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PRELIMINARY STUDY OF HOT MIX ASPHALT CONTAINING WATER TREATMENT AND SEWAGE SLUDGE

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Throughout the world, considerable quantities of water treatment sludge (WTS) and sewage sludge (SS) are produced as waste. This study assessed in the laboratory, the possibility to use both waste products when they are incorporated as filler at 1% with relation to the total mass of a hot mix asphalt - HMA. To this end, both waste products were initially reduced to ash through a calcination process. Resistance tests under monotonic load (Marshall and indirect tension tests), and cyclic load (resilient modulus test) were applied on mixes that contained WTS and SS. Besides, moisture damage (modified Lotmman test), and abrasion (Cantabro) resistance were assessed. An analysis of variance (ANOVA) test was performed in order to verify if the results are statically equal or not to those of the control HMA. As a general conclusion, it is reported that both materials show a resistance increase under monotonic load and higher stiffness under cyclic load (cohesion) when they are incorporated into the mix as filler despite the fact that the asphalt content used was less than the control mix. However, some problems are observed associated with moisture damage resistance, and friction wear (adherence).

Keywords: Water treatment sludge, sewage sludge, mineral filler, hot mix asphalt.

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1. INTRODUCTION

1.1. PROBLEM STATEMENT AND OBJECTIVE

Raw water treatment plants (WTP), and sewage treatment plants (STP) produce wastes known as water treatment sludge (WTS) and sewage sludge (SS), [1] [2] [3]. WTS and SS are considered solid waste that contain organic matter and chemical treatment waste such as coagulants (aluminum and iron salts), and auxiliary coagulants (organic polymers) [2]. WTS and SS properties depend on the raw water and water treatment quality as well as the treatment method applied [4]. Currently, these types of sludge are considered environmental liabilities to be avoided due to the high potential for contamination and toxicity that place public health and the environment at risk [5] [6]. The main source of contamination is caused by the high concentrations of aluminum and heavy metals present in the sludge affecting aquatic and terrestrial microorganisms [7]. These types of sludge are also considered environmental liabilities due to the large volumes produced and the areas required for their final disposal. However, one way of reducing the volume of the sludge is by means of its dehydration and calcination into ash to be later disposed of in that state [1]. Calcination is a treatment carried out on solid waste, mainly in developed countries. In Europe, 53% of sludge production is reused in agriculture activities and recovery of degraded areas, and 21% is incinerated [8]. However, the current forms of final disposal of the WTS and SS can be considered momentary due to the possible migration of heavy metals to the water table level or to water bodies [9]. There are unconventional forms of sludge disposal, among which stand out: recovery and reuse of coagulants for wastewater treatment [10]; substrate for the construction of wetlands; use in the production of construction materials, such as bricks; manufacturing of cementing material, geo-materials, soil improvements, among others [2], [11].

Currently, there is little information on sludge production at the national or international level [12]. Data gathered from the Basic Sanitation Company of the State of Sao Paulo (SABESP) in Brazil estimated the production of sludge of five STPs at 2.500 tons per day in the year 2015 [13]. In China, the production of STP sludge was approximately 6.25 million tons (dry solid weight) [11]. Given a production of 710 trillion cubic meters in 2010 [14], it is estimated a production of 1,180 trillion cubic meters by the year 2050 in China. In 2007, in Jordan, a production of 456 tons of WTS was estimated according to the Ministry of Wand Irrigation [3]. In the Czech Republic, 34.494 tons of WTS were estimated in 2006 [4]. On the island of Taiwan, a dehydrated sludge production of 0.67 million tons was also estimated [15]. In the Netherlands, an annual WTS production of 40,000 tones was estimated as well [16]. On the island of Bahrain, in the Middle East, about 9.000 tons of WTS were laid out in an area of 695 km^2 [17]. The SS production in the countries of the European Union EU-27 were estimated 3552 million tons in2015 [18]. Given the production scenario of WTS and SS, the safe and environmentally correct disposal of waste is considered a global challenge due to its high production volumes [6]. Brazil passed the 12.305 Law in 2010 [19] instituting the National Solid Waste Policy, which obliges WTPs and STPs to adopt safe sludge regulations and new practices that contribute to sustainable development. On the other hand, the construction and rehabilitation of road pavements require large volumes of materials that need to be mobilized, which constitutes WTS and SS in potential waste as a form of safe final disposal [20]. In this sense, statistical data of the survey carried out by the National Confederation of Transport - CNT in the year 2017 describe the conditions of the pavements in Brazil and the need to investigate materials that are durable over time and that contribute to the preservation and conservation of the environment. Brazil has a road network of approximately 1.74 million kilometers, of which: 78.7% are unpaved roads, 12% paved and 9.1% are under planning and previous studies [21].

1.2. BACKGROUND

The WTS and SS chemical features depend mainly on the raw water or wastewater to be treated, the final quantity of treated water, and the chemical products applied during the different procedures. As per the ash collected from the sludge, the chemical features depend mainly on the type of calcination used. The typical composition of some WTS and SS reported in the waste is mainly composed by Silicon Dioxide (SiO_2), lime (CaO), aluminum (AlO_3) and iron (Fe_2O_3). The CaO and Al_2O_3 can develop cementing and pozzolanic properties that can increase the adherence and the contact among particles of aggregates in the hydraulic concretes or hot mix asphalt. However, the SiO_2 may decrease said property [22]. The elements from the composition of the WTS and SS are considered of inert nature and thermally stable.

Various researchers have tried to the use WTS and SS as alternative materials for the construction of civil engineer works [17] [2] [23] [20] [24]. To this effect, they are used as cementing material for mortar, concrete, and other applications [25] [26] [3], prefabricated elements, ceramics and bricks [27] [15] [28], soil improvement [29] [30] [31], granular layers of pavement [6] and used as materials for asphaltic mix in pavement [17]. The latter studied the incorporation of ash calcined at 500 ºC of SS as filler material in asphalt mixtures. As a general conclusion, they reported that the volumetric and Marshall resistance parameters of the mixture which used SS filler meets the minimum requirements established in the standards of the Bahrain transport department. [15] indicate that the use of WTS in substitution of 10% of clay for the manufacturing of bricks can destroy the pathogenic elements and immobilize heavy metals during the burning process. In this context, the safest and environmentally correct final disposal of WTS and SS can contemplate their encapsulation into the matrix of asphalt cement for pavement mixtures.

1.3. OBJECTIVE

Based on this literature review, only the study reported by [17] used SS as a filler in asphalt mixtures. However, in this study, a limited experimental phase was carried out, since only the resistance under mechanical load in the Marshall test was evaluated. Therefore, in the current study the authors evaluated the mechanical response under monotonic and cyclic loading, the resistance to moisture damage and abrasion properties of a hot mix asphalt (HMA), when 1% of WTS and SS were added as additional filler with regard to the total mass of the mixture (for an approximate total in the AMF of 7% of total filler: conventional filler + filler of alternative material). Only the additional content of 1% alternative filler was evaluated in order to evaluate if a small content of WTS and SS generates significant changes in the resulting HMA. The previous thing to evaluate in future investigations, the influence of using different contents and forms of addition of the WTS and SS sludge. This paper studies the technical feasibility of using ash from WTS and SS as additional filler material in HMA, in order to find a safe final disposal for these by-products and to contribute to the preservation and conservation of the environment. This paper could be considered an innovative technique, because these types of alternative materials have not been studied for HMA in the way it is proposed here. In order to evaluate whether the WTS and SS fillers produced statistically significant effects on the HMA mix properties, analysis of variance (ANOVA) was performed with F-test with a confidence level of 95%.

2. MATERIALS AND METHODS

2.1. CHARACTERIZATION OF MATERIALS

The physical characteristics of the asphalt cement AC 50-70 used are presented in Table 1 and meet the quality requirements for the manufacturing of HMA according to the specification of the Brazilian National Department of Transportation Infrastructure – DNIT 031.

Table 1. General properties of AC 50-70.

Test	Method	Unit	Requirement		Value
			Min	Max	
Test on the original AC					
Penetration (25°C, 100 g, 5 s)	ASTM D5-06	0.1 mm	50	70	51.1
Penetration Index	NTL 181-98	-	-1.5	+0.7	-0.67
Softening point	ASTM D 36-06	° C	46	-	52.0
Specific gravity	AASHTO D70-08	-	-	-	1.022
Viscosity at 135° C	AASHTO D 316-13	cP	274	-	337
Viscosity at 150° C	AASHTO D 316-13	cP	112	-	177
Viscosity at 177° C	AASHTO D 316-13	cP	57	285	66
Flashpoint	ASTM D 3143-19	°C	235	-	338
Ductility (25°C, 5cm/min)	ASTM D 113-17	Cm	100	-	>105
Tests on the residue of AC after the RTFOT					
Mass loss	ASTM D 2872-12	%	-	0.5	0.1
Penetration, in % of the original penetration	ASTM D5-06	%	55	-	81
Increase of the softening point	ASTM D 36-06	° C	-	8	7.5

The coarse aggregate used for the production of the HMA comes from rocks of calcareous origin (limestone - LS). Table 2 shows the properties of the granular aggregates. To comply with the specifications of the DNIT 031, the original particle sizes distribution of the aggregates was modified, taking as reference the average values in percentages of the grain size distribution band (type C) that the specification for the elaboration of the mixtures demands (see Fig. 1).

Table 2. Physical properties of the granular aggregate.

Test	Standard	Unit	Result	Requirement
Sand equivalent value	ASTM D 2419-09	%	66	min 55
Abrasion in Los Angeles machine	ASTM D131-06.	%	21	max 50
Form Index	DNIT 086-94.	---	0.7	min 0.5
Soundness of aggregates by use of magnesium sulfate	ASTM-C88.	%	7	max 12
Adhesion of Aggregate to bituminous material	DNIT 078-94.	Qualitative	Satisfactory	Satisfactory
Bulk specific gravity	ASTM C 127-07	---	2.64	----
Bulk specific gravity saturated-surfaced -dry	ASTM C 127-07	---	2.59	----
Absorption	ASTM C 127-07	%	0.8	----
Specific gravity of fine aggregates	ASTM C 128-07.	---	2.7	----

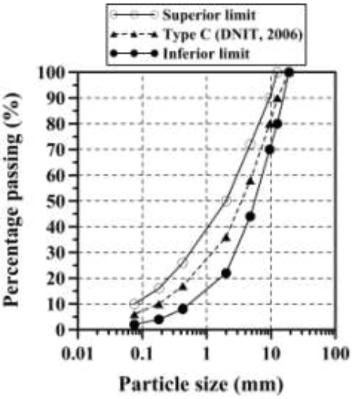

Fig. 1. Aggregate gradation for HMA type C according to DNIT 031.

The chemical composition of the LS, WTS and SS is presented in Table 3 and was obtained based on X-ray fluorescence (XRF) tests. It is observed that LS is mainly composed of CaO (72.8%). In comparison with the typical chemical composition presented of WTS and SS, the LS presents important and inverse differences in the amounts of CaO and SiO_2. The sludge has a higher SiO_2 content but a lower CaO content compared to the LS.

Table 3. XRF results for the analyzed LS, WTS and SS.

Material	Chemical compound, % in mass								
	CaO	SiO_2	Fe_2O_3	Al_2O_3	K_2O	MgO	P_2O_5	TiO_2	Other oxides
LS	72.8	14.4	3.1	3.0	3.0	2.3	0.9	0.3	0.2
WTS	4.4	52.8	8.1	14.4	---	---	0.2	---	20.1
SS	2.6	51.2	8.2	15.7					22.3

WTS and SS from treatment plants located in the city of Brasilia (Brazil) were chosen as filler to be added to the mixture in 1% with respect to the total mass. For the incorporation of these by-products in the HMA, the sludge was initially air-dried (average temperature 30 °C) for a period of 15 days. Then, the mass losses of sludge were determined, and then it was subjected to calcination temperatures of 200, 300, 500 and 800 ºC for 45 minutes (Fig. 2). The calcination process was carried out in order to eliminate the moisture and organic matter, and to transform the by-products into ash to be later incorporated into the mixture as a filler. From the results obtained it was obvious that the mass loss increased with regard to the calcination temperature. The greatest loss of mass is attributed mainly to the decrease of moisture and the combustion of organic matter. Therefore, in all the temperatures evaluated, greater mass loss is observed in the SS. In order to determine the optimal WTS and SS calcination temperature, physical characteristics were evaluated (penetration -

ASTM D-5 and softening point - ASTM D-36-95) on a mastic manufactured by mixing the AC 50-70 with filler of both materials. For this purpose, 10 samples of mastic with WTS and SS calcined at temperatures of 0, 200, 300, 500 and 800 ºC were manufactured. A calcination temperature of 0 °C corresponds to the air- dried condition. Each sample of mastic was made with a mass ratio of filler (F) and AC 50-70 of F / AC = 25%, at a temperature of 150 °C and agitated for a 5 minutes in a paddle mixer at 350 rpm. The proportion of F / AC = 25% guarantees the workability of the material, while higher proportions make the mixing process difficult. During the mixing time of 5 minutes, the total coating of the particles was observed. Obviously, the mastics have a reduction in penetration (Fig. 3) and an increase in the softening point (Fig. 4) with respect to the tests carried out on the conventional asphalt AC 50-70. The above is an indication of the increase in the consistency of the material due to the presence of filler particles inside the mastic. In this sense, the presence of particles in the matrix of the AC 50-70 causes greater difficulty to exert the penetration of the needle in the penetration test and a higher temperature is necessary for the displacement of the steel sphere during the softening point test. Based on the above, in Fig.s 3 and 4 it is observed that the calcination temperatures of the sludge influence the interaction with the AC 50-70. A calcination temperature of 500 ° C in the WTS and SS generated the highest stiffness in the mastic (lower penetration and higher softening point). Consequently, this temperature was chosen in order to produce the filler of both sludges. In order to determine the density of the fine particles of both sludges calcined at 500 ° C, the BS 812: Part 2: 1995 test was carried out. The densities obtained were 1.68 and 1.39 g / cm^3 for WTS and SS, respectively. These densities are lower compared to those obtained for the LS of 2.7 g/cm^3.

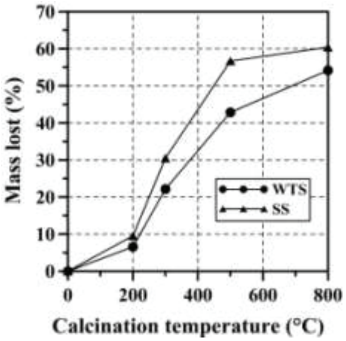

Fig. 2. Mass variation - Incineration temperature.

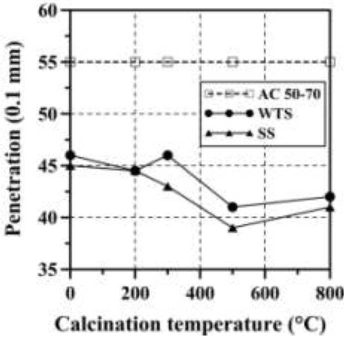

Fig. 3. Evolution of the penetration with the calcination temperature of WTS and SS.

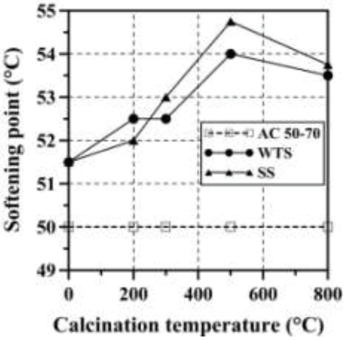

Fig. 4. Evolution of the softening point with the calcination temperature of WTS and SS.

2.2. RESISTANCE TESTS

The hot mix asphaltic mixtures of study correspond to HMA type C according to DNIT 031. Initially, 20 Marshall briquettes (5 samples x 4 percentages of asphalt) were manufactured, compacted to 75 blows per side with dimensions of 4" in diameter and 2.5" in height, following the guidelines established by the ASTM specification D1559. These so-called control briquettes, used the AC 50-70 and LS as granular aggregate. The central curve indicated in Fig. 1 (type C) was used as the reference particle size distribution. The fine portion of this curve that acts as filler in the control mixture is also composed of the same LS material. The compaction and mixing temperatures were 140 °C and 150 °C, respectively. These temperatures were obtained based on the criteria established by the ASTM D6925 specification for dense and hot type mixtures (the viscosity required to obtain the mixing and compaction temperatures is 85 ± 15 SSF - 170 cP and 140 ± 15 SSF - 280 cP, respectively). Later, 40 additional Marshall briquettes were manufactured (5 samples x 4 percentages of asphalt x 2 incorporations of filler), following the same process executed on the control samples, but adding the selected fillers of WTS and SS in 1% with respect to the total mass of the HMA. The Marshall test was carried out on all the samples in order to obtain the volumetric composition of the mixtures (percentage of air voids - Va, voids in the mineral aggregate - VMA and voids filled with asphalt - VFA) and the resistance under monotonic load under test temperature of 60° C and deformation speed of 48 mm/minute until rupture (stability - S) in a Marshall stability testing apparatus. Based on the results obtained in this phase, the optimum percentage of asphalt to be used was chosen for each type of mixture (control, with addition of 1% of WTS and SS) for the execution of the following phases.

Indirect Tensile Strength (ITS) tests

Using the optimum asphalt content determined in the Marshall test, 4 Marshall briquettes were manufactured for each type of mixture (control, with addition of 1% WTS and SS) in order to measure the indirect tensile strength by diametral compression in a loading frame, following the guidelines established by ASTM D6931. Each sample was subjected to the application of monotonic loading at a deformation rate of 50 mm/minute until rupture. The test temperature was 25°C.

Modified Lottman test

In order to evaluate the resistance to moisture damage, 24 Marshall briquettes were manufactured (4 samples x 3 types of mixture - control, with addition of 1% WTS and SS x 2 groups). The briquettes were manufactured using the optimum asphalt content determined from the Marshall test and were divided into two groups (unconditioned and conditioned). The briquettes were compacted with 25 blows per face following the standards established. Twenty-five blows were used to guarantee a void volume with air between 6 to 8% required by the modified Lottman test standard. The number of blows is the result of the evaluation of the air voids volume with the number of blows in the control sample (Fig. 5). The first group of samples (unconditioned) were subjected to tests of tensile strength by diametral compression with a deformation speed of 50 mm/minute at a temperature of 25 ºC. The second group (conditioned samples) were conditioned by saturation by vacuum, freezing at -5 °C during 16 hours and heating at a temperature of 60 °C during 24 hours. Finally, the tensile strength was determined at 25 ºC in the same way as the group of unconditioned briquettes. The result of the test (tensile strength ratio - TSR) is defined as the percentage of the ratio between the average tensile strength of conditioned and unconditioned samples.

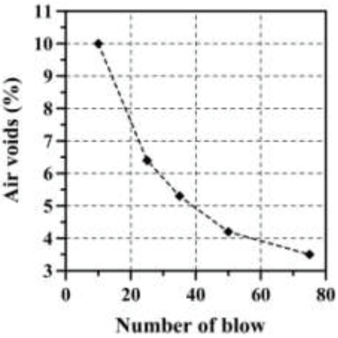

Fig. 5. Evolution of air voids with the number of blows in the compaction.

Resilient modulus tests

On the control HMA mixture and the HMA with addition of 1% of WTS and SS as filler, tests of resilient modulus under cyclic loading by diametral compression were performed. The tests were carried out at a temperature of 25 °C, following the guidelines established in ASTM D 4123-82. Each load cycle consists of a load period of 0.1 seconds and 0.9 seconds of recovery. The magnitude of the applied load was 1.2 kN (less than 30% of the strength obtained in the tensile strength test by diametral compression). The resilient modulus testwas carried out in a Universal Testing Machine (UTM) on 4 Marshall briquettes for each asphalt mixture studied.

Cantabro test

Wear tests without abrasive load in the Los Angeles machine were carried out on 4 Marshall samples for each type of mixture analyzed (control and mixtures with addition of 1% of WTS and SS as filler). It was applied 300 turns at 33 revolutions per minute (Cantabro test). The briquettes used the optimum asphalt content determined from the Marshall tests. The temperature of the samples during the test was 25 °C. The specimen mass loss is determied as a percentage of the its original mass and the final mass after of test. The Cantabro abrasion loss test was developed as a relative measure of the resistance to disintegration (e.g., raveling) of open graded mixtures. However, for the case of dense HMA mixtures, it can be used in order to evaluate durability (generally including non-load-associated cracking and raveling or weathering) and cohesion properties [33], [34].

3. RESULTS

3.1. MARSHALL TEST

The results obtained from the Marshall tests on the analyzed mixtures are presented in Fig.s 6-9. Based on the results obtained, it can be reported:

i) For a particular asphalt content, it is evident that the asphalt mixtures with the addition of 1% WTS and SS as filler present lower Va with respect to the control mixture. In this sense, the additional presence of filling causes a greater densification of the aggregates and consequently lower Va.

ii) The incorporation of 1% of WTS and SS as filler reduces the VMA, and neither of them comply with the minimum specified requirement of 15% according to DNIT 031. The above is an indicator that the aggregate is covered by an asphalt film that is not thick enough as a product of a greater number of particles.

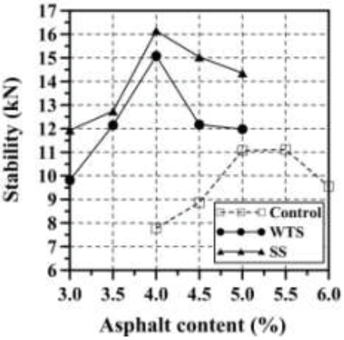

Fig. 6. Evolution of stability with the percentage of asphalt.

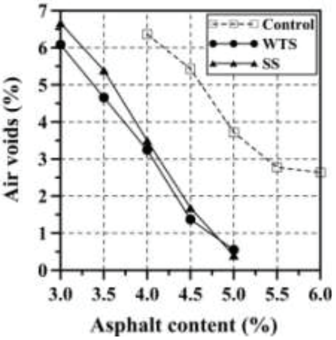

Fig. 7. Evolution of the Air voids with the percentage of asphalt.

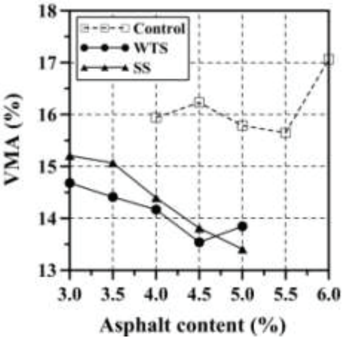

Fig. 8. Evolution of the VMA with the percentage of asphalt.

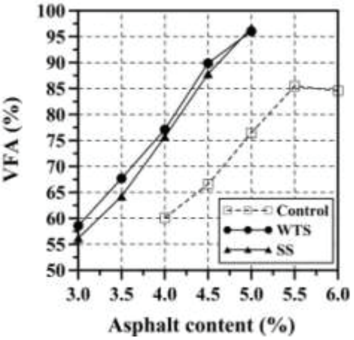

Fig. 9. Evolution of the VFA with the percentage of asphalt.

iii) The incorporation of 1% of the fillers produces an increase of VFA with respect to the control sample and they only satisfy the range specified by [29] (75-82% for rolling layers) for the samples manufactured with 4.0-4.3 % asphalt.

iv) The addition of 1% filler in the HMA generated an increase in the resistance under monotonic loading in the Marshall test (based on the increase in S) and reduction in the percentage of asphalt cement. In this sense, the presence of the WTS and SS materials increased the contact points and increased the cohesion in the asphalt mixture, probably due to the greater physical-chemical surface interactions. In addition, this increase in S is due to the decrease in voids with air in the mixtures that incorporated WTS and SS.

v) The optimum percentage of asphalt cement for the control mixture was 5.1%, and for the tested mixtures with addition of 1% WTS and SS, the best performance in the Marshall test was obtained when 4.0% and 4.1 % of CA were used, respectively. As mentioned in the methodology, with these percentages of asphalt, the samples were manufactured for the following phases of tests.

3.2. INDIRECT TENSILE STRENGTH (ITS) TESTS

Table 4 shows the Indirect Tensile Strength by diametral compression (ITS) of the control asphalt mixture and the mixtures that incorporated 1% WTA and SS as filler. It is observed in the table that the RT values of all the mixtures meet the minimum value of 0.65 MPa specified by DNIT 031. Additionally, an increase in ITS was observed in the samples that incorporated 1% WTA and SS as filler. The values of RT increased despite the reduction of the optimum percentage of asphalt and probably due to the reduction of the volume of voids (Va). The increase of ITS in the mixtures with the sludges indicates greater adhesion between the particles, which may be related to the increase in stiffness of the mastic and the possible physico-chemical interactions between the fine sludge particles and the AC 50-70.

Table 4. Indirect Tensile Tests results.

Mixture type	Asphalt optimum [%]	Air voids [%]	ITS [MPa]	Coefficient of variation [%]
Control	5.1	3.72	0.98	6.3
WTS	4.0	3.27	1.24	4.5
SS	4.1	3.58	1.07	5.7

3.3. MODIFIED LOTTMAN

Table 5 shows the results of the modified Lottman test. It is observed that the addition of 1% of WTS and SS as filler in the HMA produces a significant reduction in their resistance to moisture damage, expressed by the reduction of the TSR parameter. The TSR values obtained in the asphalt mixtures of study with alternative materials do not meet the minimum requirement of 80%. The reduction of resistance to moisture damage can be associated with the reduction of asphalt cement, which would be generating a very thin coating thickness of aggregates with asphalt (based on the reported results of VMA in the Marshall test). Additionally, the fine particles of WTS and SS tend to have high contents of quartz (SiO_2) and this mineral hinders the adherence with the asphalt.

Table 5. Lottman test results.

Mixture type	Asphalt optimum [%]	$ITS_{unconditioned}$ [MPa]	Air voids [%]	$ITS_{conditioned}$ [MPa]	Air voids [%]	TSR [%]	Coefficient of variation [%]
Control	5.1	7.95	6.3	7.59	6.3	96	4.7
WTS	4.0	7.54	6.7	5.37	6.4	71	3.8
SS	4.1	6.02	6.9	4.47	7.0	74	1.9

3.4. RESILIENT MODULUS

Table 6 shows the magnitude of the resilient modulus of the control asphalt mixture and the mixtures that incorporated 1% WTS and SS as filler. An increase in stiffness under cyclic load of the mixtures is observed using WTS and SS as filler with respect to the control mixture. The asphalt mix that showed the highest modulus was the one with 1% WTS as a filler. The increases of the resilient modulus are consistent with the increase in the cohesion and resistance under monotonic load observed in the Marshall test. This can be attributed mainly to the reduction of voids with air Va. Likewise, the increase of the cohesion of the mixtures with the sludge can be associated to an increase in the contacts as a result of the incorporation of the WTS and SS ashes given that the above mentioned particles tend to present high contents of SiO_2 which is a material associated with high hardness, mechanical strength and interlocking in the skeleton mineral [35].

Table 6. Resilient modulus test results.

Mixture type	Asphalt optimum [%]	Air voids [%]	Resilient Modulus [MPa]	Coefficient of variation [%]
Control	5.1	3.72	3569	3.5
WTS	4.0	3.19	5679	2.8
SS	4.1	3.57	4444	3.4

3.5. CANTABRO TEST

Table 7 shows the results of the Cantabro test. There is a decrease in the Cantabro wear resistance of the mixtures that added 1% WTS and SS. As in the modified Lotmann test, the greatest mass loss reported during the Cantabro test can be attributed to the greater number of particle contacts and the incorporation of quartz (SiO_2) into the mixture (product of the incorporation of 1% of WTS and SS). They require a greater amount of asphalt to adhere.

Table 7. Cantabro test results.

Mixture type	Asphalt optimum [%]	Air voids [%]	Cantabro Test	
			Abrasion Loss [%]	Coefficient of variation [%]
Control	5.1	3.72	4.5	3.5
WTS	4.0	3.21	6.6	2.8
SS	4.1	3.61	11.5	3.7

3.6. ANOVA ANALYSIS

Four analyses were carried out: (I) comparison of all materials (HMA control and addition of 1% of WTS and SS); (II) comparison of HMA mixtures with incorporation of 1% of WTS and SS; (III) Comparison of control HMA and incorporating 1% WTS and (IV) Comparison of control HMA and incorporating 1% SS. According to results obtained, ANOVA analysis with a confidence level of 95% shows that the WTS and SS have a significant effect on the all mechanical properties evaluated ($Fo > F_{0.05}$). The variations obtained may be associated with physical-chemical phenomena, as a result of the interactions between the fillers and the asphalt.

4. CONCLUSIONS

In the present study, the properties hot asphalt mixtures (HMA) prepared with the incorporation of 1% (by mass) of fillers obtained from calcinated water treatment sludge (WTS) and sewage sluge (SS) were investigated. The laboratory tests include: mechanical response under monotonic and cyclic loading, the resistance to moisture damage and Cantabro abrasion. Based on the results obtained, it is concluded that:

- Using lower asphalt content with respect to the control mixture, the incorporation of the WTS and SS particles increased the resistance under monotonic loading (stability) and the stiffness under cyclic loads (modulus resilient) of the HMA mixtures. The above can be an indicator of increased resistance to permanent deformations in high temperature climate. The gains in stability and resilient modulus are associated with the reduction of voids with air, the incorporation of a greater number of particles that increased the number of contacts and the cohesion of the mixture, and the inclusion of quartz particles which is a material of high hardness.
- As a result of the reduction of voids with air, the incorporation of WTS and SS particles increased the indirect tensile strength under dry condition (unconditioned). However, the decrease in the asphalt content, associated with a thin coating thickness of the aggregates (based on the reported results of VMA) and incorporation of quartz particles (SiO_2), hinder adhesion with the asphalt, generating a decrease in the resistances to moisture damage and abrasion.

- The ANOVA analysis showed that the WTS and SS used as filler have a significant effect on the all properties evaluated (Marshall strength, resilient modulus, indirect traction and abrasion resistance in Cantabro test) in comparison with the control HMA analyzed.
- The incorporation of WTS and SS in asphalt mixtures represents an alternative to the reduction of environmental problems related to the final disposal of these solid waste. However, additional studies must be carried out to analyze the effect of replacing the traditional filler of asphalt mixtures for both residues either partially or in its totality. Likewise, it is suggested to carry out an experimental program where the other mechanical properties such as rutting, cracking at low temperatures, resistance to aging and resistance to fatigue are analyzed

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LIST OF FIGURES AND TABLES:

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