3.6	3	2.4	5	2-10
Percentage of optimum bitumen			6.2	6	5.8	5.9	5.6	-

Table 2. Open Graded Aggregates Used for Asphalt Mixtures

Sieve size	Percent passing					
	Air Cooled Blast Furnace Slag (A)	Siliceous Sand (S)	No.6 100% A	No.7 0.85A+0.15S	No.8 Natural Aggregate	Allowable Limit ASTM D3515 for Open Graded
¾"	100	100	100	100	100	100
½"	90	100	90	91.5	85	85-100
⅜"	65	100	65	70	60	60-90
No.4	20	90.5	20	30.5	20	20-50
No.8	5	47.5	5	10.5	5	5-25
No.16	4	47.5	4	10	3	3-19
No.30	4	7.5	4	4.5	3	-
No.50	4	7.5	4	4.5	3	0-10
No.100	4	7.5	4	4.5	3	-
Mineral filler	4	7.5	4	4.5	3	-
Percentage of Optimum bitumen			5.4	5.7	5.9	-

Table 3. Bitumen Specifications used in Asphalt Mixtures

Bitumen Specification	Standard Used	Amount
Specific Gravity	ASTM D70	0.98
Degree of Penetration (x 0.1 mm.)	ASTM D5	64
Softening Point, (°C)	ASTM D36	50
Ductility (cm.)	ASTM D113	>100

Table 4. Specifications of Specific Gravity and Absorption of Water by Aggregates Retained on Sieve No. 8

Types of Aggregate	Standard Used	Bulk Specific Gravity	Water Absorption (%)
Air Cooled Blast Furnace Slag	ASTM C127-77	2.78	3.1
Siliceous Gravel		2.44	3.3
Lime Gravel		2.28	3.9

Table 5. Shape Characteristics of Aggregates

Types of Aggregate	Standard Used	Percentage of Lamination For 9.5 mm Grains (%)	Percentage of Elongation For 9.5 mm Grains (%)	Maximum Limit (%)
Air Cooled Blast Furnace Slag	BS812-part 1	8.1	3.7	25
Siliceous Gravel		21.4	18.9	
Lime Gravel		22.7	20.8	

Table 6. Resistance Characteristics of Aggregates

Types of Aggregates	Aggregate Characteristics	Standard Used	Result	Maximum Limit (%)
Air Cooled Blast Furnace Slag	Aggregate Impact Value (AIV) %	BS812-Part 112	18.6	30
Siliceous Gravel			14.5	
Lime Gravel			23.8	
Air Cooled Blast Furnace Slag	Aggregate Crushing Value (ACV) %	BS812-Part 110	21	25
Siliceous Gravel			15.5	
Lime Gravel			27	
Air Cooled Blast Furnace Slag	Los Angeles Abrasion %	ASTM C131-76	27	40 to 45 According to AI Standard
Siliceous Gravel			19	
Lime Gravel			27	

4.1 Analysis of Marshall Test Results

4.1.1 Dense Graded Materials

In this series of tests, five Marshall Samples with different percentage of air cooled blast furnace slag and siliceous sands were made. The Marshall test results showed that by increasing the percentage of air cooled blast furnace slag, the Marshal stability and specific gravity will increase. This is shown in figures 1 and 2. Meanwhile, the Figure 2 shows that the Marshall stability of asphalt mixtures containing air cooled blast furnace slag has higher values, compared to the asphalt mixtures containing siliceous aggregates.

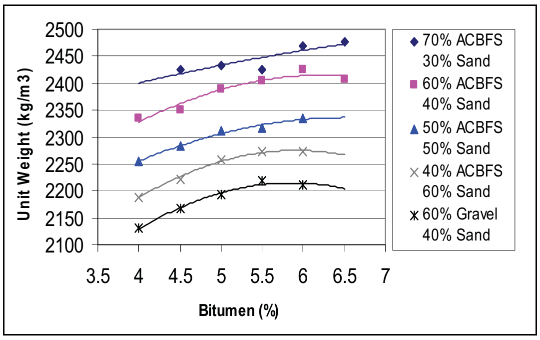

Figure 1. Specific Gravity for Five Types of Asphalt Mixtures

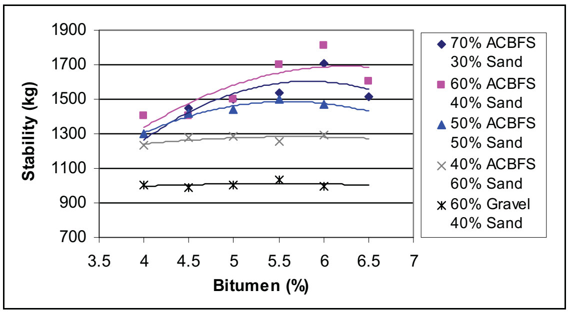

Figure 2. Marshall Stability for Five Types of Asphalt Mixtures

Figure 3 shows that the percentage of voids in mineral aggregates (VMA) is reduced by air cooled blast furnace slag. The reason is due to the existence of lower lamination and elongation increased of the air cooled blast furnace slag. The minimum voids of mineral aggregates recommended by Asphalt Institute are 14 percent for gradation of nominal maximum particle size of 12.7 mm. The results show that the VMA of asphalt mixtures made with air cooled blast furnace slag is above the limit value given by the Asphalt Institute.

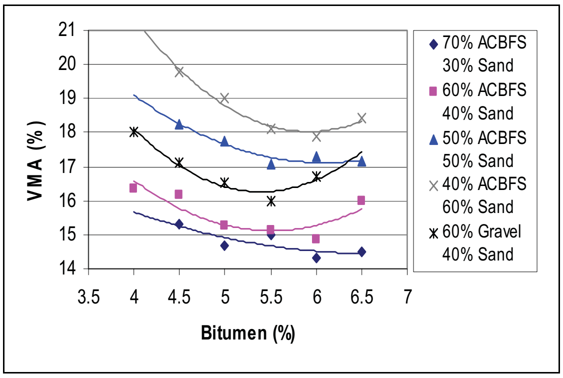

Figure 3. the Voids in Mineral Aggregates for Five Types of Asphalt Mixtures

Figure 4 indicates that with increase of air cooled blast furnace slag, the asphalt flow and its flexibility increases. The changes in the configuration of the curves also show that the asphalt mixtures with air cooled blast furnace slag are in the range limited by the Asphalt Institute.

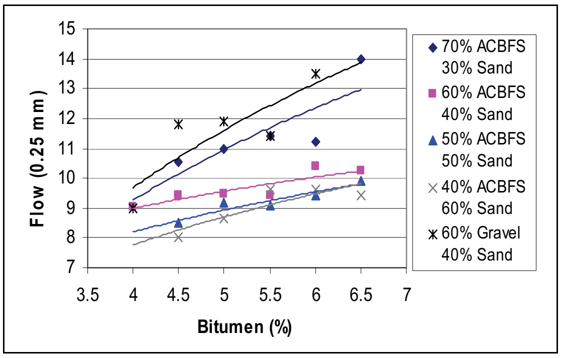

Figure 4. Flow Curves for Five Types of the Asphalt Mixtures

4.1.2 Open Graded Materials

At this stage three series of Marshall Specimens with different percentage of air cooled blast furnace slag were tested. The sieves analyses of these samples are denoted by No.6, No.7 and No. 8 and are given in Table 2.

The results shown in Figure 5 indicate that, the stability of the porous asphalt mixtures containing air cooled blast furnace slag has higher values than the asphalt mixtures containing natural aggregates. This is the benefit of the porous asphalt while, the greatest weakness of the porous asphalt mixtures are their low stability.

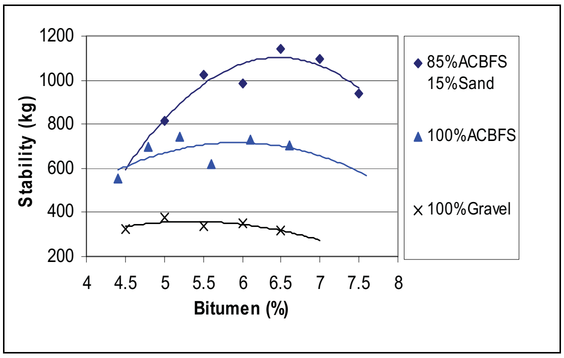

Figure 5. Marshall Stability of Three Types of Porous Asphalt Mixtures

5. Resistance to Deterioration

To investigate the resistance of asphalt mixtures to moisture, the Texas Boiling Tests were used according to ASTM D3625 [6]. In these series of tests, six types of asphalt mixtures were made. These series included two test samples with siliceous aggregates, two with air cooled blast furnace slag and two with lime aggregates. The bitumen used in these samples was pure bitumen with penetration grade of 60-70. To recognize the stripping of the material easily, the grains larger than 2.36 mm (sieve No. 8) were used. After mixing the aggregates with bitumen at average temperature of 160 C° and cooling them at ambient temperature, the mixture was inserted in boiling water for ten minutes. Then, the samples were left at room temperature for one day and then with counting the stripped grains, the percentage of stripped materials was calculated. The test results are shown in Figure 6.

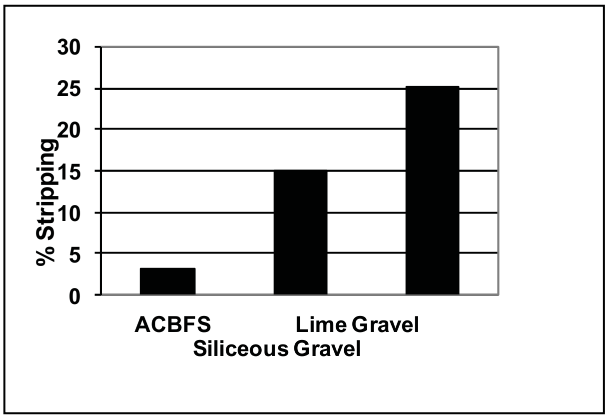

Figure 6. Results of Texas Boiling Tests

Figure 6 shows that asphalt mixtures containing air cooled blast furnace slag have a good performance against stripping. Furthermore, after curing, the air cooled blast furnace slag can be used in the porous asphalt mixtures in the rainy areas or places with high humidity

6. Skid Resistance

To evaluate the skid resistance of asphalt mixtures made with air cooled blast furnace slag, two types of dense graded and open graded mixtures with different percentages of air cooled blast furnace slag and natural aggregates (description shown in Tables 1 and 2) were made. The size of the made samples were 50×100×150 mm. In these series of tests the skid resistance characteristics of the two different types of textures (micro and macro) were investigated. To evaluate the micro texture in wet condition, the English Pendulum Method was used according to ASTM E303-93 and the BPN numbers for each test were calculated.

Figures 7 and 8 show the result of English Pendulum Tests for different sample gradation mixtures. According to Road Publication Note 27, the allowable limited BPN for three groups of roads are given in Table 8.The durability of the micro texture against traffic is measured according to PSV indicator. For evaluation of the macro texture and according to ASTM E965-96, the sand patch method was used and texture depth for each sample was determined. Figures 9 and 10 show the results of the sand patch tests. Also the durability of macro texture against traffic was analyzed according to the aggregate abrasion value (AAV).

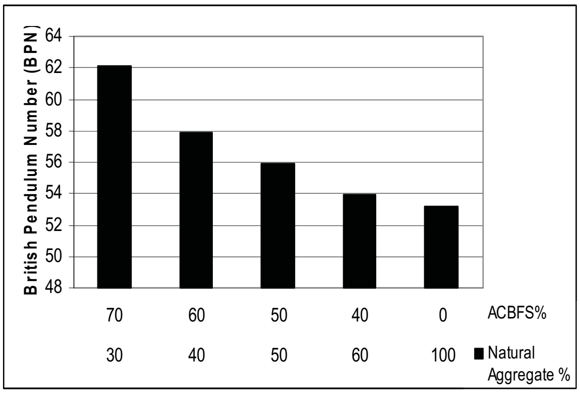

Figure7. BPN Figures for Dense Graded Samples

Figures 7 and 8 show that skid resistance has direct correlation with the amount of air cooled blast furnace slag. Comparing BPN number of the open graded asphalt containing air cooled blast furnace slag with the allowable limit is given in Table 7. It is clear that at least 50% of the air cooled blast furnace slag in asphalt mixtures can be used for heavy traffic roads.

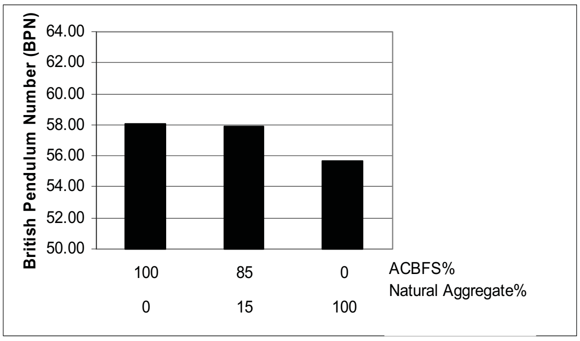

Figure 8. BPN Figures for Open Graded Samples

Table 7. Minimum BPN for Wet Conditions [8]

Category	Site Situation	Minimum skid resistance (wet surface)
A	Difficult sites such as: 1. Roundabouts 2. Bends with Radius less than 150m. on unrestricted roads. 3. Gradients Greater than 1 to 20 or lengths greater then 100m. 4. Approaches to Traffic Lights on Unrestricted Roads	65
B	Motorways, Trunks and Class 1 Roads and Heavily Trafficated Roads in Urban Areas (Carrying more than 2000 Vehicles Per Day)	55
C	All other Sites	45

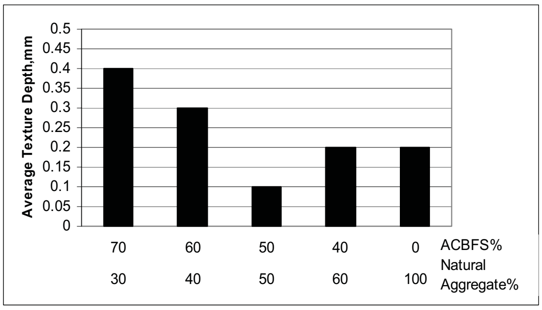

Figure 9. Depth of Texture for Dense Graded Samples

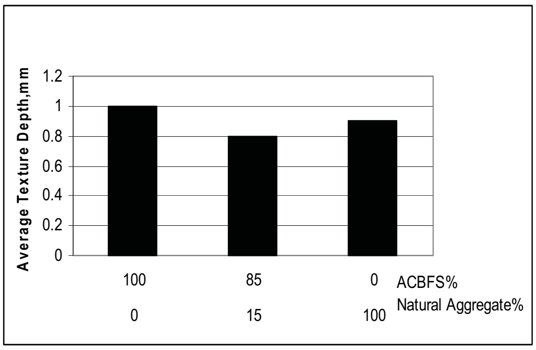

Figure 10. Depth of Texture for Open Graded Sample

7. Summary

Based on large production of air cooled blast furnace slag in iron and steel foundries, and due to good physical properties and skid resistance of these types of materials, special attention have been paid to the using of air cooled blast furnace slag in asphalt mixtures in recent years.

Using air cooled blast furnace slag in asphalt mixtures contribute both skid and stripping resistance. These two properties are very important for asphalt mixtures and few aggregates are able to have these two properties together.

Stripping phenomena appears more often in porous asphalt mixtures. So using air cooled blast furnace slag aggregates will improve stripping and revealing the failure of the porous asphalt mixtures.

The Marshall Laboratory Tests showed that, Marshall Stability is higher when air cooled blast furnace slag is used in asphalt mixtures. Since the porous asphalt mixtures have low Marshall Stability, therefore using air cooled blast furnace slag aggregates will improve Marshall Stability.

8. Conclusions

The research carried out concluded to the following results:

1. The results of Marshall Tests showed that by increasing the percentage of the air cooled blast furnace slag aggregates, the Marshall Stability increases in asphalt mixtures and compared to other aggregates used in asphalt mixtures has more stability.

2. Test results of Texas Boiling for asphalt mixtures containing air cooled blast furnace slag showed higher resistance to stripping.

3. Test results for skidding showed that, the skid resistance increases by increased air cooled blast furnace slag.

4. Using the air cooled blast furnace slag in porous asphalt contributes in higher Marshall Stability, compared to the natural aggregate asphalt, mixtures (Figure 2).

9. References

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