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Use of mining wastes in asphalt concretes production

Uso de residuos mineros en la producción de hormigones asfálticos

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Abstract
Mining waste is a serious environmental problem in all countries where mining is carried out. Considering large amount of mining waste from the exploitation and processing of nickel laterites in Cuba and Brazil, the work takes as a hypothesis that, if it demonstrates the real possibility of using such waste as a partial substitute for aggregates in the production of asphalt concrete, the negative environmental impact caused by them in the places where they are deposited could be reduced. The objective of the work is, to demonstrate the suitability of mining waste from nickel and cobalt processing dams in the municipalities of Moa and Nicaro, in the province Holguín, Cuba. Such wastes come from Ammonium Carbonate Leaching and Pressurized Acid Leaching processes. The research methodology it has based on taking representative samples from the waste dams, their subsequent physical, chemical and mineralogical characterization, and the characterization of the aggregates and asphalt cement used in the mixtures under study. The design of the asphalt concrete mixtures was carried out using the Marshall method. Subsequently, a comparative analysis was made on the behavior of the asphalt concretes made with limestone and mining waste fillers investigated. It´s demonstrated, from the results of the laboratory tests, that it is possible to manufacture asphalt concretes with the use of mining residues from the processing of nickel laterites from Moa and Nicaro, satisfactorily fulfilling the required technical parameters.
Keywords: *Mining waste; asphalt concrete; mineral tailings; aggregates*

Resumen
Los residuos mineros constituyen un serio problema ambiental en todos los países donde se realice explotación minera. Teniendo en cuenta la gran cantidad de residuos mineros procedentes de la explotación y procesamiento de las lateritas niquelíferas en Cuba, el trabajo toma como hipótesis que, si demuestra la posibilidad real de emplear dichos residuos como sustituto parcial de los áridos en la producción de hormigón asfáltico, se pudiera disminuir el impacto ambiental negativo que provocan los mismos en los lugares donde se encuentran depositados. El objetivo del trabajo es demostrar la aptitud de los residuos mineros procedentes de presas de los procesos de beneficio de níquel y cobalto en los municipios de Moa y Nicaro, en la provincia de Holguín, Cuba. Tales residuos proceden de procesos de Lixiviación Carbonato Amoniacal y Lixiviación Ácida Presurizada. La metodología de investigación partió de la toma de muestras representativas en las presas de residuos, su posterior caracterización física, química y mineralógica, se realizó la caracterización de los áridos y cemento asfáltico utilizados en las mezclas objeto de estudio. Se realizó el diseño de las mezclas de hormigón asfáltico mediante el método Marshall. Posteriormente se hizo un análisis comparativo del comportamiento de los hormigones asfálticos realizados con fíller calizo y fíller de los residuos mineros investigados. Se demostró, a partir de ensayos de laboratorio, que es posible la fabricación de hormigones asfálticos con el empleo de residuos mineros del procesamiento de las lateritas niquelíferas de Moa y Nicaro, cumpliendo satisfactoriamente con los parámetros técnicos exigidos.
Palabras claves: Residuos mineros; hormigón asfáltico; colas minerales; áridos

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1. Introduction

The demand for the use of recycled materials has increased significantly due to the lack and limitation of available natural resources. It is well recognized that, during the mineral exploitation processes, a significant negative environmental impact is produced, similar to or greater than that related to the exploitation of quarries for the production of aggregates for construction. But even worse is the enormous amount of mining waste that results from its preparation, separation and general processing. For example, in the province Holguín, located in the eastern part of the Republic of Cuba, three important laterite deposits have been exploited for many years, as ore to obtain nickel and cobalt, two of them in Moa and one in Nicaro. Given the characteristics of the mineral deposits, the exploitation is carried out in the open, with great aggressiveness to the environment, since from the beginning large areas are cleared, which translates into deforestation of forests.

The metallurgical processes used in the processing plants for the extraction of nickel and cobalt from Moa and Nicaro are of two types: the ammoniacal carbonate technology (also known as the CARON process) and the pressure acid leaching technology (Pressure Acid Leaching). In both cases, enormous amounts of mining waste are generated, systematically accumulating in dams that occupy large areas, and which aggravate the negative environmental impact of the process. Additionally, the analysis should consider the fact that the lateritic reserves are high and that other processing plants are being planned, which would presumably increase the amount of available waste.

Asphalt concrete, given its good qualities, such as stability, chemical resistance, impermeability, good cost-benefit balance, and others, are used extensively in construction, mainly for paving streets, highways, airfields, etc. Classically the raw materials used for the manufacture of asphalt concrete are asphalt cement, aggregates and different types of additives or additions. Regarding its volume, the aggregates represent the most considerable part of this agglomerate, therefore having great relative weight with respect to transportation costs, hence the convenience of using local materials for this purpose. Of course, the use of local materials requires compliance with the specifications established in the regulations, for which a study is required that certifies their suitability for the intended use.

The mechanical performance and working conditions of asphalt mixtures are directly influenced by the behavior of the mastic (combination of asphalt cement, filler and air) (Al-Khateeb et al., 2017). According to (Bardini et al., 2010) the filler is used as a material to fill the voids between the coarse and fine aggregates. The surface of the mineral powder represents around 90-95% of the total surface of the grains that make up the asphalt concrete. On the other hand, asphalt concrete needs this very fine material to promote the achievement of its technical parameters (ASTM D242-95, 2017). The filler contributes to the closure of the mixture, modifies the working conditions, resistance to water and aging. Due to the small size of the particles and their surface characteristics, the filler reacts as an active material, manifesting itself in the properties of the filler/asphalt interface, so it is not just an inert material as presented by the general definition of DNER-EM 367, 1997).

The structural characteristics of the filler are very important as they directly intervene in the filler/asphalt interaction. These interactions can contribute to the increase of cohesive forces and thus prevent the increase of cracks and increase the stiffness of the mastic (Antunes et al., 2015). The influence of filler characteristics on the behavior of asphalt mastics has been recognized by several authors (Antunes et al., 2016); (Bastidas et al., 2021); (Cesare et al., 2019); (Rondón et al., 2020). According to the study by Antunes et al. (2016) the chemical composition of the fillers studied does not report a great influence on some properties of the mastic. On the other hand, the results obtained by Barr et al. (2014) indicate that the active behavior of fillers in the formation of mastics is not related to the size of the particles but rather to their shape, surface texture, specific surface area and mineralogical nature, allowing the concept of Files can be divided into two components: physical (hardening) and chemical (adhesiveness).

Within the scope of these concepts, numerous studies are framed in the use of alternative materials as a substitute for filler in asphalt mixtures. The preliminary study by (Sangiorgi et al., 2017) suggests that all the fillers tested can be considered as a valid alternative to natural filler in bituminous mixtures. Other researchers have demonstrated the potential of using mining waste in the production of mastics and asphalt mixes (Arabani and Mirabdolazimi, 2011); (Cesare et al., 2019); (Kütük-Sert and Kütük, 2013); (Betancourt et al., 2017); (Sharapov et al., 2018). In Brazil, the author (Silva, 2017) has studied the replacement of filler by mineral residues from the exploitation of iron ore in the region of the so-called "Ferrous Quadrilateral". The results point to the viable use of this residue as a good alternative from the technical and environmental point of view.

The foregoing allows us to arrive at the hypothesis that, if the accumulated mining waste is used in the production of asphalt concrete, the exploitation of virgin material would be reduced, the negative environmental impact produced by the accumulated tailings dams would be mitigated and economic advantages would be achieved. for the concept of reduction in transportation costs, by using said residues locally. The objective of this work is the study of the possibility of using mineral tailings in the replacement of filler in asphalt mixtures, in order

2. Materials and methods

The work was developed within the framework of a research project between Cuba and Brazil related to the use of mining waste for the production of construction materials. This experimental study was carried out in the Infrastructure Laboratory (INFRALAB) of the University of Brasília (UnB). (Figure 1) outlines the general methodology followed in the research and shows the main information of the experimental study carried out.

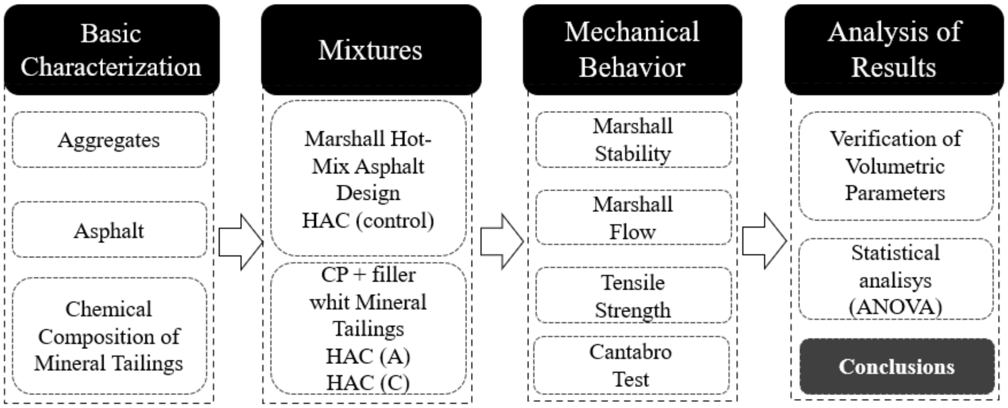


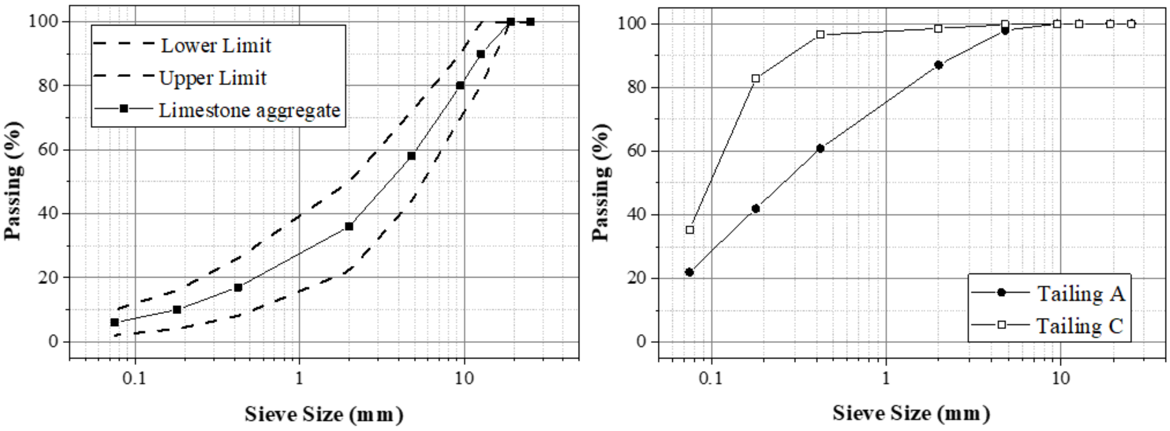
Figure 1. *Methodological scheme followed in the investigation*

The component raw materials of the asphalt mixtures are characterized separately, to evaluate their compliance with the regulated specifications. Subsequently, a control mixture composed of aggregates and limestone filler and asphalt cement is dosed. Two other mixtures are produced from this granulometry, completely replacing the portion of limestone filler with mineral tailings. In order to study the effect of this substitution on the asphalt mixture, some mechanical tests are carried out on a set of three test bodies for each mixture. The test results are subjected to an analysis of variance ANOVA test to verify the significance of the differences.

2.1 Characterization of the materials

The materials used in the preparation of asphalt mixtures in this research are dolomitic limestone aggregates from the Brasilia region, dolomitic limestone fillers and mineral tailing, as well as CA 50-70 asphalt cement widely used in the region. To produce asphalt concrete, the average values of the intervals known as "C" specified in the DNIT 031 ES (2006) standard are used.(Figure 2 a) shows the granulometric intervals chosen for the manufacture of asphalt concrete.

The mineral tailings used in this study were collected in the nickeliferous laterite mines located in the town of Moa, Holguín province of the Republic of Cuba and their granulometric curves are shown in (Figure 2 b). These materials are identified based on their method of production, A for (Pressure Acid Leaching) and C for the CARON process.



a) *b)*

Figure 2. *a) Granulometry used in the elaboration of the HAC. b) Granulometry of the mineral tailings.*

The use of mineral tailings is based on the fact that these residues have a high fineness, as shown in (Table 1), so presumably they could be used as filler in asphalt mixtures. The chemical composition detailed in (Table 2) shows that these residues are rich in iron content, which confers a much higher density when compared to the density of natural filler from limestone rocks. This particular can impact the result of the physical parameters determined to asphalt concrete.

Table 1. *Physical properties of mineral tailings used*

Material	***Density (g/cm^3)***	***Specific surface BET (m^2/g)***	***Fineness modulus***	***Z Potential (mv)***
Tailing C	*4,0223*	*3,864*	*0,71*	*-10,37*
Tailing A	*3,7801*	*2,119*	*2,02*	*-0,39*

Table 2. *Chemical composition of mineral tailings*

Element	***Ca***	***Mg***	***Si***	***Fe***	***K***	***S***	***Mn***	***Al***	***Ni***	***Cr***	***Ti***
Sample C	*0,10*	*5,62*	*5,77*	*75,87*	*0,01*	*0,36*	*1,18*	*3,21*	*2,20*	*0,00*	*0,16*
Sample A	*3,68*	*0,22*	*3,16*	*80,28*	*0,02*	*5,50*	*0,42*	*3,35*	*0,17*	*2,88*	*0,15*

Coarse and fine aggregates and filler limestone come from the region of the Federal District of Brazil. (Table 3) shows the results of the characterization of these materials in accordance with international standards. When analyzing the results, it is concluded that these materials meet the specifications, so they are suitable for the production of asphalt concrete.

Table 3. *Physical properties of aggregates*

Test	***Test method***	***U/M***	***Result***	***Specification***
"Los Angeles" machine	*AASHTO T 96-02*	*%*	*22,5*	*Max. 50*
Fractured particle	*ASTM D5821*	*%*	*86,2*	*-----*
Sand equivalent (fine aggregate)	*ASTM D2419*	*%*	*68,0*	*Min. 55*
Aggregate durability *(Sodium or magnesian sulfate)*	*AASHTO T 104-99*	*%*	*9,03*	*Max. 18*
Coaarse aggregate – adhesivity to asphalt	*DNER-ME 078-94*	*----*	*Satisfy*	*----*
Specific gravity and absorption Fine aggregate	*AASHTO T 84-00*	*----/%*	*2,60/2,1*	*----*
Specific gravity and absorption coarse aggregate	*AASHTO T 85-91*	*----/%*	*2,64/0,8*	*----*

The results of the characterization of the asphalt cement CA 50-70 used for the manufacture of the mixtures are shown in (Table 4). According to the specifications of the DNIT 095 (2006) standard (DNIT 095/, 2006), this material meets the requirements to be used as a binder in the mixtures produced for this study.

Table 4. *Characterization of AC 50/70 used in HAC production*

Test	***U/m***	***Specifications***	***Results***	***Test method***
Density	*g/cm^3*		*1,002*	*AASHTO T 228*
Penetration (100g, 5s,25°C)	*0,1mm*	*50-70*	*56*	*ASTM D5 / D5M*
Softening Point	*°C*	*≥46*	*48*	*ASTM D36 - 95*
Ductility a 25°C, min.	*cm*	*≥60*	*>100*	*ASTM D113*
Fulgor point	*°C*	*>235*	*320*	*ASTM D3143*
Combustion point	*°C*		*380*	
Effect of heat and air (RTFOT) a 163° C, 85 min				*ASTM D2872*
Mass variation, max.	*% mass*	*0,5 max.*	*0,19*	
Brookfield viscosity				*ASTM D4402*
a 135°C, Sp 21, 20 rpm	*cP*	*141, min.*	*350*	
a 150°C, Sp 21, 20 rpm	*cP*	*50, min.*	*210*	
a 177°C, Sp 21, 20 rpm	*cP*	*30-150*	*80*	

2.2. Dosage of the mixtures

For the study of the influence of the use of mineral tailing as a substitute for mineral filler, three hot asphalt concretes (HAC) were elaborated. The first mixture is produced based on coarse, fine and filler aggregates, from limestone rocks and CA50-70 asphalt cement. The physical and mechanical parameters of this mixture will be used to evaluate the influence of the replacement of the natural filler by mineral tailings and will be coded as HAC (control). The second and third concrete are manufactured maintaining the same dosages of the materials, with the exception of the filler, which will be replaced by mineral tailings A and C, respectively. The coding of the latter will be HAC (A) and HAC (C) to identify the filler material that is being used in each of the concretes. Figure 3 shows part of the process followed in the laboratory for the production of asphalt concrete and the Marshall test.

Figure 3. *Dosage procedure by Marshall Method at laboratory*

In this study, the optimal asphalt content for the HAC (control) is determined following the assumptions of the Marshall Method. In this case, 5 asphalt contents are evaluated that vary in intervals of 0.5%, starting at 4.5% up to 6% of the total weight of the respective mixtures. For each asphalt content, three specimens of 1200 g of SCC mix are produced, with approximate dimensions of 10 cm in diameter and 6 cm in height. The materials are mixed and compacted at temperatures of 155°C and 145°C, respectively, determined from the Brookfield viscosity curve of CA 50-70. The mechanical compaction process is carried out by applying 75 blows per face. Once the test bodies have been prepared, the physical and volumetric parameters necessary to determine the optimum asphalt content are determined. The volumetric parameters, void volume (Vv), voids in the mineral aggregate (VAM) and the asphalt-voids ratio (RBV) are determined. Based on these results and following the recommendations of the work by Soares et al. (2000), the optimum asphalt content is defined, which will also be used in the preparation of the HAC(A) and HAC(C) mixtures.

The influence of the substitution of the filler by the mineral tailing in the mechanical properties of the HAC is made from the comparison of stability (E), Flow (F), the Marshall stiffness coefficient (E/F), the resistance to indirect traction (RT) and the

Cantabrian wear test. For the determination of the parameters E and F, test tubes immersed in a water bath at 60°C for 50 min are used and a displacement of 50 mm/min is applied in the Marshall press, as established in the (AASHTO T 245, 2015) standard.

2.3. Indirect tensile strength by diametral compression – RT

The evaluation of the tensile strength (RT) is carried out following the methodology proposed in the standard (DNIT 136, 2018). The test consists of applying a progressive compression load in the diametric direction at a speed of 50 mm/s, resulting in tensile stresses in the test body (CP). The determination of RT in kPa is determined by equation 1. It is important to emphasize that in this work a temperature of 25°C was adopted to carry out this test.

$$RT = \frac{2000P}{\pi t D} \tag{1}$$

Where P corresponds to the maximum breaking load in (N), h and d, are the height and diameter in (mm) respectively.

2.4. Cantabro Test

The Cantabro test was developed to determine abrasive wear in open mixes (ASTM D7064, 2004). In the case of dense asphalt mixtures, it can be used to evaluate the durability and cohesion properties between the asphalt and the aggregates. The percentage of abrasion is determined in a Marshall specimen by the difference between the initial and final mass after being subjected to 300 revolutions in the drum of the "Los Angeles" machine at a speed of 33 rpm at a temperature of 25 °C. In the present study, three Marshall samples of each mixture produced are tested.

2.5. Statistical analysis

In order to evaluate the differences between the control mixture and those produced with the mineral tailings, ANOVA analysis of variance tests are applied, adopting a confidence level (1-α) of 95%. It is important to highlight that previous studies such as those by (Lopes et al., 2013) point out that not all physical parameters of asphalt mixtures have a normal distribution. The classic statistical tests are applied to the results of the Marshall and RT tests and the adhesiveness represented in the Cantabro test. The normal distribution of the results is verified through a Shapiro-Wilk normality test.

3. Results

At this point the results obtained during the experimental campaign and their respective analyzes are presented. Initially, the data of the dosing process and the result of the asphalt content used in the study are exposed. The results of the mechanical tests and the percentages of mass loss due to abrasion are shown below.

3.1 Preparation of mixtures

The results of the Marshall dosing process for the HAC mixture (control) are presented in (Table 5). For the asphalt mixtures produced in Brazil, the DNIT 031 ES (2006) standard establishes the quality specifications of volumetric and mechanical parameters that must be met. The values specified for the volumetric parameters are the volume of voids (Vv) from 3 to 5%, voids in the mineral aggregate (VAM) minimum of 15% and the asphalt-voids ratio (RBV) between 75 to 82%. In the case of the Marshall stability mechanical parameter, a minimum value of 500 kgf is specified. From the results in Table 5 an optimum asphalt content of 5.2% is determined.

***Table 5.** Results of Marshall dosage method to HAC (control).*

CA (%)	E (kN)	F (mm)	E/F (kN/mm)	Gmb (g/cm³)	DMT (g/cm³)	VV (%)	VAM (%)	RBV (%)
4,5	10,0	2,0	5,0	2,329	2,451	5,2	15,43	66,03
5,0	12,5	2,8	4,4	2,342	2,433	3,9	15,40	74,86
5,5	15,8	3,2	4,9	2,340	2,415	3,2	15,92	79,98
6,0	14,3	4,0	3,6	2,338	2,397	2,5	16,44	84,72
6,5	11,8	5,2	2,3	2,335	2,379	1,9	16,99	88,87
CA: Asphalt Content; E: Marshall Stability; F: Fluence; E/F Marshall Rigity Coefficient; Gmb: Apparent Specific Gravity of the Mix; DMT: Theoretical Maximum Specific Gravity; Vv: Air Voids; VAM: Voids in the Mineral Aggregate; RBV: Asphalt-Voids Rate.								

As described in the methodology, the mixes produced using the mineral tailings are dosed with the same asphalt content obtained for the control mix. Table 6 shows the results of the physical and volumetric parameters for the HAC(control), HAC(A) *and HAC(C) mixes made with 5.2% asphalt cement. It is important to point out that the results shown correspond to the average of three test bodies manufactured for each type of mixture studied. When comparing the values obtained from the physical parameters Gmb and DMT, an increase in favor of the HAC(A) and HAC(C) mixtures is observed, which is associated with the difference between the densities of the mineral tailing used and the natural filler. On the other hand, the results of the volumetric parameters Vv, VAM and RBV show similarity between all the mixtures and satisfy the asphalt concrete production specifications.*

Table 6: *Parameters of asphaltic mixes studied*

Parameter	***Specification***	***HAC (control)***	***HAC (A)***	***HAC (C)***
CA		*5,2%*	*5,2%*	*5,2%*
Gmb (g/cm³)	-	*2,338*	*2,444*	*2,431*
DMT (g/cm³)	-	*2,425*	*2,532*	*2,526*
Vv (%)	*3-5*	*3,7*	*3,6*	*3,9*
VAM (%)	*15 min.*	*15,70*	*16,14*	*16,39*
RBV (%)	*75-82*	*76,37*	*77,71*	*76,00*

3.2. Marshall parameter results

Figure 4 shows the results of the Marshall test carried out on three specimens for each asphalt concrete. The stability results are expressed in Kn and when compared with the quality parameters of the standard (DNIT 031 ES, 2006), it is verified that all the HACs meet the specifications. The graph details, for comparative purposes, the average stability of HAC(control), and it is possible to perceive that the mixtures HAC(A) and HAC(C) exceed this value. In the case of flow, there are no regulated limits for asphalt mixtures produced in Brazil and their results are shown to establish comparisons.

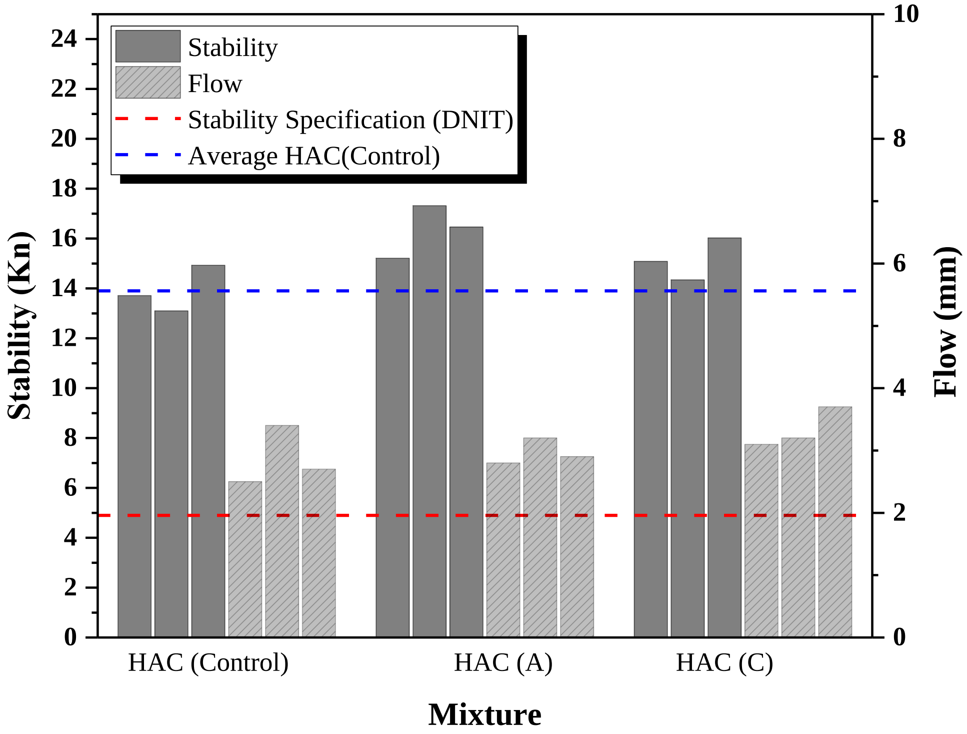


Figure 4. *Marshall Stability and Flow Results*

In order to establish the statistical analysis of these mechanical parameters in the mixtures studied, the average values and the typical deviation are presented in (Table 7). The verification of the normal distribution of the results is carried out through the comparison of the probability value (p) and α=0.05. As can be seen in (Table 7), all the asphalt concretes show a normal distribution of the parameters E, F and E/F according to the Shapiro-Wilk normality test.

Tabla 7. *Statistical values of the mechanical parameters obtained in the Marshall test*

Parameter	*Mix*	$\overline{X}$	σ	*p*	*Normal distribution*
E(kN)	*HAC (Control)*	*13,91*	*0,93*	*0.63*	*Satisfy*
	HAC (A)	*16,33*	*1,06*	*0,79*	*Satisfy*
	HAC (C)	*15,15*	*0,84*	*0,87*	*Satisfy*
F (mm)	*HAC (Control)*	*2,87*	*0,46*	*0,35*	*Satisfy*
	HAC (A)	*2,97*	*0,21*	*0,46*	*Satisfy*
	HAC (C)	*3,00*	*0,26*	*0,36*	*Satisfy*
E/F (kN/mm)	*HAC (Control)*	*4,93*	*0,94*	*0,11*	*Satisfy*
	HAC (A)	*5,50*	*0,15*	*0,12*	*Satisfy*
	HAC (C)	*5,07*	*0,48*	*0,77*	*Satisfy*
$\overline{X}$ *: Mean value,* σ*: Standard deviation, p: probability value*					

From the results of (Figure 4) and (Table 7), it is evident that the substitution of the natural filler for tails A and C confers increases in the average E of 17.39 and 8.9%, respectively, when compared with the results of the control mixture. However, these results are not statistically significant according to the ANOVA variance analysis test (F=4.86 < F0.05=5.14). This behavior is maintained for the other parameters obtained from the Marshall test.

In the case of Marshall flow, the results exhibit greater similarity, showing increases of only 3.4 and 4.5% in favor of the HAC(A) and HAC(C) mixtures, respectively. The ANOVA test (F=0.112 < F0.05=5.14) confirms that these differences are not statistically significant. The Marshall stiffness coefficient depends on the relationship between the parameters E and F, so it maintains the pattern of not presenting significant differences between the mixtures analyzed. The increases in E/F are 11.5% for the mix produced with tail A and 2.8% for the one produced with C. The results F=0.703 < F0.05=5.14 confirm that it should not be reject the null hypothesis H0 in the variance analysis showing that there are no significant variations. Analogously to the result exposed by (Silva, 2017), the incorporation of these residues does not cause significant variations in the stiffness of the mixtures when compared to the conventional mixture.

3.3. Results of the RT test

Figure 5 shows the results of the diametral tensile strength test applied to a set of three CPs for each type of material. In addition, the value specified in the DNIT 031 ES (2006) standard is highlighted and it is verified that all HACs meet the minimum limit of this parameter. For comparative purposes, the average value of the resistance RT of the HAC (Control) elaborated totally with the limestone material is exposed. The average value obtained for HAC(control) is 0.99 MPa with a standard deviation (σ*) of 0.038 MPa, meanwhile, for HAC with the addition of mineral tailing A and C average values of 1.014 and 0.99 are obtained. MPa and standard deviations of 0.066 and 0.039 MPa, respectively.*

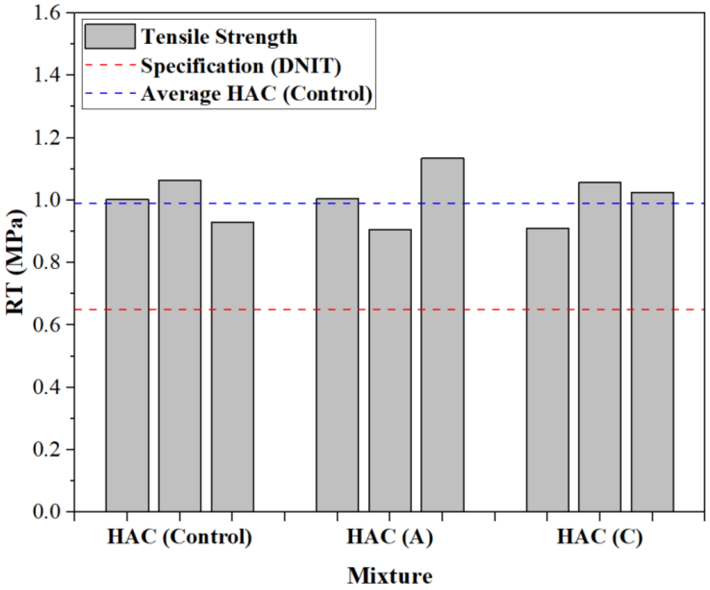


Figure 5. *Results of RT test*

It is important to comment that all the tested groups present a normal distribution of the results, as corroborated by the p values of 0.906; 0.851 and 0.408 for the HAC(Control), HAC(A) and HAC(C) mixtures, respectively. The analysis of variance carried out on these results shows that the substitution of limestone filler for mineral tailing A and C does not confer a significant increase in the tensile strength of the mixtures produced (F=0.036 < F0.05=5.14) . The results indicate, however, that the specifications of use are satisfied with magnitudes very close to the control mixture. These results may be indicative that the tensile strength behavior is better related to the volumetric content of the filler than to the type of filler itself, as verified in the work of (Bastidas, 2017).

3.4. Results of the Cantabro test

The mass loss results for the tested mixtures and the applied normality test are detailed in Table 8. These results are similar if the mass loss of the HAC(A) and HAC (C) mixtures is compared with the mixture of reference HAC(Control) and it is verified in the analysis of variance with values of F=1.61 < F0.05=5.14. From the Cantabro test it can be inferred that there is no loss of cohesion between the mineral skeleton and the asphalt cement, with the replacement of the limestone filler by mineral tailings.

***Table 8**. Statistical values of Cantabro test*

Parameter	Mix	$\overline{X}$	σ	p	Normal Distribution
Cantabro Abrasion test	HAC (Control)	6,41	0,08	0,637	Satisfy
	HAC (A)	6,67	0,15	0,780	Satisfy
	HAC (C)	6,31	0,18	0,061	Satisfy

$\overline{X}$: Mean value, σ: Standard deviation, p: probability value

4. Conclusions

This article evaluates the use of nickel and cobalt mining residues as a substitute for mineral filler in asphalt mixtures. To achieve this objective, three asphalt mixtures were prepared. The first is produced with aggregates and limestone filler and its volumetric and mechanical parameters are taken as reference values. The remaining mixtures are produced by substituting, in the reference granulometry, the filler portion for mining waste. The mixtures are subjected to a group of mechanical tests from which it is concluded that:

The mineral residues studied can be used as a substitute for filler in asphalt mixtures, without the variations in the volumetric parameters (Vv, VAM and RBV) exceeding the use specifications.

The analysis of the Marshall mechanical parameters points to an increase in the stability of the mixtures produced with the waste and maintains the flow value practically constant, which affects the variation of the Marshall stiffness coefficient. It is demonstrated through classical statistical analysis that these variations in the results are not significant and that the use of these residues as filler does not compromise the quality specifications of the asphalt mixtures produced.

The behavior of other mechanical parameters such as RT resistance and Cantabrian wear maintain the pattern of not representing significant variations and not altering the quality specifications.

The use of mineral tailings can be considered a viable technique from the technical point of view, since their incorporation does not reduce the parameters of use regulated for asphalt mixtures. From the environmental point of view, the use of residues in asphalt mixtures can be considered as a measure to mitigate the negative environmental impact generated by the accumulation of these residues. However, it is recommended that additional studies be carried out in order to evaluate the mechanical behavior of the mixtures under cyclic loads (resilient modulus, fatigue and dynamic modulus).

5. References

AASHTO T 104-99. (2016). *Standard Method of Test for Soundess of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate (p. 11). American Association of State and Highway Transportation Officials.*

AASHTO T 228. (2009). *Standard Method of Test for Specific Gravity of Semi-Solid Asphalt Materials (p. 3). American Association of State and Highway Transportation Officials.*

AASHTO T 245. (2015). *Standard Method of Test for Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus (p. 8). American Association of State Highway and Transportation Officials (AASHTO).*

AASHTO T 84-00. (2004). *Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (p. 9). American Association of State and Highway Transportation Officials.*

AASHTO T 85-91. (2004). *Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (p. 10). American Association of State and Highway Transportation Officials.*

AASHTO T 96-02. (2019). *Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (p. 12). American Association of State and Highway Transportation Officials.*

Al-Khateeb, G. G., Irfaeya, M. F., & Khedaywi, T. S. (2017). *A new simplified micromechanical model for asphalt mastic behavior. Construction and Building Materials, 149, 587–598. https://doi.org/10.1016/j.conbuildmat.2017.05.129*

Antunes, V., Freire, A. C., Quaresma, L., & Micaelo, R. (2015). *Influence of the geometrical and physical properties of filler in the filler-bitumen interaction. Construction and Building Materials, 76, 322–329. https://doi.org/10.1016/j.conbuildmat.2014.12.008*

Antunes, V., Freire, A. C., Quaresma, L., & Micaelo, R. (2016). *Effect of the chemical composition of fillers in the filler-bitumen interaction. Construction and Building Materials, 104, 85–91. https://doi.org/10.1016/j.conbuildmat.2015.12.042*

Arabani, M., & Mirabdolazimi, S. M. (2011). *Experimental investigation of the fatigue behaviour of asphalt concrete mixtures containing waste iron powder. Materials Science and Engineering: A, 528(10–11), 3866–3870. https://doi.org/10.1016/j.msea.2011.01.099*

ASTM D113. (2017). *Standard Test Method for Ductility of Asphalt Materials (p. 5). ASTM International.*

ASTM D2419. (2014). *Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate (p. 5). ASTM International.*

ASTM D242-95. (2017). *Standard Specification for Mineral Filler For Bituminous Paving Mixtures. ASTM International. https://doi.org/10.1520/D0242_D0242M-19*

ASTM D2872. (2019). *Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test) (p. 12). ASTM International.*

ASTM D3143. (2008). *Standard Test Method for Flash Point of Cutback Asphalt with Tag Open-Cup Apparatus (p. 6). ASTM International. https://doi.org/10.1520/D3143-08*

ASTM D36 - 95. (2000). *Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus) (p. 4). ASTM International. https://doi.org/10.1520/D0036-95R00E01*

ASTM D4402. (2002). *Standard Test Method for Viscosity Determinations of Unfilled Asphalts Asphalt at Elevated Temperatures Using the Brookfield Thermosel Apparatus a Rotational Viscometer 1. In Annual Book of ASTM Standards (Vol. 87, Issue Reapproved, pp. 1–5). https://doi.org/10.1520/D4402*

ASTM D5 / D5M. (2019). *Standard Test Method for Penetration of Bituminous Materials (p. 4). ASTM International. https://doi.org/10.1520/D0005_D0005M-19A*

ASTM D5821. (2018). *Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate (p. 5). ASTM International. https://doi.org/10.1520/D5821-01*

ASTM D7064. (2004). *Standard Practice for Open-Graded Friction Course (OGFC) Mix Design (p. 6). ASTM International. https://doi.org/10.1520/D7064-04*

Bardini, V. S. S., Klinsky, L. M. G., & Fernandes, J. L. (2010). *A importância do fíler para o bom desempenho de misturas asfálticas. Minerva, 7(1), 71–78.*

Barr, B., Momm, L., Guerrero, Y., & Bernucci, L. (2014). *Characterization of granite and limestone powders for use as fillers in bituminous mastics dosage. Anais Da Academia Brasileira de Ciências, 86(2), 995–1002. https://doi.org/10.1590/0001-3765201420130165*

Bastidas-Martínez, J. G., Rondón-Quintana, H. A., & Muniz de Farias, M. (2021). *Behavior of asphalt mastics containing different materials as filler. Canadian Journal of Civil Engineering, 48(4), 347–355. https://doi.org/10.1139/cjce-2019-0342*

Bastidas, J. G. (2017). *Asfaltos e misturas modificadas com materiais alternativos. Brasilia: Universidade de Brasília.*

Cesare, S., Piergiorgio, T., Claudio, L., & Francesco, M. (2019). Application of Mining Waste Powder as filler in Hot Mix Asphalt.

MATEC Web of Conferences, 274(February), 04002. https://doi.org/10.1051/matecconf/201927404002

DNER-EM 367. (1997). *Material de enchimento para misturas betuminosas (p. 3). Departamento Nacional de Estradas de Rodagem.*

DNER-ME 078-94. (1994). *DNER-ME 078: Agregado graúdo - adesividade a ligante betuminoso (p. 3). Departamento Nacional de Estradas de Rodagem.*

DNIT 031 ES. (2006). *Pavimentos flexíveis - Concreto asfáltico - Especificação de serviço (p. 14). Departamento Nacional de Infraestructura de Transportes. http://www.dtt.ufpr.br/Pavimentacao/Notas/DNIT031_2006_ES.pdf*

DNIT 095/. (2006). *Cimentos asfálticos de petróleo - Especificação de material (p. 6). Departamento Nacional de Infraestructura de Transportes. http://ipr.dnit.gov.br/normas-e-manuais/normas/especificacao-de-material-em/dnit095_2006_em.pdf*

DNIT 136. (2018). *Determinação da resistência à tração por compressão diametral-Método de ensaio. In Departamento Nacional de Infraestrutura de Transportes (p. 6).*

Kütük-Sert, T., & Kütük, S. (2013). *Physical and Marshall Properties of Borogypsum Used as Filler Aggregate in Asphalt Concrete. Journal of Materials in Civil Engineering, 25(2), 266–273. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000580*

Lopes, M. D. M., Castelo Branco, V. T. F., & Soares, J. B. (2013). *Utilização dos testes estatísticos de Kolmogorov-Smirnov e Shapiro-Wilk para verificação da normalidade para materiais de pavimentação. TRANSPORTES, 21(1), 59. https://doi.org/10.4237/transportes.v21i1.566*

Rondón-Quintana, H. A. H. A., Ruge-Cárdenas, J. C., Bastidas-Martínez, J. G., Velandia-Castelblanco, M. Y., & Muniz De Farias, M. (2020). *Use of Thermally Treated Bentonite as Filler in Hot Mix Asphalt. Journal of Materials in Civil Engineering, 32(5), 0–10. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003127*

Sangiorgi, C., Tataranni, P., Mazzotta, F., Simone, A., Vignali, V., & Lantieri, C. (2017). *Alternative Fillers for the Production of Bituminous Mixtures: A Screening Investigation on Waste Powders. Coatings, 7(6), 76. https://doi.org/10.3390/coatings7060076*

Serguio Betancourt, Sosa, E. R., Ribeiro, L. F. M., Farias, M. M. de, & García, L. M. (2017). *Posibilidades de empleo de colas minerales como forma de atenuar su impacto ambiental negativo. In E. Capriro (Ed.), XI Simposio Internacional de Estructuras, Geotecnia y Materiales de Construcción (p. 10). Convención UCLV 2017.*

Sharapov, R. R., Kharlamov, E. V., & Gabdullin, T. R. (2018). *The Use of Metallurgical Wastes in Road Construction. Materials Science Forum, 931, 674–678. https://doi.org/10.4028/www.scientific.net/MSF.931.674*

Silva, R. G. O. da. (2017). *Caracterização de concreto asfáltico elaborado com rejeitos de minério de ferro do quadrilátero ferrífero [Universidade Federal de Ouro Preto]. https://www.nugeo.ufop.br/uploads/nugeo_2014/teses/arquivos/silva-2017-tese-doutorado-nugeo.pdf*

Soares, J. B., Freitas, F. A. ., Castelo Branco, V., & Motta, L. M. G. (2000). *Método de Previsão do Teor Ótimo de Ligante em Misturas Asfálticas tipo CBUQ. In ABPv (Ed.), 32° Reunião Anual de Pavimentação (pp. 148–160). ABPv - Associação Brasileira de Pavimentação.*