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Assessment of an Asphalt Mixture employing a Blast Furnace Slag Pretreated with a Polymer

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Abstract

Blast furnace slags (BFS) could be used as substitutes of the coarse fraction of natural aggregates (NA) in the production of hot mix asphalts (HMA). However, its high porosity and absorption are generally seen as disadvantages in HMAs. For this reason, this study used a polymer employed in soil stabilization processes in order to partially fill the air voids of a BFS. Then, this pre-treated BFS material (BFS-SMK) substituted the coarse fraction of a NA in an HMA. The mechanical resistance and the moisture damage resistance was evaluated performing Indirect Tensile Strength and Marshall Tests. Additionally, Cantabro and resilient modulus tests were performed. An ANOVA - analysis of variance was carried out. As a general conclusion, the BFS-SMK could be used as a substitute material for NA in HMA.

Keywords: *Soiltech MK III, asphalt mixture, blast furnace slag, polymer*

1. Introduction

Blast furnace slags (BFS) are produced in huge quantities as waste in the iron production. BFSs can be used as substitutes of natural aggregates (NA) in road and highway projects. This waste material is highly heterogeneous nature with complex characteristics and properties [1], and they have interesting properties such as similar chemical composition with the clinker, low unit weight, particles with rough surface texture and high angularity, and good compatibility with the bitumen [2]. According to [3-10], BFSs produces aggregates with high rough texture and porosity, angular form, good compatibility with asphalt binders, and greater consumption of asphalt. However, these materials have some disadvantages when are used in hot mix asphalts (HMA). The main disadvantage is the greater absorption and consumption of asphalt due to its high surface and inter-granular porosity [2-6]. Another disadvantage is its low wear resistance in abrasion tests like Los Angeles and Micro-Deval [2]. In order to solve these problems, BFS porosity could be filled with a material compatible with the asphalt.

The present study used a polymer in order to fill the air voids of a BFS (BFS-SMK) to later be used as replacement for the coarse NA fraction in the manufacture of an HMA called MDC-19 by [11]. On MDC-19 (HMA type), an experimental program was performed to evaluate the resistance under monotonic and cyclic load, and the resistance to abrasion and moisture damage. An ANOVA (analysis of variance, with a confidence level of 95%) was performed to assess whether BFS-SMK caused statistically significant effects on the properties analyzed in the MDC-19.

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The polymer used is Soiltech MK III (SMK). This material is used mainly in soil stabilization processes (mainly base and sub-base layers) for road construction projects. Additionally, it is used in the potholes repair for asphalt or concrete pavements. This material was chosen in this study due to its coating, bonding and waterproofing properties. Further, it gains strength from mechanical compaction and does not become brittle when cured because it is an elastomeric polymer type. This polymer has the ability to dissolve in water, it uses water as a carrier to lubricate the particles, its color is dark brown and it is not a flammable. According to Ranjitha et al. [12] and Giridhar et al. [13], SMKs pH ranges from 8 to 9, the boiling point is 100 °C approximately, the specific gravity is greater to 1.0 and its density is 1.05 g/cm^3 at 23 °C.

2. Materials and Methods

2.1. Materials

The BFS used (Figure 1a) is an air-cooled type (ACBFS, slowly cooled outdoors), produced in Colombia. Visually and comparing with the natural aggregate (NA) used (Figure 1b), the BFS particles have more air voids.

a) b)

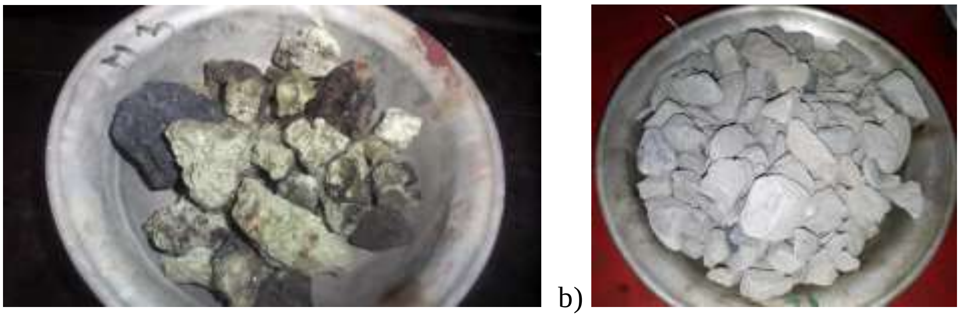

Figure 1. Particles of a) BFS; b) NA

The NA, the BFS and the AC 60-70 were evaluated following the [11] standard (Tables 1 and 2). Specific gravity (Sg), absorption (Ab), fractured particles (F), flattening and elongation index (FI and EI, respectively), plasticity index (PI), 10% of fines (10%F), Micro-Deval (MD) and Abrasion in Los Angeles machine (LA) of NA and BFS were obtained following AASHTO T85, ASTM D5821, NLT 354, ASTM D4318, DNER-ME-096, AASHTO T327, AASHTO T 96 standards. It is observed that BFS undergo low wear resistance based on abrasion tests (LA and MD). However, they have good resistance to crushing (10%F). Besides, particles of BFS have good geometry.

Table 1. NA and BFS test results

Material	Sg (-)	Ab (%)	F (%)	FI (%)	EI (%)	PI (%)	10%F (kN)	MD (%)	LA (%)
NA	2.52	1.62	89	8.92	7.63	0.0	133.2	18.8	23.7
BFS	2.11	4.50	93	4.70	3.04	0.0	111.1	33.7	47.2

Table 2. AC 60-70 characterization

Test, Standard	Result

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Penetration (mm/10), ASTM D5	62.5
Penetration Index (-), NLT 181	-0.94
Viscosity at 60 °C (Poises), ASTM D4402	1770.3
Softening point (°C), ASTM D36	49.1
Flash and fire points (°C), ASTM D92	289.4
Ductility (cm), ASTM D113	135
Sg (-),AASHTO T228	1.012

2.2. Control MDC-19 design

The control MDC-19 (using NA as aggregate) was designed based on Marshall Test (AASHTO T245-15). 75 blows per face were applying in order to compact each sample. The particle size distribution is displayed in Figure 2. Three samples were manufactured and tested for each percentage (in mass) of asphalt to obtain the optimum asphalt content (OAC). The mixing (MT) and compaction (MC) temperatures were 150±3 °C and 140±3 °C, respectively. MT and MC were obtained based on viscosity tests. Volumetric composition of HMAs was obtained based in the AASHTO T269-14.

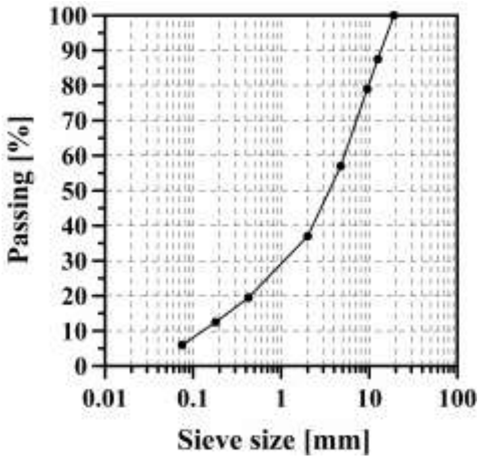

Figure 2. Particle size distribution curve (MDC-19)

2.3. BFS treatment with SMK

Traditionally, SMK is mixed with water in a proportion ranging between 0.2% and 1% (in order to estimate the optimum dosage). However, this proportion is used in soil stabilization processes, in which all particles are not covered by the polymer. In this study, it is necessary to try to coat completely the particles with the polymer. For this reason, a ratio of SMK/water of 1/3 in volume was chosen by trial and error, taking into account that all BFS particles were totally covered and bonded with the polymer. SMK and water were mixed thoroughly in a laboratory tray. The BFS were submerged into the polymer and kept there during 24 hours. The temperature of SMK and water was maintained in 20 °C. The BFS particles covered with the polymer were called BFS-SMK (Figure 3). BFS-SMK particles were characterized in a similar way to NA and BFS. Specific gravity and absorption of BFS particles were 2.12 and 2.4%, respectively. Micro-Deval and Abrasion in Los Angeles machine test results were 23.5% and 31.7%, respectively. Compared to BFS, BFS-SMK particles decreased adsorption, the specific gravity remained similar and the abrasion resistance increased.

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Figure 3. BFS-SMK particles

2.4. Marshall and Indirect Tensile Strength (ITS) tests

Marshall Tests were performed on samples made with the OAC but replacing in mass 12.5% (material retained in sieve ½”), 21% (material retained in sieve 3/8”) and 43% (material retained in sieve No. 4) of the NA by BFS (called MDC-BFS12.5, MDC-BFS21 and MDC-BFS43, respectively) and BFS-SMK (called MDC-BFS-SMK12.5, MDC-BFS-SMK21 and MDC-BFS-SMK43, respectively). Three samples by each replacement were manufactured to perform the Marshall test. MT and MC were the same to control MDC-19 (150±3 °C and 140±3 °C, respectively).

For the case of ITS test, initially six Marshall-type samples were manufactured following AASHTO T283-14 standard using the OAC and NA as total aggregate (without BFS and BFS-SMK, control MDC-19). Unlike the AASHTO T283-14 method, the samples were not manufactured until they reached a Va of 7±1%. It was decided, for better comparison, to use the Va achieved with the OAC. Three samples were tested under dry conditioned (D) and other three in wet conditioned (W). TSR = W/D (in percentage) was obtained in order to evaluate the resistance to moisture damage. ITS test was performed at 25 °C.

Additionally, other 6 samples (3 tested in D condition and 3 in W condition) were tested using the OAC and replacing the NA by BFS (MDC-BFS12.5, MDC-BFS21 and MDC-BFS43) and BFS-SMK (MDC-BFS-SMK12.5, MDC-BFS-SMK21 and MDC-BFS-SMK43). These samples were tested following the same procedure described above, in a similar way that those without BFS replacement (control MDC-19).

2.5. Resilient modulus (RM) tests

Using a Universal Testing Machine (UTM), RM tests was performed according to BS EN 12697-26 standard. This test was performed under three loading frequencies (2.5 Hz, 5.0 Hz and 10.0 Hz) and two temperatures (20 °C and 30 °C) on the control MDC-19, and the mixtures with substitution of NA by BFS and BFS-SMK that showed good performance in the Marshall and ITS tests. Additionally, the use of a significant amount of slags was taking in account. Six samples were employed for each RM test (three for each temperature).

2.6. Cantabro Test

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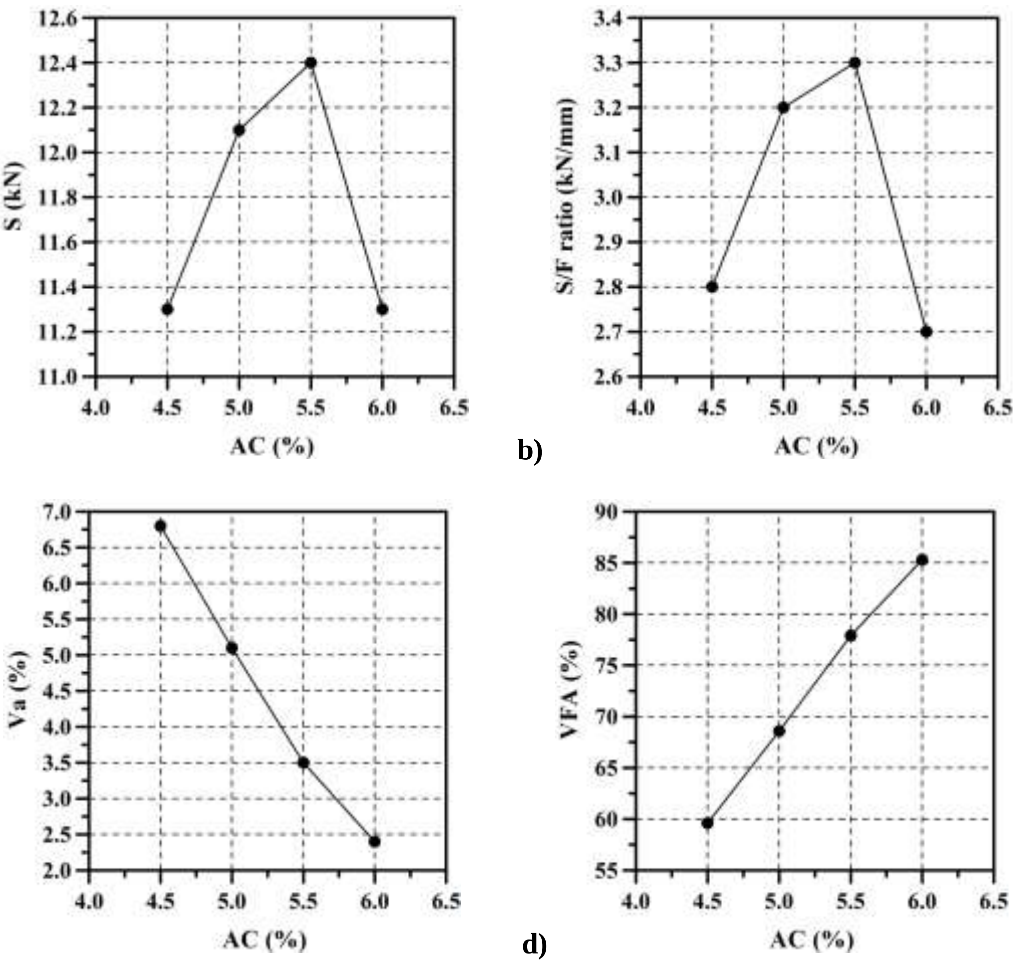
According to [14], Cantabro test is a useful test for providing durability indices of HMAs. Three samples of each MDC-19 mixture were tested following NLT 352-86 standard. The same samples used in the RM tests were employed to carry out Cantabro test (because RM is a non-destructive test). Each test was carried out at 20 °C using an LA drum and applying 500 revolutions.

3. Results and analysis

3.1. Marshall and ITS tests

The Marshall test results of MDC-19 are showed in Figure 4. The OAC obtained was 5.3% according to guidelines established by [11]. In the Figure 4, Va is the air voids content, VFA is the voids filled with asphalt, S is the stability and S/F is the stability/flow ratio.



a) b) c) d)

Figure 4. a) S, b) S/F ratio, c) Va content, d) VFA

Tables 3 and 4 shows the Marshall and ITS Tests results, respectively. When the coarse particles of NA are replaced by BFS, S/F ratio, D and W decreases with the increment of the BFS content. The above is mainly due to the increase in the Va content. Additionally, the greater number of BFS particles to cover with asphalt (due to lower specific gravity compared with NA) does not allow good adhesion, decreasing the ITS resistance. On the other hand, when BFS-SMK was used, this

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treated BFS with SMK help to reduce Va and adsorption, and as a result, an increase in S/F ratio, TSR and ITS is observed (these increments are statistically significant based on the ANOVA analysis, $F>F_{0.05}$). The above, despite the fact that the mixture with BFS-SMK has greater Va compared to control MDC-19. These increments are due to the SMK film that partially covers the air voids and the porous of the BFS. S/F ratio increased, with respect to control MDC-19, 16% and 10% when was used MDC-BFS-SMK12.5 and MDC-BFS-SMK21, respectively, as substitute of the NA. When MDC-BFS-SMK43 was used, the S/F ratio was similar compared to control MDC-19. For the case of D the increments were 20%, 12.4%, and 7% when MDC-BFS-SMK12.5, MDC-BFS-SMK21 and MDC-BFS-SMK43 was used, respectively, and for W, were 25%, 16.3% and 10%, respectively. Comparing MDC-19 mixtures with BFS, those with BFS-SMK increased the S/F ratio between 21% to 25%, the D between 20% to 25% and W between 32% to 39%.

Table 3. Results of Marshall test

Type	F (mm)	S (kN)	S/F (kN/mm)	Va (%)
Control	3.7	12.8	3.5	3.7
MDC-BFS12.5	3.8	12.1	3.2	7.9
MDC-BFS21	3.8	12.1	3.2	9.1
MDC-BFS43	4.1	11.6	2.8	9.9
MDC-BFS-SMK12.5	3.6	14.4	4.0	5.1
MDC-BFS-SMK21	3.7	13.9	3.8	6.2
MDC-BFS-SMK43	3.8	12.9	3.4	7.2

Table 4. Results of Indirect Tensile Strength Test

Type	D (kPa)	W (kPa)	TSR (%)	Va (%)
Control	1093.3	933.3	85.4	3.9
MDC-BFS12.5	1061.9	837.0	78.8	7.7
MDC-BFS21	1024.9	820.3	80.0	8.8
MDC-BFS43	937.9	738.3	78.7	9.7
MDC-BFS-SMK12.5	1309.0	1162.5	88.8	5.3
MDC-BFS-SMK21	1228.9	1085.6	88.3	6.0
MDC-BFS-SMK43	1166.2	1022.1	87.6	6.9

3.2. Resilient modulus (RM)

Figure 5 shows the results of RM tests. 12.5% of substitution was not chosen in order to use a greater amount of slags. MDC-BFS43 was not taken into account due its poor behavior in the ITS and Marshall tests.

The MDC-BFS-SMK21 mixture have higher stiffness or RM than the control MDC-19. The increase in RM was between 15% to 30% for 20 °C and 55% to 124% for 30 °C (these increments are statistically significant based on the ANOVA analysis, $F>F_{0.05}$). For the case of MDC-BFS21 and MDC-BFS43, these mixtures develop similar RM compared to control MDC-19 for both temperatures.

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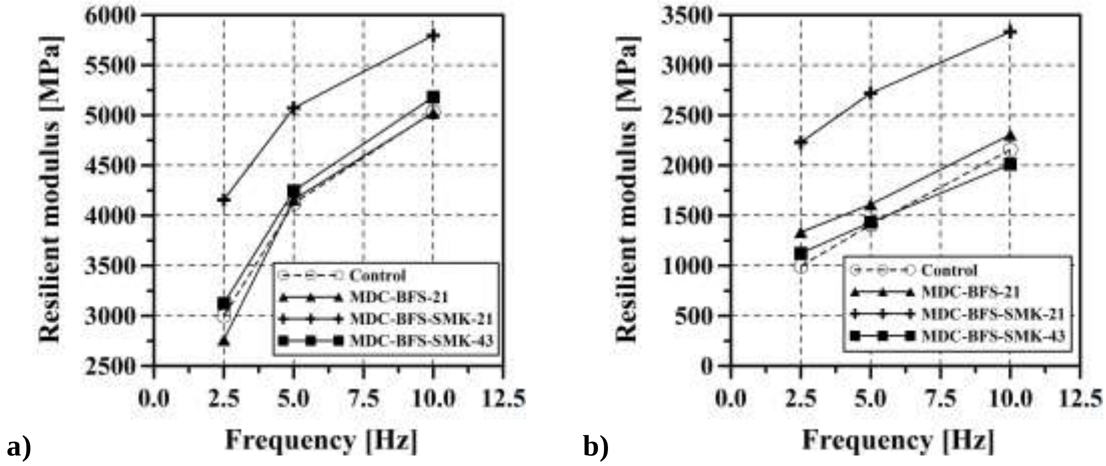

Figure 5. RM at a) 20 °C and b) 30 °C

3.3. Cantabro test

Cantabro test result is showed in Figure 6. MDC-19 with BFS generates a significant Cantabro mass loss compared to the control mixture. However, this mass loss is less when BFS-SMK is used because its particles have a greater wear resistance in the LA machine and MD test compared to BFS. Additionally, MDC-19 mixtures with BFS-SMK show lower Va contents than those with BFS.

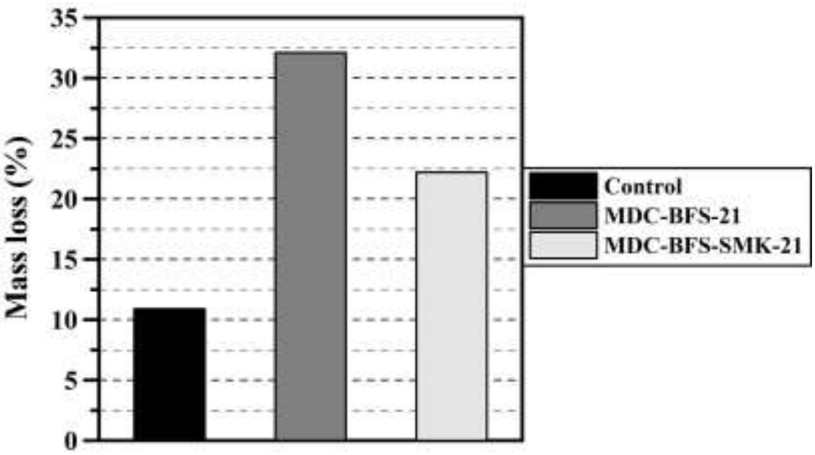

Figure 6. Results of Cantabro Test

4. Conclusions

In this research, the porosity of a BFS was partially filled using a polymer (SMK) that is widely employed in soil stabilization processes. Then, this pre-treated material was employed as replacement of the coarse NA fraction in an MDC-19 (HMA type). Based on the results obtained, the following conclusions can be taken:

- The substitution of the coarse NA fraction by BFS in the MDC-19 increased the Va content and decreased the moisture damage resistance and mechanical resistance evaluated through S/F ratio, D and W parameters. However, a contrary behavior was achieved when BFS-SMK was used. Using BFS-SMK, MDC-19 increased S/F ratio, D and W (indicating an increase in Marshall resistance and moisture damage resistance).

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- When RM increases in an HMA, greater is your stiffness under cyclic loading and rutting resistance. HMA with BFS tends to show a similar RM compared to control MDC-19. An increase in RM was obtained when 21% of the NA was substituted by BFS-SMK. However, similar RM, compared to control HMA was obtained, when 43% of NA was substituted by BFS-SMK.
- The ANOVA analysis showed that the BFS-SMK used as a partial replacement for NA has a significant effect on the monotonic properties and the stiffness under cyclic loading of HMAs.
- The MDC-19 with BFS increased the Cantabro mass loss compared to the control MDC-19. The BFS-SMK help to improve the wear resistance (Cantabro test), however, the MDC-19 with BFS-SMK are still less resistant compared to the control MDC-19.
- The treatment performed on BFS with SMK polymer was positive because the Va and porosity of BFS decreased and the wear resistance increased. Additionally, the BFS-SMK could be used to substitute the coarse fraction of NAs in order to improve the properties of HMAs.

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