UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Study of hot mix asphalt with incorporation of waste glass powder as filler

Diana Marcela Suárez-Lineros [a], Juan Sebastián Acosta-Hernández [a], José David Bonivento-Hernández [a] & Juan Gabriel Bastidas-Martínez [a]

[a] *Civil Engineering Program, Universidad Piloto de Colombia, Bogotá D.C, Colombia. diana-suarez1@upc.edu.co*

Received: May 9th, 2019. Received in revised form: Accepted:

Resumen
La implementación de materiales alternativos es un aporte a la mitigación del impacto ambiental y a la creación de nuevas técnicas de la Ingeniería civil sostenible. En Colombia se producen 17 millones de toneladas de residuos sólidos, los cuales afectan negativamente a la preservación y conservación del medio ambiente en términos de la disposición final de residuos sólidos. Éste documento tiene como objetivo estudiar en laboratorio la aplicación del uso de residuos triturado de vidrio (RTV) en sustitución parcial y total del llenante mineral de una mezcla asfáltica densa en caliente. Para tal fin, se realizó el diseño de una mezcla asfáltica convencional con cemento asfáltico (CA 60/70) y agregados pétreos naturales, a fin de obtener el porcentaje óptimo de asfalto. Posteriormente, se fabricaron 2 mezclas asfálticas de estudio con sustituciones del 50 y 100% del peso total del llenante mineral de la mezcla de control, correspondientes al 3 y 6% de RTV sobre el total de la mezcla. Luego, se realizaron ensayos para evaluar la respuesta ante la acción de la carga monotoníca (estabilidad y flujo Marshall y resistencia a la Tracción Indirecta), así como también la adherencia (Desgaste a la abrasión – cántabro). Los resultados indican que sustituyendo el 50% del llenante convencional con RTV en la mezcla asfáltica, puede mejorar la rigidez y la adherencia. Finalmente, la utilización del residuo de vidrio de la forma propuesta es viable, por permitir una forma de disposición final de residuos sólidos, que contribuye a la preservación y conservación del medio ambiente.

Palabras clave: mezclas asfálticas modificadas; glassphalt.

Abstract
The implementation of alternative materials is a contribution to the environmental impact mitigation and the creation of new techniques of environmental civil engineering. In Colombia, 17 million tons of glass are produced per year, which affect negatively the preservation and maintenance of the environment in terms of the final disposition of solid wastes. This document has as objective to study at laboratory scale the application of crushed waste glass (CWG) as a partial and total replacement of the compact asphaltic mixture in high temperatures. For this purpose, the design of a conventional asphaltic mixture with asphaltic cement (AC 60/70) and stony nature mineral aggregates was made, this to get the optimum percentage of asphalt. Subsequently, 2 asphaltic mixture study samples were made by substituting 50% and 100% of the total weight of the control mixture mineral filler, corresponding to the 3 and 6% of CWG on the total of the mixture. Then, experiments were carried out to assess the response to the action of monotonic loads (stability and Marshall flux and indirect traction resistance), as the adherence to (wear to burning - Cantabrian). The results show that replacing the 50% of the conventional filler with crushed waste glass on the asphaltic mixture can improve the stiffness and adherence. Finally, the use of waste glass as proposed is viable, allowing a way to a final disposition of solid wastes, that improves the preservation and maintenance of the environment.

Keywords: modified asphalt mixtures; glassphalt.

1 Introduction

Statistical data on the condition of the Colombian road network carried out by Instituto Nacional de Vias (INVIAS) indicate that Colombia has a road network consisting of approximately 9,300 kilometers, of which: 74.93% are paved roads, 24.87% unpaved roads and 0.20% are in the planning phase and previous studies for improvement. From the paved roads, approximately 63.6% are in good condition and 36.4% in regular to deficient condition [1]. Given this panorama, in order to strengthen the Colombian road network, is necessary to create new materials for the construction of roads, mainly for the surface course, which are durable, economical and that contribute to the preservation and conservation of the environment. Being the preeminent technical study on pavement mixtures, since it is the most used material for the road's construction in the world [2].

Dense asphalt mixtures are mainly composed of natural stone aggregates and asphalt. The natural stone aggregates are divided into three large fractions depending on their size (thick, fine and filler), which make up the stony skeleton of the mixture and are responsible for receiving and transmitting the loads coming from the vehicles. In another hand, asphalt covers the aggregate´s surface and allows the particles to adhere to the mixture [3]. The interaction between the filler and the asphalt is commonly known as asphalt mastic and is responsible for the physical-mechanical characteristics of the mixture and for the development of the most common phenomena of pavement damage, such as sagging and fatigue. [4] [5] [6].

Several researchers have studied the physical, chemical and rheological characteristics of asphalt mastic with conventional and alternative materials, to characterize the mechanical behavior of the mixture and induce pavement performance during the useful life [5] [6] [7] [8] [9]. The study of alternative materials for pavements is considered a viable alternative from an environmental point of view due it allows final disposal of solid waste, reduces the exploitation of quarries and purpose new sources of materials that can be used as a filler in the mixture. Solid wastes are considered to be materials that result from daily consumption or industrial activities, which are rejected by the generator and are susceptible to use or final disposal [3]. In Colombia, annual production of 13.6 million tons of solid waste is estimated, which only 17% are recycled [10]. Improper management of solid waste causes environmental problems related to lack of capacity in sanitary landfills, contamination of water sources and overexploitation of renewable and non-renewable natural resources [11] [12].

Since the early 1970s, research has been conducted on the technical possibility of incorporating glass waste into asphalt mixtures, commonly known as Glassphalt [13]. [14] studied the incorporation of glass particles smaller than 4.75 mm as a replacement for the fine aggregates in a dense asphalt mixture. As a great conclusion, the authors reported that recycled glass produces a positive effect on the functional characteristics of the pavement, allowing greater light reflection, which improves night visibility.

[5] analyzed the behavior of hot asphalt mixtures with different types of fillers, such as limestone, cement and glass dust. The results indicate that the use of alternative mineral fillers in the asphalt mixture considerably increases Marshall stability due to the decrease in the percentage of total voids of the specimens. Concluding that the glass dust improved it behavior.

[15] determined that the use of glass in asphalt mixtures reduces aging susceptibility and increases resistance against permanent deformation and fatigue life with respect to asphalt mixing with conventional materials.

[16] evaluated the mechanical characteristics of the asphalt mixture with substitution of natural stone aggregates with glass residues in percentages of 0%, 5%, 10%, 15%, and 20%, with respect to the total mass of the mixture. To this end, the Marshall test, indirect tensile strength (monotonic load), dynamic modulus and dynamic creep was performed. Based on the results obtained, the authors evidenced increased stiffness and reduced deformation as a function of the percentage of glass added compared to conventional asphalt concrete. Due to the low absorption of the glass, it is concluded that it is necessary to decrease the asphalt content as the percentage of glass is increased. The stiffness modulus increased because the glass particles have an angular shape, which allows a better accommodation between the conventional stone aggregates of the mixture. On the other hand, the authors conclude that the increase in resistance to permanent deformation is attributed to the properties of glass such as hardness and fracture.

[17] replaced the fine aggregate of an asphalt mixture with different solid waste such as plastic and glass. In conclusion, the authors report that the optimum percentage for the use of crushed glass waste in an asphalt mixture is in a range of 2.5% to 7.5%. Otherwise, the Marshall Stability of the asphalt mixture with solid waste increased 50% more than the conventional mixture.

[18] Studied the behavior of asphalt mixtures by indirect tensile tests, fatigue test for modified asphalt mixtures with 5%, 10%, 15% and 20% glass with respect to weight. The results conclude that the use of glass in asphalt mixtures improves the internal cohesion of the mixture and increases its resistance to deformations, since the glass in the asphalt mixture produces a greater angle of internal friction, this characteristic reduces the tensile stress in the sample and prevents the initial cracking and the propagation of the cracks in the mixture.

In synthesis, with respect to mechanical behavior, the incorporation of glass in substitution of aggregates in the conventional asphalt mixture increases the response to the action of the monotonic and dynamic load. Literature report increases in Marshall Stability, Indirect Tensile Strength, resilient modulus, dynamic modulus and fatigue resistance [5] [17] [19] [20]. The foregoing evidence an increase in stiffness and consequently the reduction of permanent deformation. This could be attributed to the physicochemical interactions of glass with asphalt. However, additional and local studies should be performed in order to validate the results presented. Moreover, economic studies report the validation of the pavement technique. However, high production costs are stated in the crushing of glass [18].

Under this background, the present study seeks the application of solid glass waste as filler in a dense asphalt mixture, in order to be used as an alternative material for roads. This article considers the application of an innovative technique for Colombia, to incorporate the recycling of alternative materials in the way proposed to contribute to the preservation and conservation of the environment.

2. Materials & Methods

2.1 Crushed glass waste

Glass is defined as an inorganic fusion product that has cooled in a rigid condition without crystallization [21]. The material used during the investigation comes from a Recycling Center located in the city of Bogotá, whose purpose would be the landfill disposal. Table 1 shows the glass chemical composition obtained in technical literature according to [3] [14] [19].

Table 1. Chemical composition of the crushed glass residue.

Component	[3]	[14]	[19]
Silicon Dioxide SiO2 (%)	71.41	70.87	72.1
Sodium Oxide Na2O (%)	12.05	12.4	13.1
Calcium Oxide CaO (%)	7.46	8.84	8.1
Magnesium Oxide MgO (%)	3.72	0.11	2.50
Aluminum Oxide Al2O3 (%)	1.21	1.47	1.6
Di Potassium Monoxide K2O (%)	0.46	0.79	---
Di Iron Trioxide Fe2O3 (%)	0.30	0.03	---
Sulfur Trioxide SO3 (%)	0.29	0.20	0.3
Strontium Oxide SrO (%)	0.24	---	---
Zinc Oxide ZnO (%)	0.042	---	---
Others	2.82	5.29	2.3
Lost by ignition LOI (%)	2.807	---	0.41

From the results of Table 1, it can be shown that the three main chemical components of glass are Silicon Oxide, Sodium Oxide and Calcium Oxide with percentages of 71.41%, 12,048%, and 7,462%.

The glass was crushed manually with a compaction hammer in the laboratory until a particle size of less than 0.075 mm was obtained, as evidenced in Figure 1. Some authors [22] [14] [23] suggested that the size of glass particles is related to the performance of the asphalt mixture's mechanical behavior, being 4.75 mm the maximum particle size with optimum results, glass particles with larger sizes cause less mechanical strength and durability of the mixture.

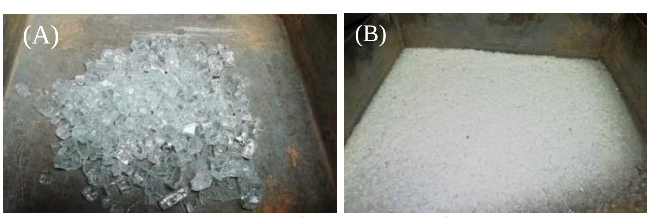


Figure 1. Glass residue: (a) Initial form; (b) Form after crushing.

2.2 Asphalt Cement

The Asphalt Cement (AC) used is from the Barrancabermeja Colombian refinery and corresponds to type 60-70. Table 2 presents the physical characterization tests of AC 60-70 under the standards established in Article 450 of the Instituto Nacional de Vias INVIAS (2013). From the results of the physical characterization, it can be concluded that the asphalt meets the requirements range of INVIAS for the manufacture of asphaltic mixtures for pavements.

Table 2. Results of the physical characterization of asphalt CA 60-70

Item	Test	Unit	Specification	Limits	Result
1	Penetration	0.1 mm	INV E-706	máx 70	66.0
2	Softening Point	ºC	E - 712	máx 54	48.0
3	Absolute viscosity (60°C)	P	E - 716/717	min 1500	2400
4	Ductility	cm	E - 702	min 100	150
5	Solubility in trichlorethylene	%	E - 713	min 99	99.9
6	Ignition Point	ºC	E - 709	min 230	296.0
Short-term aging in thin film furnace in motion RTFOT					
7	Loss of mass	%	E-720	máx 1	0.8
8	Viscosity ratio at 60 ° C after and before RTFOT	%	E-717	máx 54	50
9	Penetration to the residue after RTFOT with respect to the original penetration	%	E-706	min 54	75
10	Softening point increase	ºC	E - 709	máx 9	5

2.3 Stone Aggregates

The stone aggregate used for the preparation of asphalt mixtures is from the alluvial quarry Rio Coello located in the department of Tolima. The granulometry recommended for the production of the HMA 19 mixture is indicated in Figure 2.

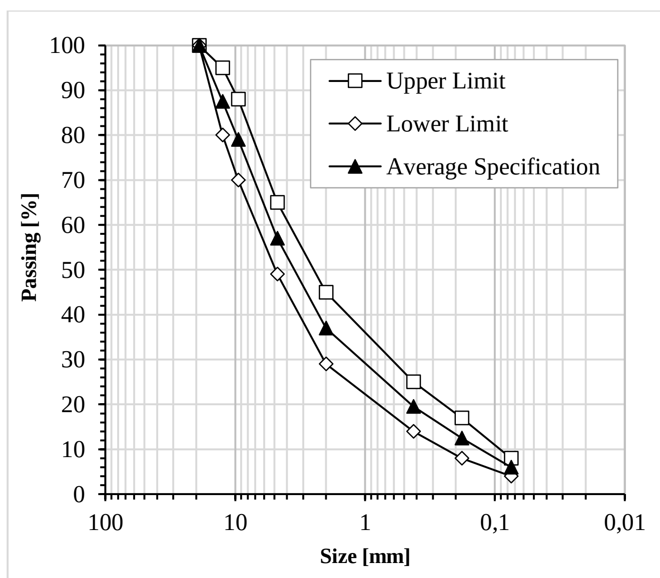


Figure 2. Granulometric specification for the HMA 19 mixture (INVIAS).

The characterization of the physical-mechanical properties of the stone aggregates was carried out following the specifications indicated by INVIAS for the Hot Mix Asphalt of continuous gradation HMA 19, for a high traffic level (NT3). The results obtained are shown in Table 3. According to the results found, it can be concluded that the aggregates used fulfill the parameters for the manufacture of asphalt mixture referred to in [24]

Table 3. Characterization of physical-mechanical properties of aggregates.

Test	INVIAS Code	Unit	Specification	Result
Flattening index	INV E-230	%	---	19
Elongation index	INV E-230	%	---	14
Percentage of fractured faces	INV E-227	%	100	85.2
Specific gravity of coarse aggregate	INV E-223	---	---	2,60
Coarse aggregate absorption	INV E-223	%	---	3,1
Specific gravity of fine aggregate	INV E-222	---	---	2,64
Fine aggregate absorption	INV E-222	%	---	2,9
Sand equivalent	INV E-133	%	min 50	63
Los Angeles Machine Wear	INV E-218	%	máx 25	19,5
Solidity	INV E-220	%	máx 18	13,34
Organic matter content	INV E-212	---	máx 3	<1
Blue methylene value	INV E-235	mg/g	máx 10	1,25

2.4 Marshall Test

The optimal percentage of asphalt in the control mixture was obtained using the Marshall methodology, following [24]. The manufacturing and compactation temperatures of the mixture were 135 and 160 ° C respectively, according to the eco-viscosity method. For the purposes of this study, 3 Marshall briquettes were made for each of the probable asphalt contents (See Figure 4). The testing asphalt contents were: 4.5, 5.0, 5.5 and 6.0% respectively, that means, 12 briquettes were made. The results obtained in the Marshall test, referring to the volumetric composition of the mixtures (percentage of air voids - Va, in the mineral aggregates - VMA and full of asphalt - VFA) and the resistance parameters under monotonic load at a deformation rate of 48 mm/minute until breaking (Stability - S, Flow-F and S/F ratio) are presented in Figure 3. Based on the results obtained in this phase, the optimum percentage of asphalt to be used in the control mixture was chosen for the execution of the subsequent phases.

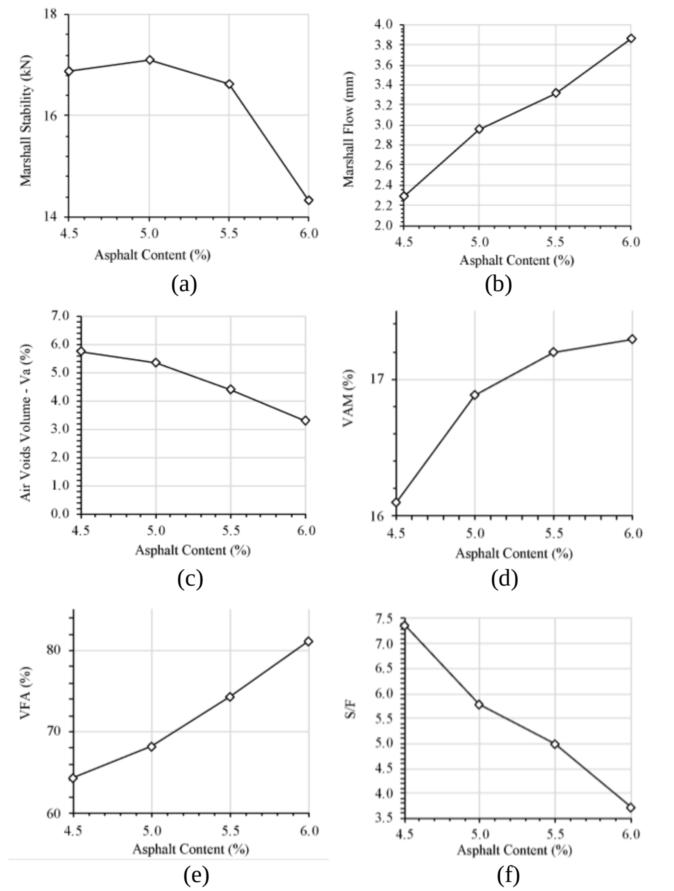


Figure 3. Evolution of the Marshall test parameters with asphalt content: (a) Stability; (b) Flow; (c) Air Volume; (d) Voids in natural aggregates; (e) Voids filled with asphalt; (f) Stability-Flow Ratio.

Figure 4. Briquettes used in the Marshall Test.

The results indicated an optimal asphalt content of 5%, mainly considering the maximum Marshall Stability. It also meets the volumetric parameters such as the volume of air voids (VA), asphalt filled voids (VAF) and voids in the mineral aggregate (VAM) required in the specification [24].

2.5 Evaluation of the control asphalt mixture and with crushed residual glass.

From the optimal asphalt cement content determined for the control mixture, two asphaltic study mixtures were made with 50% and 100% substitutions of the total weight of the filler of the control mixture, corresponding to 3% and 6% of CWG respectively. The percentages of addition of CWG were chosen based on the recommendations made by [3] [19] [21].

2.6 Indirect tensile test

Using the asphalt content determined in the Marshall test for the control mixture, 6 Marshall briquettes were additionally manufactured for each type of mixture (control, 50% and 100% CWG as filler). In order to measure the resistance to indirect traction by diametral compression at 25 ° C in a loading press, following the guidelines established by [25] (Figure 5). Each briquette was subjected to the application of monotonic loading at a deformation rate of 50 mm/minute until rupture. Indirect Tensile Strength (ITS) in kPa was determined using Equation 1, where P is the maximum breaking load in N, h and d is the height and diameter in millimeters of each briquette respectively.

$$\boldsymbol{ITS = \frac{2000.P}{\pi.h.d}} \quad (\mathbf{1})$$

The resistance determination was converted into conditioned (dry) samples. Samples conditioned or in wet conditions were subjected to a water bath at 60 ° C for 24 hours, then placed at for two hours at 25 ° C for the performance of the test, in order to establish the Indirect Tensile Strength Ratio (ITSR). The relationship is proportional between the saturated ITS and dry ITS, according to the presentation in Equation 2.

$$\boldsymbol{ITSR = \frac{ITSs}{ITSd}} \qquad (2)$$

Figure 5. Indirect tensile strength test.

2.7 Cantabrian Test

On three Marshall samples for each type of mixture analyzed (control, 50% and 100% CWG as filler) wear tests (without abrasive loading) were carried out on the Los Angeles machine, applying 300 turns at 33 revolutions per minute [26] (see Figure 6). The briquettes used the optimal asphalt content from the Marshall test. The temperature of the samples during the test was 25 ° C.

The loss of mass of the sample is a the difference between the initial mass of the sample and the final mass after the test. The wear test has become a relative measure of the decay resistance of open gradation mixtures. However, in the case of hot dense asphalt mixtures, it can be used to assess durability (generally includes cracking, fractures and wear associated with loads) and cohesive properties [27] [28].

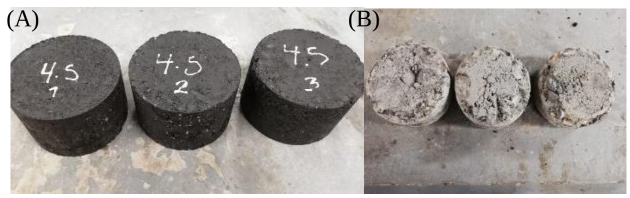
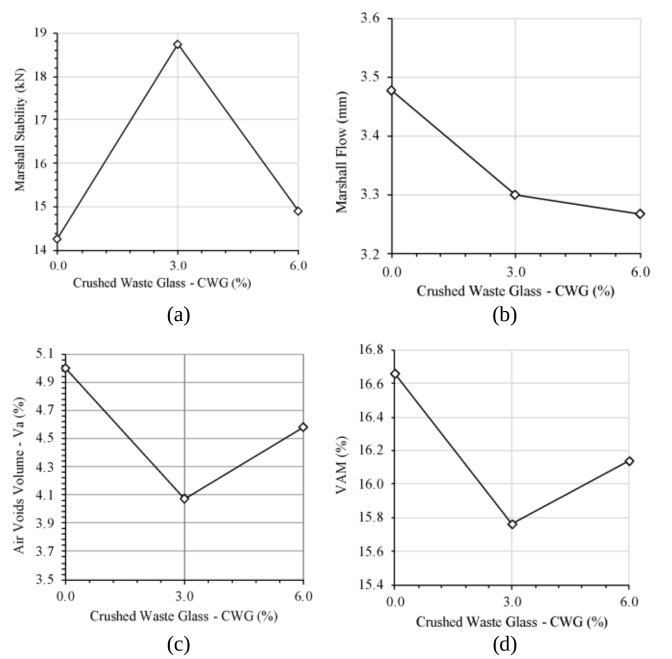


Figure 6. Marshall Briquettes: (a) before (b) after the wear test

3 Results and Discussion

3.1 Stability and flow test - Marshall

The stability and flow results for the control mixture and asphalt mixtures with incorporation of 3 and 6% of CWG are presented in Figure 5.



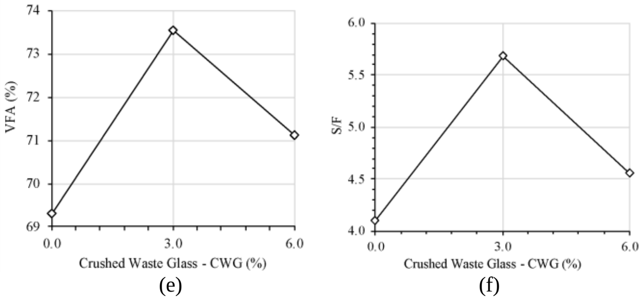


Figure 5. Evolution of the Marshall test parameters with the percentage of crushed glass residue in the mixture: (a) Stability; (b) Flow; (c) Air Volume; (d) Voids in natural aggregates; (e) Voids filled with asphalt; (f) Stability-Flow Ratio.

According to the results obtained, the asphalt mixture with 3% of CWG addition showed the best behavior in response to the monotonic load response, defined by the greater Marshall Stability and Stiffness (S /F). In this sense, an increase in Stability of approximately 31% and reduction of Marshall flow in approximately 5.4% of the mixture with the addition of 3% of CWG with respect to the control mixture can be evidenced. The increase in Marshall stability and stiffness in the 3% CWG mix is attributed to the reduction in air volume, as well as to the physical-chemical interactions of filler surfaces with asphalt. The interactions between the asphalt and the CWG filler considerably increases the consistency of the asphalt [29]. The increase in asphalt consistency due to contact with the CWG can be attributed to the presence of Silicon Oxide, providing greater rigidity in the mixture.

With regard to volumetric parameters (Va, VAM and VFA), asphalt mixing and mixtures with the participation of CWG can be evidenced to satisfy the parameters required for high traffic volume roads [24]. However, the mixture with 3% of CWG presented the smaller Va and higher VFA, which can be concluded with the replacement of 50% of the filler with CWG leads to a better arrangement of particles in the stony scheme of the mixture.

3.2 Indirect Tensile Strength (ITS)

Figures 7 and 8 show the results of the ITS obtained for the briquettes without conditioning (dry) and conditioned (saturated), as well as the relationship between them.

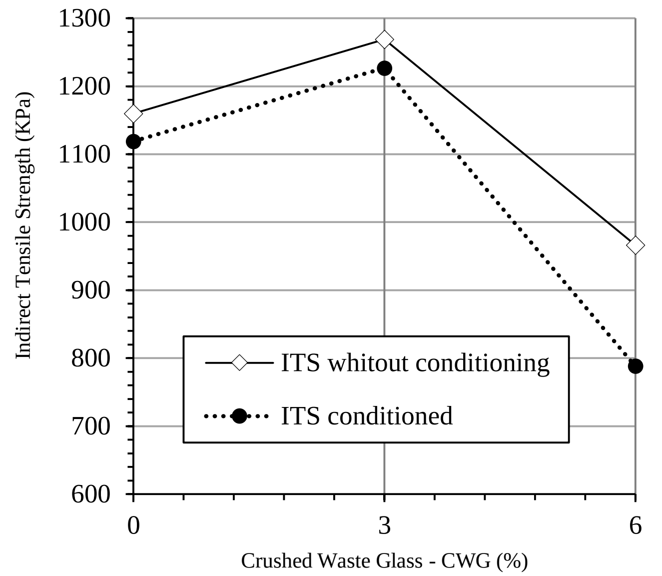


Figure 6. Evolution of Indirect Tensile Strength with the percentage of crushed glass waste in the mixture.

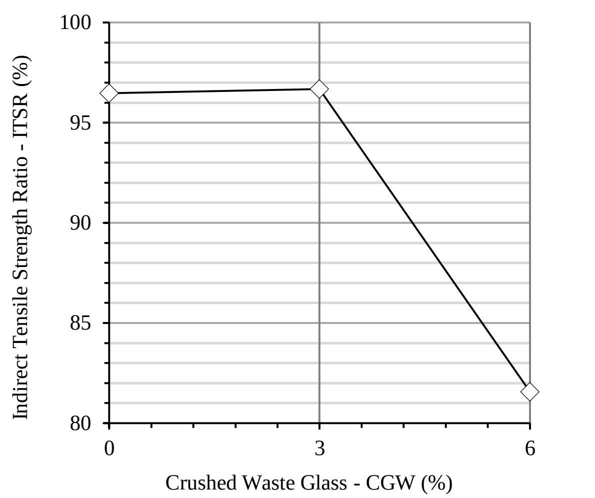


Figure 7. Evolution of the Indirect Tensile Strength Ratio with the percentage of crushed glass waste in the mixture.

From the results, it can be evidenced that the mixture with 3% CWG exhibits the best behavior before ITS in the samples with and without conditioning in relation to the control mixture, being an indicator of greater adherence between the particles. In this sense, the mixture with 3% CWG showed an increase of ITS by approximately 9.4% with respect to the control mixture. The increase of the ITS in the alternative mixture is attributed to the reduction of Va and increase of the VFA, an inverse relationship between the volume of air voids and the ITS is observed. This is because a low volume of air indicates good cohesion between particles.

The ITSR is an indication of the adherence of the mixture due to variations in temperature and presence of water [30] [31].

From the results, it can be evidenced that the mixture with 3% CWG showed a slight increase in the ITSR with respect to the control mixture. However, the asphalt mix with 6% CWG significantly decreases the ITSR with respect to the control mix. In this sense, it can be concluded that the presence of CWG in partial substitution of the mineral filler of the mixture keeps the adherence of the mixture with respect to the control mixture, providing the durability of itself. The aforementioned can be attributed to the reduction of air volume and physical-chemical interactions by contact between asphalt-filling mineral materials.

3.3 Cantabrian wear loss test

The results obtained for the Cantabrian wear loss test are presented in Figure 6.

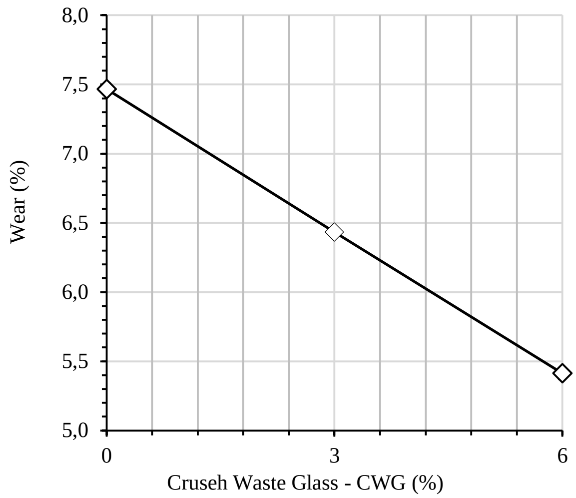


Figure 6. Evolution of Cantabrian Wear with the percentage of crushed glass waste in the mixture.

From the results acquired, it is possible to show that asphalt mixtures with 3% and 6% CWG showed a reduction of the abrasion wear percentage in the Cantabrian test with reference to the control mixture. In this sense, the control mixture has an abrasion wear percentage of 7.5% and the mixtures with 3% and 6% CGW presented a wear percentage of 6.5% and 5.4% respectively. The above can be attributed similary to the previous results, to the reduction of the air volume and the physical-chemical interactions due to the contact between the asphalt-filling mineral materials. Consequently, the presence of CGW increases the adhesion of the mixture according to the results presented in the literature [32] [33].

4 Conclusions and recommendations

This article evaluates in the laboratory the mechanical behavior before the action of the monotonic load (Marshall and indirect traction), as well as the adherence (ratio of tensile strength and Cantabrian wear) of a conventional asphalt mixture and two asphalt mixtures with 3 % and 6% of Crushed Glass Waste, corresponding to 50% and 100% of the total filler. Based on the results found, it can be concluded that:

• The incorporation of 50% of CWG as a conventional filler, contributes to increased cohesion and adherence between aggregates and asphalt, allowing greater stiffness in the asphalt mix.

• The increase in stiffness of the asphalt mixture with 50% replacement of filler with CWG, can be attributed to the physical-chemical interactions between asphalt and silicon oxide present in the crushed glass waste, allowing the increase of the asphalt consistency and consequently the increase in Marshall Stability and Indirect Traction Resistance.

• The incorporation of residual glass in asphalt mixtures can be considered a solution that contributes to the correct disposal of solid waste, considering that it is a technical alternative in Pavement Engineering and is environmentally sustainable. However, additional laboratory studies should be performed to validate the results.

ACKNOWLEDGMENT

The Authors thank the Universidad Piloto de Colombia for the support for conducting the Research.

5 Bibliographic references

[1] Instituto Nacional de Vias, *Estado de la red vial criterio técnico primer semestre 2018*. 2018, p. 2019.
[2] H. M. Elghatas, M. Y. . Aman, and A. S. Ali, “An assessment on the physical and rheological properties of asphalt binder modified with micro bauxite powder (MBP),” *Adv. Civ. engeneering Mater.*, vol. 19, pp. 30–37, 2019.
[3] M. Arabani, S. Tahami, and M. Taghipoor, “Laboratory investigation of hot mix asphalt containing waste materials,” *Road Mater. Pavement Des.*, vol. 18, no. 3, pp. 713–729, 2016.
[4] D. Anderson, H. Bahia, and R. Dongre, “Rheological Properties of Mineral Filler-Asphalt Mastics and Its Importance to Pavement Performance,” in *Effects of Aggregates and Mineral Fillers on Asphalt Mixture Performance*, vol. 19, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 1992, pp. 131-131–23.
[5] H. Wang, I. L. Al-Qadi, A. F. Faheem, H. U. Bahia, S.-H. Yang, and G. H. Reinke, “Effect of Mineral Filler Characteristics on Asphalt Mastic and Mixture Rutting Potential,” *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2208, no. 1, pp. 33–39, 2011.
[6] A. Zulkati, W. Y. Diew, and D. S. Delai, “Effects of Fillers on Properties of Asphalt-Concrete Mixture,” *J. Transp. Eng.*, vol. 138, no. 7, pp. 902–910, 2011.
[7] Y. Xue, H. Hou, S. Zhu, and J. Zha, “Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture: Pavement performance and environmental impact,” *Constr. Build. Mater.*, vol. 23, no. 2, pp. 989–996, 2009.
[8] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and P. Shafigh, “Using waste plastic bottles as additive for stone mastic asphalt,” *Mater. Des.*, vol. 32, no. 10, pp. 4844–4849, 2011.
[9] Y. Tan and M. Guo, “Using surface free energy method to study the cohesion and adhesion of asphalt mastic,” *Constr. Build. Mater.*, vol. 47, pp. 254–260, 2013.
[10] DANE, “Cuenta ambiental y económica de flujos de materiales - Residuos Sólidos 2012-2014,” *Boletín Técnico*, pp. 1–14, 2016.

[11] C. Elías, J. Jiménez, J. Montón, P. Muñoz, J. Prieto, and F. Serrano, *Ciencias para el mundo contemporáneo: Impacto Ambiental, el Planeta Herido*, Mc Graw Hi. Madrid, España, 2012.

[12] DNP, "Informe Nacional de aprovechamiento 2017," *Supt. Serv. Públicos, Dep. Nac. Planeación*, vol. 1, p. 57, 2017.

[13] Z. T. Abu Salen, T. S. Khedawi, M. B. Baker, and R. Abendeh, "Effect of Waste Glass on the Properties of Concrete," *J. Mater. Civ. Eng.*, no. 11, pp. 117–131, 2017.

[14] N. Su and J. S. Chen, "Engineering properties of asphalt concrete made with recycled glass," *Resour. Conserv. Recycl.*, vol. 35, no. 4, pp. 259–274, 2002.

[15] G. D. Airey, A. C. Collop, and N. H. Thom, "Mechanical Performance of Asphalt Mixtures Incorporating Slag and Glass Secondary Aggregates," *8th Conf. Asph. PAVEMENTS South. AFRICA*, no. October 2016, pp. 1–15, 2004.

[16] G. H. Shafabakhsh, S. M. Mirabdolazimi, and Y. Sajed, "Investigation of dynamic behavior of hot mix asphalt containing waste materials; case study: Glass cullet," *Case Stud. Constr. Mater.*, vol. 1, pp. 96–103, 2014.

[17] V. Singh and R. Sakale, "the Effect of Using Waste Plastic and Waste Glass on the Asphalt Pavement Properties," *Int. J. Res. Eng. Technol.*, vol. 07, no. 02, pp. 24–32, 2019.

[18] M. Arabani, S. M. Mirabdolazimi, and B. Ferdowsi, "Modeling the fatigue behaviors of glasphalt mixtures," *Sharif Univ. Techology Sci. Iran.*, vol. 19, no. 3, pp. 341–345, 2012.

[19] H. Jony, M. Al-rubaie, and I. Y. Jahad, "The Effect of Using Glass Powder Filler on Hot Asphalt Concrete Mixtures Properties," *Eng. Tech. J.*, vol. 29, no. 1, pp. 44–57, 2011.

[20] Y. Issa, "Effect of Adding Crushed Glass to Asphalt Mix," *Arch. Civ. Eng.*, vol. 62, no. 2, pp. 35–44, 2016.

[21] M. Arabani, "Effect of glass cullet on the improvement of the dynamic behaviour of asphalt concrete," *Constr. Build. Mater.*, vol. 25, no. 3, pp. 1181–1185, 2011.

[22] S. Wu, W. Yang, and Y. Xue, "Preparation and Properties of Glass-asphalt Concrete Shaopeng," *J. Mater. Sci. Mater. Electron.*, vol. 14, no. 10–12, pp. 685–688, 2003.

[23] Z. T. Abu Salem, T. S. Khedawi, M. B. Baker, and R. Abendeh, "Effect of waste glass on properties of asphalt concrete mixtures," *J. Mater. Civ. Eng.*, vol. 11, no. 1, pp. 117–131, 2017.

[24] INVIAS, *Instituto Nacional de Vias - Mezclas asfálticas en caliente de gradación continua (Concreto asfaltico) Artículo 450-13*, vol. 1. 2013.

[25] ASTM Standard D 6931, "Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures," *Www.Astm.Org*, vol. i, pp. 1–5, 2017.

[26] NLT-352/00, "Caracterización de las mezclas bituminosas abiertas por medio del ensayo cántabro de pérdida por desgaste," *Normas de Laboratorio del Transporte España*. 2000.

[27] I. L. Doyle, J.D. Howard, "Characterization of dense-graded asphalt with the Cantabro test.," *J. Test. Eval.*, vol. 44, no. 1, pp. 77–88, 2016.

[28] B. C. Cox, B. T. Smith, I. L. Howard, and R. S. James, "State of Knowledge for Cantabro Testing of Dense Graded Asphalt," *J. Mater. Civ. Eng.*, vol. 29, no. 10, p. 04017174, 2017.

[29] D. Suarez, J. Acosta, and J. . Bastidas-Martínez, "Evaluación de cementos asfálticos con adición de residuos de vidrio triturado," in *XXI Simposio Colombiano sobre Ingenieria de Pavimentos*, Medellin, Colombia, 2018, p. 2018.

[30] M. Sadeghnejad, M. Arabani, and M. Taghipoor, "Predicting the impact of temperature and stress on the glasphalt mixtures' rutting behavior," *Int. J. Pavement Res. Technol.*, vol. 11, no. 3, pp. 300–310, 2018.

[31] F. MORENO-NAVARRO, G. GARCÍA-TRAVÉ, M. RUBIO-GÁMEZ, and M. J. MARTINEZ-ECHEVARRIA, "Analysis of the Moisture Susceptibility of Hot Bituminous Mixes Based on the Comparison of Two Laboratory Test Methods," *Dyna*, vol. 81, no. 183, p. 49, 2014.

[32] K. N. Dalloul, "Study of the effect of crushed waste glass as coarse sand and filler in the asphalt binder," The Islamic University of Gaza, 2013.

[33] B. F. Kallas and V. P. Puzinauskas, "A study of mineral fillers in asphalt paving mixtures," *Proc. Assoc. Asph. Paving Technol.*, vol. 30, p. 493, 1961.