USE OF CALCIUM CARBONATE SLUDGE AS FILLER IN HOT MIX ASPHALT CONCRETE SLUDGE

UTILIZAÇÃO DE LAMA DE CARBONATO DE CÁLCIO COMO FÍLER EM CONCRETO ASFÁLTICO USINADO A QUENTE

USO DE LODO DE CARBONATO DE CALCIO COMO FILTRANTE EN HORMIGÓN ASFÁLTICO MECANIZADO EN CALIENTE

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ABSTRACT

Using industrial solid waste in the composition of asphalt mixtures can provide economic and environmental gains for the generating sector and civil construction. This work evaluated the feasibility of using calcium carbonate sludge as a filler material in producing hot-mix asphalt concrete. The methodology was based on current standards, using a reference trace based on the Marshall dosage to measure the ideal content of petroleum asphalt cement and replacing three levels (2%, 3% and 4%) of stone dust with carbonate calcium sludge in the mixtures. The stability and creep parameters results did not show a statistically significant difference despite the increase in resistance (1394.41 kgf) and lower deformation (3.48 mm) using 3% residue compared to the reference mixture. On the other hand, the values for the percentage of voids and the bitumen-void ratio showed statistical differences, reaching values of 5.29% and 69.86%, respectively, with the incorporation of 3% of the sludge. It was concluded that there is a possibility of reducing petroleum asphalt cement in the composition of the mixtures and a potential for using this residue as a filler in hot-mix asphalt concrete.

KEYWORDS

Industrial solid waste; Calcium carbonate sludge; Hot mix asphalt concrete; Asphalt paving.

RESUMO

A utilização de resíduos sólidos industriais na composição de misturas asfálticas pode proporcionar ganhos econômicos e ambientais para o setor gerador e para a construção civil. Este trabalho avaliou a viabilidade do uso de lama de carbonato de cálcio como material de enchimento na produção de concreto asfáltico misturado a quente. A metodologia foi baseada nas normas vigentes, utilizando um traço de referência baseado na dosagem Marshall para medir o teor ideal de cimento asfáltico de petróleo e substituindo três níveis (2%, 3% e 4%) de pó de pedra por lama de carbonato de cálcio nas misturas. Os resultados dos parâmetros de estabilidade e fluência não apresentaram diferença estatisticamente significativa apesar do aumento na resistência (1394,41 kgf) e menor deformação (3,48 mm) utilizando 3% de resíduo em relação à mistura de referência. Por outro lado, os valores da percentagem de vazios e da relação betume-vazio apresentaram diferenças estatísticas, atingindo valores de 5,29% e 69,86%, respetivamente, com a incorporação de 3% de lama. Concluiu-se que existe possibilidade de redução do cimento asfáltico petrolífero na composição das misturas e potencial de utilização deste resíduo como carga em concretos asfálticos usinados a quente.

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PALAVRAS-CHAVE

Resíduo sólido industrial; Lama de carbonato de cálcio; Concreto asfáltico usinado à quente; Pavimento asfáltico.

RESUMEN

El uso de residuos sólidos industriales en la composición de mezclas asfálticas puede proporcionar ganancias económicas y ambientales para el sector generador y la construcción civil. Este trabajo evaluó la factibilidad de utilizar lodo de carbonato de calcio como material de relleno en la producción de concreto asfáltico de mezcla en caliente. La metodología se basó en las normas vigentes, utilizando una traza de referencia basada en la dosificación Marshall para medir el contenido ideal de cemento asfáltico de petróleo y reemplazando tres niveles (2%, 3% y 4%) de polvo de piedra por lodo de carbonato de calcio en el mezclas. Los resultados de los parámetros de estabilidad y fluencia no mostraron una diferencia estadísticamente significativa a pesar del aumento de la resistencia (1394,41 kgf) y la menor deformación (3,48 mm) utilizando un 3% de residuo con relación a la mezcla de referencia. Por otro lado, los valores para el porcentaje de huecos y la relación betún-huecos mostraron diferencias estadísticas, alcanzando valores de 5,29% y 69,86%, respectivamente, con la incorporación de un 3% de lodo. Se concluyó que existe la posibilidad de reducir el cemento asfáltico a base de petróleo en la composición de las mezclas y el potencial de utilizar este residuo como relleno en concreto asfáltico maquinado en caliente.

PALABRAS CLAVE

Residuos sólidos industriales; Lodo de carbonato de calcio; Hormigón asfáltico mecanizado en caliente; Pavimento asfáltico.

1. INTRODUCTION

Asphalt pavements are essential for users' daily lives in developing and developed countries. Due to the increase in traffic volume, there is an increasing number of road construction projects, thus requiring large quantities of natural construction materials.

Hot mix asphalt production requires 90 to 95% by mass of aggregates (KHASAWNEH; ALSHEYAB, 2020; TAHMOORIAN; SAMALI, 2018). Around 1.36 trillion tons of asphalt are used annually to pave roads and airports (DEVULAPALLI; KOTHANDARAMAN; SARANG, 2019). This non-renewable material causes severe environmental problems (DYER; DE LIMA, 2022).

Mining activities are associated with the extraction of aggregates, causing soil erosion, loss of biodiversity, destruction of fauna and flora, geological risks, geomorphological changes, and soil, air and water contamination. Inyim et al. (2016) estimate that 50% of total greenhouse gas emissions from pavement construction are linked to the extraction of natural resources. Considering these undesirable scenarios, developing new, more sustainable paving technologies is elementary. To this end, the reuse of industrial solid waste in the incorporation or partial replacement of these materials in hot asphalt mixes can be considered one of the alternatives to reduce the extraction of non-renewable natural resources, the cost of building roads, and the generation of carbon dioxide emissions.

Several research have been conducted on using industrial solid waste in asphalt pavements as filler materials of different particle sizes. Among which, we can mention the use of dregs and grits (MODOLO *et al.*, 2010), iron powder residue (ARABANI; MIRABDOLAZIMI, 2011), andesite residue (UZUN; TERZI, 2012), biomass ash (MELOTTI *et al.*, 2013), ceramic tile waste (SILVESTRE *et al.*, 2013), glass waste (SHAFABAKHSH; SAJED, 2014), plastic waste (KÖFTECI; AHMEDZADE; KULTAYEV, 2014), coal waste (MODARRES; RAHMANZADEH; AYAR, 2015), fly ash biomass (PASANDÍN *et al.*, 2016), tire rubber waste (PASANDÍN; PÉREZ, 2017), silicon-manganese iron slag (OLIVEIRA *et al.*, 2017), construction and demolition waste (AL-BAYATI; TIGHE; ACHEBE, 2018; ARTUSO; LUKIANTCHUKI, 2019), red sludge (ZHANG *et al.*, 2019), calcium carbide residue (DULAIMI *et al.*, 2020), ferronickel slag (COSME; FERNANDES; FERNANDES, 2021), ash of incinerated acid sludge (SHISHEHBORAN *et al.*, 2021), graphite (PEREIRA; LACERDA; MODOLO, 2021), sugarcane residue (LE, 2021), water treatment plant sludge (HASAN *et al.*, 2022), sludge from the processing of ornamental rocks (FACHIN *et al.*, 2022) and scheelite residues (SOUZA *et al.*, 2023). Following this perspective, another potential waste is calcium carbonate sludge (CCS) from the cellulose and paper industry.

In 2022, Brazilian cellulose production totaled approximately 25 million tons, and Brazilian paper production reached 11 million tons (IBÁ, 2022). This production scenario highlights the generation of large volumes of waste, with the amount generated depending on the technology used and the type of paper to produce (HAQ; RAJ, 2020; MODOLO *et al.*, 2010). At all stages of the production process, these residues of organic and inorganic origin have different compositions and moisture levels.

The Kraft process is the most widespread and used paper production method in the world. It differs from the others by presenting numerous advantages, such as preserving the strength of the fibers, shorter cooking cycles with lower temperatures, and a more efficient reagent recovery system. In its last production stage, calcium carbonate sludge, or lime sludge, is generated. It is an inorganic solid residue, white, rich in calcium carbonate, with an estimated generation of 20 to 30 kg (dry basis) per ton of cellulose processed in Brazil (RIBEIRO *et al.*, 2022).

Based on this context, this research aimed to investigate the possibility of using calcium carbonate sludge as a filler, replacing natural aggregates in hot mix asphalt concrete mixtures, and contributing to an adequate disposal of this waste in civil construction.

2. MATERIALS AND METHODS

Calcium carbonate sludge was made available by a partner company. The determination of the particle size distribution was carried out using the laser particle size test using the Microtac equipment, model S3500. The specific mass was determined by helium gas pycnometry using the Pycnometer equipment, model AccuPyc II 1340 from Micromeritics. The specific surface area by nitrogen adsorption (BET) was determined using the Micromeritics TriStar II Plus equipment. Chemical characterization was determined using a PANalytical equipment, model Epsilon 1. The morphology was observed using the Scanning Electron Microscope (SEM), model EVO MA 15. The mineralogical determinations were carried out by X-ray diffraction (XRD), using diffractometer equipment from the Panalytical brand, model Empyrean.

The coarse aggregates of granitic origin had a maximum characteristic diameter (MCD) of 9.5 and 19 mm. Stone dust (passed through a 200 mesh sieve), also of granite origin, was used as fine aggregate. The petroleum asphalt cement (PAC) used as a binder was 50/70, acquired by a partner industry.

The granulometric analysis of the aggregates was carried out to comply with the rules inherent to the working ranges determined by the DNIT 031 standard (DNIT, 2006), and the physical properties were found by NBR 16917 (ABNT, 2021). The specific mass of the stone powder was carried out per the DNER – ME 084 standard (DNER, 1995), and the company provided the specific mass of the PAC. The results obtained from the analyses above are presented in Table 1.

Physical Properties	Dry Specific Mass (g/cm³)	Specific mass in saturated condition with dry surface (g/cm³)	Apparent Specific Mass (g/cm³)	Water absorption (%)
Coarse aggregate (MCD – 9.5 mm)	2.878	2.752	2.684	2.505
Coarse aggregate (MCD – 19 mm)	2.856	2.792	2.757	1.265
Stone Dust (MCD = 4.8 mm)	2.796	-	-	-
Petroleum Asphalt Cement (PAC)	1.045	-	-	-

Table 01: Physical characterization of aggregates and PAC.

Source: Authors

Based on the characterization results and granulometric composition of the aggregates, it was observed that the most suitable pavement range is range B, established in the DNIT 031 standard (DNIT, 2006). Then, the replacement levels of stone dust with CCS were defined at 0% (REF mixture), 2% CCS (CCS2%), 3% CCS (CCS3%), and 4% CCS (CCS4%) to compose the concrete asphalt, checking its adequacy to the pre-established limits as can be seen in Figure 1. Although the projected curve appears outside the range specified on the 200 mesh sieve, it is still within the tolerance range of ± 2% as per regulations. After this step and with the results of the specific mass of the aggregates and the binder, the theoretical density of each mixture was calculated according to the regulations of DNIT 428 (DNIT, 2020) and Pinto; Pinto (2015), which can be seen in Table 2.

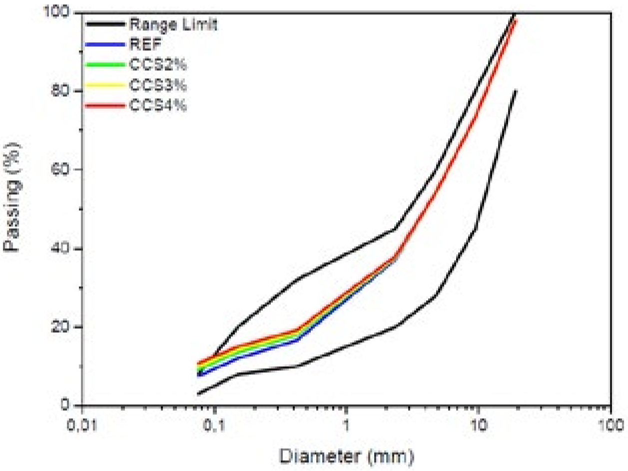


Figure 01: Granulometric distribution of asphalt mixtures without addition of PAC.

Source: Authors

Materials Mixtures	Coarse aggregate (MCD = 9.5 mm)	Coarse aggregate (MCD = 19 mm)	Stone Dust (MCD = 4.8 mm)	CCS	Theoretical Density
REF	27	27	46	0	2.6027
CCS2%	27	27	44	2	2.5994
CCS3%	27	27	43	3	2.5977
CCS4%	27	27	42	4	2.5961

Table 2: Composition of asphalt mixtures without addition of PAC and respective theoretical densities (m.s. = dry mass).

Source: Authors

The determination of the ideal asphalt cement content was obtained by the Marshall method using the reference mix, without adding residue, varying in 4.5% PAC, 5.0% PAC, 5.5% PAC, and 6.0% PAC about the mass of the mixture, according to Figure 2.

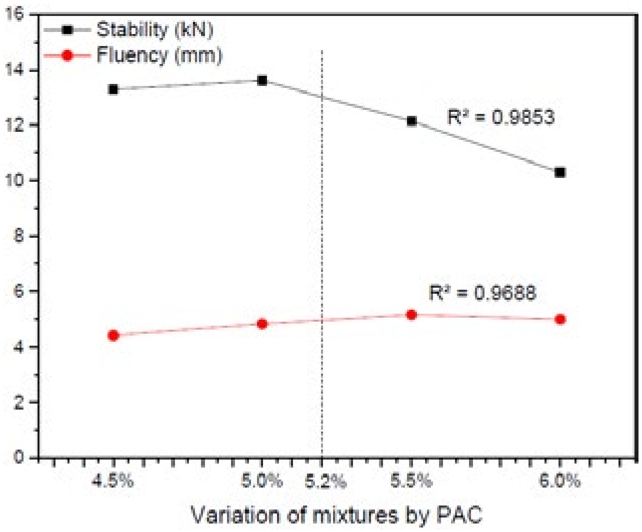


Figure 02: Intersection between the chosen PAC percentage and the corresponding stability and creep values.
Source: Authors

After defining the optimal PAC content, it was set at 5.2% for all traits. The composition of the materials presented in Table 2 was reformulated. Table 3 summarizes the final quantity of materials for each trace investigated. 4 specimens were produced for each CCS variation. The DNIT 178 standard (DNIT, 2018) recommends that for each specimen of ø100 mm and 60 mm in height, 1200 grams of asphalt mixture is required.

Materials Mixtures	MCD = 9.5 mm (g)	MCD = 19 mm (g)	Stone Dust (g)	CCS (g)	PAC (g)	Total
REF	307.15	307.15	523.30	0.00	62.40	1200
CCS2%	307.15	307.15	512.83	10.47	62.40	1200
CCS3%	307.15	307.15	507.60	15.70	62.40	1200
CCS4%	307.15	307.15	502.36	20.94	62.40	1200

Table 3: Composition of asphalt mixtures with addition of PAC.
Source: Authors

The stability and creep of the specimens were determined using the Marshall method. These tests measure the maximum resistance to radial compression and total deformation, respectively (DNER, 1995b).

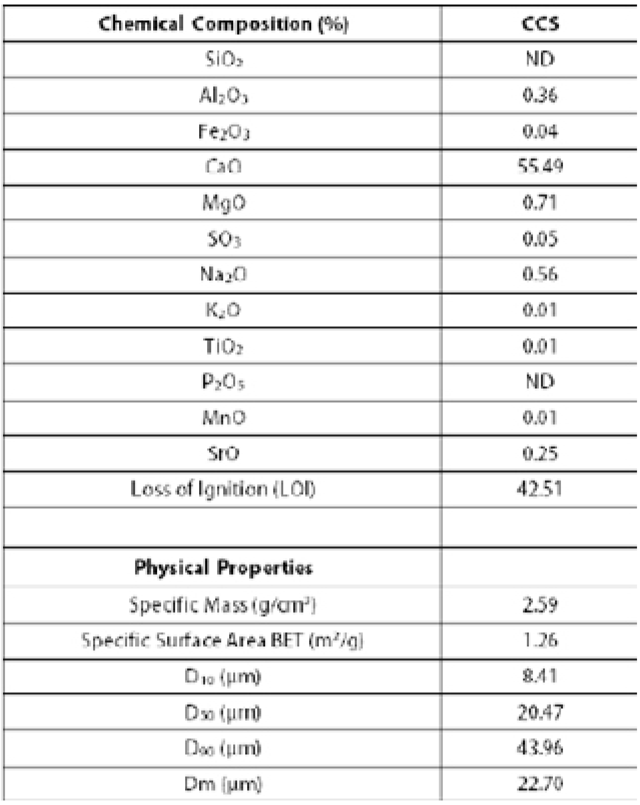
To calculate the percentage of voids, it is necessary to use the apparent and theoretical densities of the mixtures by the DNER – ME 043 standard (1995b). Thus, using the values of theoretical densities combined with information on the masses obtained by hydrostatic weighing, the apparent densities were calculated, and finally, the percentages of voids were calculated for each specimen.

To calculate the Bitumen Void ratio, the percentage of voids occupied by the CAP binder and the percentage of voids in the mineral aggregate were used. The DNER describes the method for carrying out this calculation – ME 043 standard (1995b).

Statistical analyses were also conducted to detect patterns and trends in the results obtained using the SISVAR software. Next, an analysis of variance (ANOVA) was performed using the Tukey test to determine whether the mean results of all measured parameters presented a statistically significant difference as the percentage of CCS varied. The significance level adopted for this test was 5%.

3. ANALYSIS AND DISCUSSION OF RESULTS

The chemical and physical composition of the residue is shown in Table 4. It can be seen that the calcium carbonate sludge (CaCO3) is rich in calcium oxide (CaO) and has a high fire loss due to the release of carbon dioxide. (CO2) through the decarbonation process. Using stoichiometry, it is possible to estimate the amount of CaCO3 present in this sludge, considering 0.56 g/mol of CaO molar mass and the presence of 55.49% of CaO on a dry basis. Thus, it is possible to assess the presence of 99.09% calcium carbonate. It can be seen in the literature that CaO is the typical constituent of CCS (MODOLO *et al.*, 2014; MODOLO *et al.*, 2010). As for the particle size of this waste, its particles are in the range of 2 to 105 µm but predominantly below 75 µm, which can be used as inert materials (particle packaging).



Chemical Composition (%)	CCS
SiO_2	ND
Al_2O_3	0.36
Fe_2O_3	0.04
CaO	55.49
MgO	0.71
SO_3	0.05
Na_2O	0.56
K_2O	0.01
TiO_2	0.01
P_2O_5	ND
MnO	0.01
SrO	0.25
Loss of Ignition (LOI)	42.51
Physical Properties	
Specific Mass (g/cm³)	2.59
Specific Surface Area BET (m²/g)	1.26
D_{10} (µm)	8.41
D_{50} (µm)	20.47
D_{90} (µm)	43.96
Dm (µm)	22.70

Table 4: Physicochemical characterization of CCS.

Source: Authors

Figure 3 presents the morphological and mineralogical characteristics of the CCS. It is evident that the sludge particles are agglomerated and irregular, possibly due to their generation by precipitation in industry. Analyzing the diffractogram, predominant calcite peaks are observed, corroborating the XRF results.

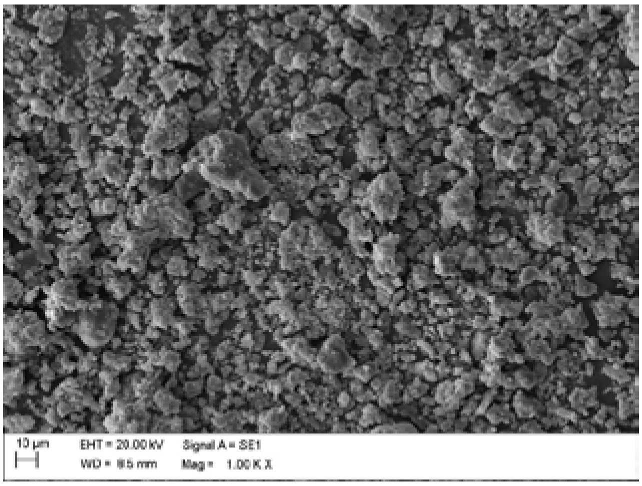


Figure 3: Morphological and mineralogical analysis of CCS.

Source: Authors

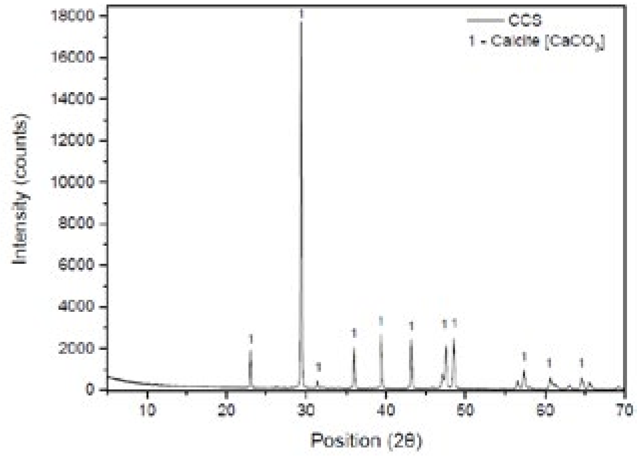


Figure 3: Morphological and mineralogical analysis of CCS.

Source: Authors

Other authors state that CCS waste can be classified as non-hazardous and, in some cases, inert according to the results of the environmental characterization by Buruberri; Seabra; Labrincha (2015), according to Decree-Law nº 152/2002, as well as Simão *et al*. (2017) and Milak *et al*. (2019) according to NBR 10004 (ABNT), 2004).

Figure 4 presents the results obtained in the Marshall test for stability and creep in the specimens of each mixture investigated. The DNIT 031 standard (DNIT), 2006) establishes a minimum value of 500 kgf for acceptable stability and a range of 2 to 4.6 mm for acceptable creep in the adopted range B. About the reference, 2% and 4% mixtures showed a reduction in the stability value of 2.88% and 12.79%. On the other hand, the mixture with 3% CCS slightly increased this criterion by 0.51%. Regarding the performance of the mixtures in the creep analysis, all formulations showed lower deformations than the REF mixture, 23.55% with 2% CCS, 25.48% with 3% CCS, and 17.99% with 4% CCS, but within limits recommended by the regulations Brazilian.

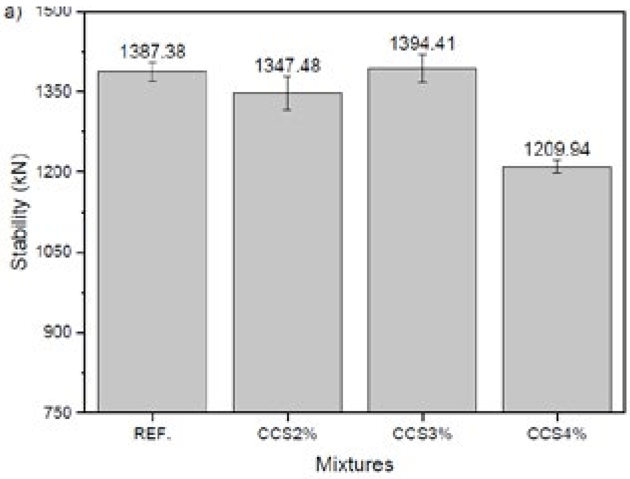


Figure 4: Averages obtained from the mixtures by the Marshall test: a) stability and b) fluency.

Source: Authors

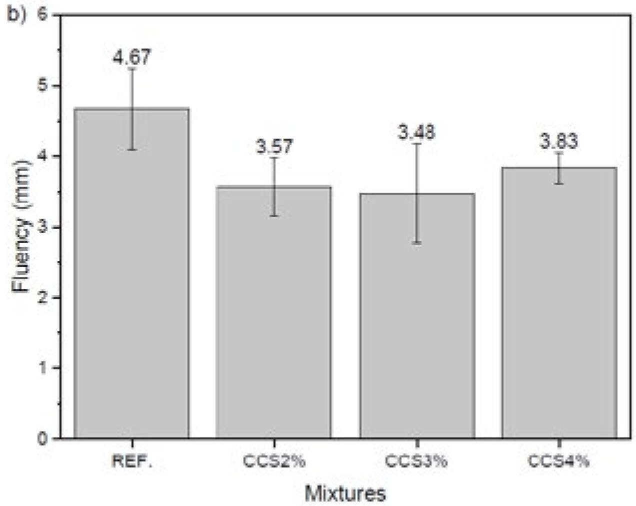
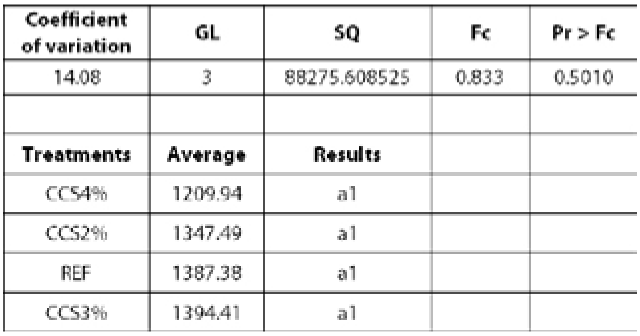


Figure 4: Averages obtained from the mixtures by the Marshall test: a) stability and b) fluency.
Source: Authors

The values for both parameters were within the norm in all variations of calcium carbonate sludge. However, the stability value with 4% CCS demonstrated a downward trend. This fact was also observed by Bardini; Klinsky; Fernandes (2010), realizing that the higher the percentage of material passing through the 75μm sieve, the voids in the granular skeleton reduced, the granular gradation is improved, and the workability of the asphalt mixture is increased, to a certain extent. Above this point, the higher the percentage passing through the 75μm sieve, the more fines impair the stability of the mixture, reducing contact between coarse particles and altering the compaction capacity. According to Arabani; Tahami (2017), stability indicates the resistance of the asphalt mixture to horizontal tension, pressure, and shear due to compression load.

Modolo et al. (MODOLO *et al*., 2010) evaluated the effect of replacing natural aggregates with dregs and grits from the cellulose and paper industry in bituminous mixtures. The authors achieved stability values of 1142 kgf and 1080 kgf using 5% dregs and 5% grits, respectively. Lins (2019) investigated the production of asphalt binder modified with lignin from the cellulose and paper industry. The author showed better stability results with 4% lignin addition, reaching values of approximately 1100 kgf. Fachin *et al*. (2022) obtained values of 1079.78 kgf using 4% sludge from processing ornamental rocks in asphalt mixtures.

In the analysis of variance for stability, according to Table 5, the p-value was 0.5010, demonstrating insufficient evidence to state a significant difference between the means obtained in each percentage of CCS used. Even without demonstrating this difference, the test still demonstrates that the experiment presented acceptable variability since the coefficient of variation was 14.08%, which is 20% lower. All means were grouped into the same group, “a1”, confirming that the experiments presented statistically equal means.

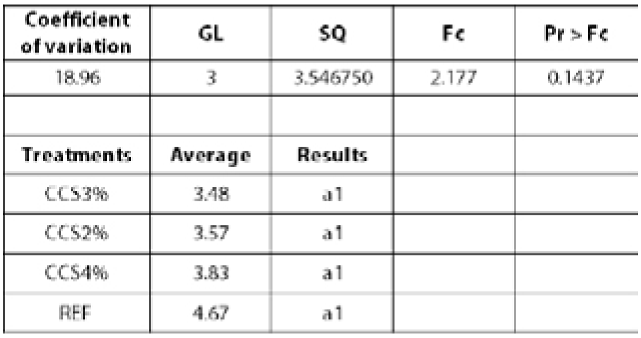


Coefficient of variation	GL	SQ	Fc	Pr > Fc
14.08	3	88275.608525	0.833	0.5010
Treatments	**Average**	**Results**		
CCS4%	1209.94	a1		
CCS2%	1347.49	a1		
REF	1387.38	a1		
CCS3%	1394.41	a1		

Table 5: ANOVA for the stability variable.
Source: Authors

In the fluency requirement, Modolo *et al*. (2010) achieved 2.5 mm and 2.9 mm values when using 5% dregs and 5% grits in bituminous mixtures, respectively. Fachin *et al*. (2022) achieved results of 4.27 mm when using 4% of the sludge from processing ornamental rocks in asphalt binders.

For this parameter, it was also observed that the ANOVA test did not identify sufficient evidence to show variation in the results as the increase in residue in the formulations investigated, according to Table 6. The results indicate a p-value of 0.1437, demonstrating insufficient evidence to affirm a significant difference between the averages obtained for fluency in each percentage of CCS used. Even without demonstrating this statistical difference, the test still demonstrates that the experiment presented acceptable variability since the coefficient of variation was 18.96%, less than 20%. All means were grouped into the same group, “a1”, confirming that the experiments presented statistically equal means.



Coefficient of variation	GL	SQ	Fc	Pr > Fc
18.96	3	3.546750	2.177	0.1437
Treatments	**Average**	**Results**		
CCS3%	3.48	a1		
CCS2%	3.57	a1		
CCS4%	3.83	a1		
REF	4.67	a1		

Table 6: ANOVA for the fluency variable.
Source: Authors

Figure 5 shows the results obtained in the Marshall test for the parameter percentage of voids in the mixture. The DNIT 031 standard (DNIT, 2006) establishes the 4% and 6% percentages as an acceptable range for the connection layer, range B. All formulations investigated presented parameters within this range.

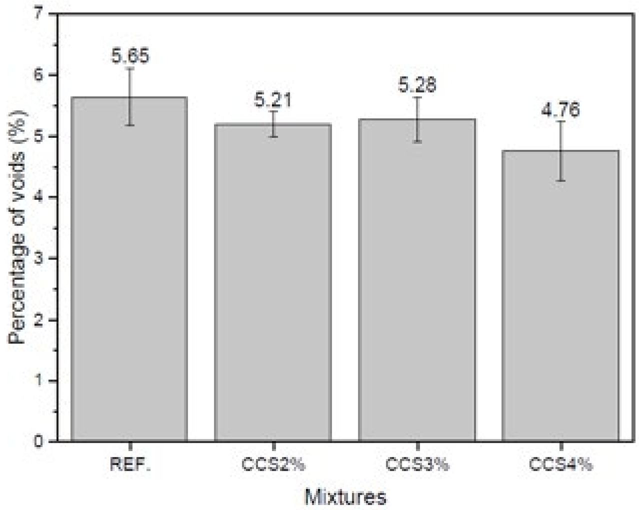


Figure 5: Percentage of voids in the asphalt mixtures investigated.

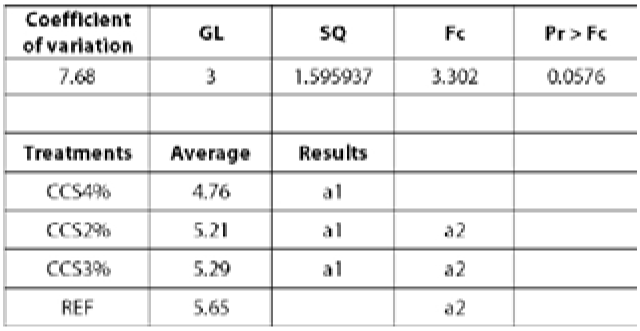
Source: Authors

As seen in Figure 5 and according to the CCS granulometry in Table 4, this residue provided a filling effect in the asphalt mixtures, thus reducing the percentage of the number of voids. Comparing these results with the literature, considering inert waste, Modolo et al. (2010) achieved a percentage of voids in asphalt mixtures of 3.8% using 5% grits and 4.9% using 5% dregs. Fachin *et al.* (2022) obtained values of 5.85% using 4% of the sludge from processing ornamental rocks in asphalt binders. Therefore, all these residues provided a filler effect.

The Rigden void index, modified by Anderson, is a method capable of analyzing the effect of the filler in the asphalt mixture, determined under standardized conditions, since the voids in the filler-asphalt binder mixture result in maximum densification of the filler (BARDINI; KLINSKY; FERNANDES, 2010). When the amount of binder increases beyond the Rigden void ratio, the particles lose contact, and the additional amount of binder causes lubrication between the particles. On the other hand, when the free amount of binder decreases, the stiffness of the mixture increases. Therefore, the thinner the filler, the lower the filler-binder ratio must be, considering that the free volume of binder causes the increase in the coating thickness of the aggregate particles.

Therefore, the higher the volumetric concentration of the filler-binder system, the aggregate particles in the mixture are closer together, and the pore volume will be smaller. Consequently, the mixtures will have greater rigidity, corroborated in stability tests.

In the analysis of variance for the percentage of voids, as shown in Table 7, the p-value was 0.5076, slightly greater than 0.05, implying that there may be some significant statistical difference between the means for the different CCS percentages. The difference between the groups is observed because the test separated the results into two groups, "a1" and "a2". The REF trace results differed significantly from those obtained when 4% CCS was added. In the case of 2% and 3% CCS, the test presented a conflict, making the statement that these mixtures differ from the others uncertain and could be statistically equal to the REF and differ from the mixture with 4% CCS or be equal to the last formulation and differ from REF.



Coefficient of variation	GL	SQ	Fc	Pr > Fc
7.68	3	1.595937	3.302	0.0576
Treatments	**Average**	**Results**		
CCS4%	4.76	a1		
CCS2%	5.21	a1	a2	
CCS3%	5.29	a1	a2	
REF	5.65		a2	

Table 7: ANOVA for the variable percentage of voids.

Source: Authors

Figure 6 shows the values obtained when calculating the bitumen/voids ratio. The DNIT 031 standard (DNIT), 2006) establishes an acceptable 65% to 72% range for the band B bonding layer. All formulations investigated presented parameters within this range despite the mixture with 4% CCS being at the upper limit.

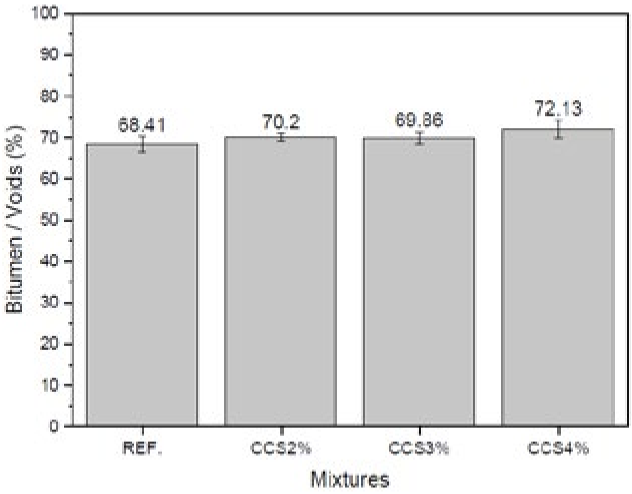
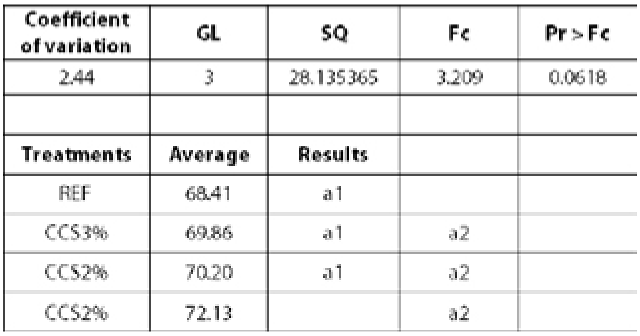


Figure 6: Bitumen/void ratio in the investigated mixtures.
Source: Authors

The bitumen-void ratio indicates the percentage of aggregate voids filled by the binder (PINTO; PINTO, 2015). Thus, for a ratio of 0%, we have a mixture without asphalt. For a ratio of 100%, it indicates that all voids are filled with asphalt. In previous studies, Fachin *et al.* (2022) achieved results of 65.16% using 4% of the sludge from the processing of ornamental rocks. It is essential to highlight that when noticing an increase in the bitumen/voids ratio as the percentage of CCS in the mixture increases, care must be taken not to exceed the limit recommended in the standard, as excess can cause cracking and reduce life—usefulness of the asphalt mixture.

In the analysis of variance for the bitumen/voids relationship, as shown in Table 8, the p-value was 0.0618, slightly greater than 0.05, implying that there may be some significant statistical difference between the means for the different CCS percentages. The difference between the groups is observed because the test separated the results into two groups, “a1” and “a2”. The REF trace results differed significantly from those obtained when 4% CCS was added. If the bitumen-void ratio increases, this means a reduction in PAC consumption in the mixture, as the residue fills the voids and improves the absorption of the binder by the mixture. In the case of 2% and 3% CCS, the test presented a conflict, making the statement that these mixtures differ from the others uncertain and could be statistically equal to the REF and differ from the mixture with 4% CCS or be equal to the last formulation and differ from REF.



Coefficient of variation	GL	SQ	Fc	Pr > Fc
2.44	3	28.135365	3.209	0.0618
Treatments	**Average**	**Results**		
REF	68.41	a1		
CCS3%	69.86	a1	a2	
CCS2%	70.20	a1	a2	
CCS2%	72.13		a2	

Table 8: ANOVA for the bitumen/void ratio variable.
Source: Authors

4. CONCLUSIONS

In this work, the use of calcium carbonate sludge in the production of hot mix asphalt mixtures was investigated. With the experimental results, it was possible to conclude that:

- The PAC content of 5.2% was well suited to the mixtures produced since the tested mixtures showed stability parameters, creep, percentage of voids, and bitumen/void ratio within the normative ranges;
- In stability and creep analyses, the 3% CCS provided an improvement in strength by 0.51% and a decrease in deformation by 25.48%, respectively, compared to the reference mixture;
- In terms of the percentage of voids, all formulations achieved lower values compared to the reference mixture, being a good indication of the filling effect provided by the residue to bituminous concretes;
- It was verified in the bitumen/void ratio that as CCS is inserted into the mix, there is a surplus of binder, indicating the possibility of adjusting the mixture to a lower PAC value and, therefore, reducing the production cost of these asphalt mixtures.

Therefore, this study demonstrates that replacing stone dust with CCS can contribute to the preservation of the environment, minimize the environmental impacts of inadequate disposal of this waste in uncontrolled landfills, reduce the extraction of non-renewable natural resources, and add less value economical in the production of hot mix asphalt mixtures.

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