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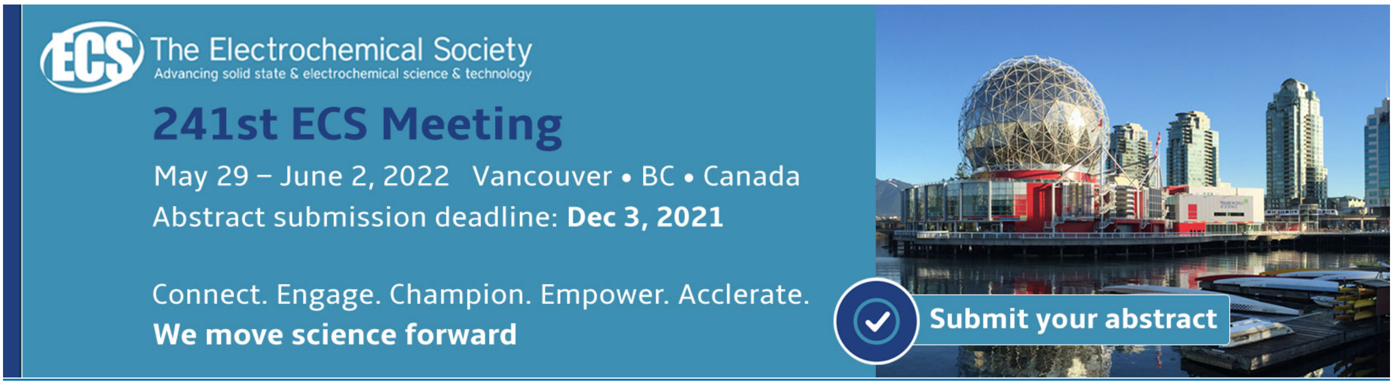

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Optimal percentage of asphalt cement in MDC-19 for flexible pavements in the city of San José de Cúcuta, Colombia

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Abstract. Samples were taken of the stone material used for the design of asphalt mixtures, extracted from the 3 water sources present in the city of San José de Cúcuta, Colombia, the Táchira, Zulia and Pamplonita rivers. The aggregates samples were analyzed under the regulations of the Instituto Nacional de Vías in its update of 2013 that applies to Colombia. Asphalt cement was used from the manufacturing plant and industrial processes located in the city of Barrancabermeja, Colombia. Five dense hot mixes-19 were designed for flexible pavement with different % of asphalt cement, 4.5%, 5.0%, 5.5%, 6.0%, and 6.5% percentages suggested by article 450-13 of the "Instituto Nacional de Vías". With each one of the percentages 3 briquettes were elaborated, taking as guide the established in the norm of tests of the "Instituto Nacional de Vías". The resistance to plastic deformation of asphalt mixtures designed in the laboratories of the Universidad Francisco de Paula Santander in the city of San José de Cucuta, Colombia and the company Maqinteligente S.A.S. was determined. The results obtained in each of the tests were tabulated and compared, determining the behavior of the stone aggregates together with the optimum percentage of asphalt cement and its working temperature in each of the mixtures designed. It was concluded that the 3 water sources provide quality material for the design of asphalt mixtures. These results were used to provide information of interest to road construction contractors, whose budgets will be favored by identifying the quality material to be incorporated into their projects, a situation that favors the final result and the delivery of the work to the satisfaction of the beneficiary community, who will see a substantial reduction in the cost of fossil fuels by reducing travel times to their destinations, this being the most notorious environmental characteristic of the research.

1. Introduction

The pavement is a structure designed under important aspects where the soil, the materials and their bearing capacity are the main ones to be found at the moment of their design. There are different types of pavements with the same number of techniques and construction materials for their elaboration, the conventionally constructed ones are the ruled pavement that is built in concrete or concrete poured in situ, the articulated pavement that is characterized by molded pieces both inside and outside the work and that are then placed in the place of final disposal, these pieces can be made in concrete, mortar or fired clay, and the flexible pavement whose most notorious feature is its black color due to the implementation of an asphalt emulsion that considers a type of oil in water systems in which the bitumen droplets are dispersed in the aqueous phase by means of an emulsion [1], a product derived from petroleum, material that allows the expansion and contraction of the road structure, deformations caused for exposure to the elements.

The mixture or asphaltic concrete is the combination of stone aggregates (SA) and an asphalt binder, a mixture whose manufacture and implementation can be cold or hot, the latter being the one commonly used. Its manufacturing process is of industrial type and is carried out in production plants, these plants must be equipped with special equipment necessary for the industrialized manufacturing system, characteristics that lead to the elaboration of a mixture with the quality standards required in the work to execute. The main characteristic that must identify a pavement, regardless of the type, materials or construction techniques, is the duration in time and the resistance to the loads received [2], property that makes the correct selection, construction and maintenance of the road project of vital importance. When talking about load support of pavements, in recent years there has been a significant progress in the implementation of new mix designs with load capacity higher than the conventionally used mixes, necessary advances due to the notorious increase in traffic volume vehicular presented worldwide. It is for this reason that new research focuses their attention on the layers constituting the pavement subbase, base and the asphalt layer or tread layer, the latter being the facing or receives deformations and initial and holistic efforts result of continuous exposure both outdoors and direct bearing and vehicular load. Research results show that the etching and loss of the asphalt film from the aggregate surface is due to the low compatibility between the materials [3].

The standards that must be met by the materials and processes inherent to the construction of a pavement guarantee the durability and good functioning of the road project, key points in the economy of the contractor due to the considerable costs in this type of engineering works. Companies that on occasion and with the implementation of innovative processes aim to significantly reduce the existing gap between construction waste and profits [4]. Asphalt production plants base their operation on efficient, safe, reliable and highly competitive processes, focused on the optimal use of available resources [5]. These companies are committed to generating financial sustainability, as the competitive spirit focuses on creating thought aimed at generating value [6], while aside conservation and environmental care [7,8], recognizing that generate large amounts of waste construction industry is a big problem environmental [9]. Having the mix design to be implemented in the road project, the characteristics of the mixture that will form the asphalt or pavement layer of the pavement must be evaluated by carrying out a series of simultaneous tests with which the future behavior is made known. of the structure under the loads to which it will be submitted according to its design. These tests to which the materials that make up the main structure of an asphalt pavement are subjected must be backed by the regulations that apply in each country of origin.

The asphalt pavements that constitute the roads in the city of San José de Cúcuta, Colombia are built with conventional asphalt mixtures of the hot-dense type with continuous granulometry, due to their advantages of comfort in driving and comfort in maintenance [10]. Unfortunately, the vast majority of these pavements present certain pathologies such as rutting, fatigue, longitudinal and transversal cracks, loss of adhesion, peeling and bumps, as well as the aging of asphalt binders, which is an irreversible process that reduces durability of pavement and leads to early damage and an increase in repair and maintenance costs [11]. These pathologies can be generated by various factors such as, the inadequate design of the mixture, the low quality of the materials, the poor treatment of the materials, the improper construction process together with poor and moderately regular maintenance.

The study and investigations that lead to the search of dosages of the SA and asphalt cement used for the design of mixtures for flexible pavements that meet the permissible values described by the “Instituto Nacional de Vías”, of Colombia, in its update of the 2013 (INVIAS-13) and that also consider the context of sustainable development through the use of materials with low environmental impact [12,13], would frame a solution to the problems presented due to the rapid deterioration of the flexible pavements in the city of San José de Cúcuta, Colombia.

The present research result compared the resistance under monotonic load of asphalt mixes designed and elaborated in the laboratory with dosage according to the weight for each one of the sizes of the SA extracted from the 3 water sources (WS) of the city San José de Cúcuta, Colombia, Táchira

River (T), the Zulia River (Z) and the Pamplonita River (P), through the elaboration of a hot dense mixes 19 (HDM-19) for flexible pavement.

2. Materials and methods

The methodology used in the research project was based on laboratory tests established in article 450-13 [14] hot asphalt mixes of continuous gradation for asphalt concrete of the INVIAS-13 regulation [15]. The granulometric analysis of the SA from the 3 WS of the city of San José de Cúcuta was carried out taking as reference the regulations indicated by the INVIAS-2013. Asphalt cement (AC) 60-70 was used from the manufacturing plant and industrial processes (MPI) located in city Barrancabermeja-Colombia. The maximum specific gravity (Gmm) as determined by the INV-E735 standard was determined by means of the rice test [16]. The HDM-19 were designed [17], with different AC %, 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%. 3 briquettes were prepared for each of the mix designs with % AC. Each of the briquettes made with % AC was tested, taking into account the stipulations of standard INV-E748 [18], stability and flow of hot asphalt mixtures using the marshall equipment. The resistance to plastic deformation of asphalt mixtures used for paving was determined. The conditions were evaluated under monotonic load and comparing each design made according to the WS where the material used was extracted.

The tests of characterization of the SA, stabilization, percentage of optimal AC and asphalt mix design, marshall test, were carried out with the equipment of the soil laboratory of the Universidad Francisco de Paula Santander (UFPS) of city of San José de Cúcuta and at the Maqinteligente S.A.S plant, where the maximum theoretical gravity tests were carried out with the help of standard INV-E735 and percentage of voids in the air INV-E736 [19]. Figure 1 shows the dimensions of each briquette, data that will be used to corroborate its deformation after the application of loads. Figure 2 shows the flow stability test where loads are applied to the briquettes to determine their deformation.

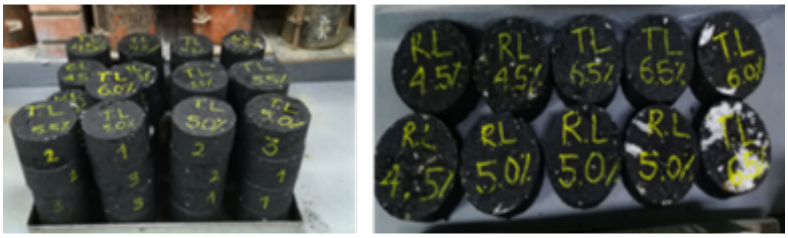

Figure 1. Briquette control test.

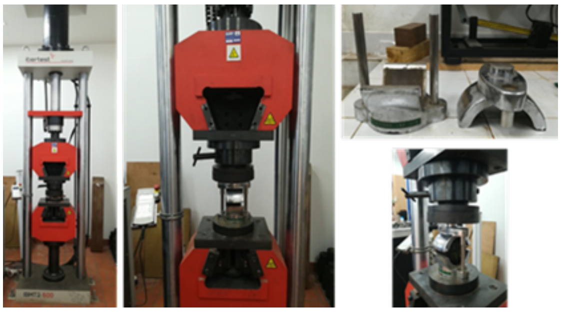

Figure 2. Stability and flow test equipment.

3. Results

3.1. General analysis of the stone material extracted from the 3 water sources

The general tests described in the INVIAS-13 [15] standard was carried out on the stone material extracted from the 3 WS present in the city of San José de Cúcuta, T, Z and P, corresponding to the aggregates used for the manufacture of HDM-19 [17] mixtures. Table 1 presents the results of the tests carried out on the samples of aggregates according to the source of water, where it is noted that the sample taken from the river Z has better parameters than those thrown by other water sources.

Table 1. General analysis of stone aggregates.

Test	INV	Parameter	Material	Water source		
				T	Z	P
Machine angels, maximum%	E-280	0.2	3⁄4"	00.24	00.22	00.30
			3⁄8"	00.25	00.18	00.27
Equivalent of sand, minimum%	E-133	50	0⁄0	56.82	52.08	33.33
Elongation index, minimum%	E-230	10	0⁄0	07.68	14.07	10.73
Flattening index, minimum%		10	0⁄0	03.01	03.47	13.33
Fractured faces, minimum%	E-227	70	3⁄4"	92.45	91.55	95.15
			3⁄8"	89.40	90.60	91.47
Specific gravity (g⁄cm^3)	E-223	Calculated	3⁄4"	02.53	02.60	02.58
			3⁄8"	02.55	02.50	02.53
	E-222		Sand	02.56	02.55	02.56
Absorption%	E-223		3⁄4"	01.20	01.30	01.50
			3⁄8"	02.40	05.50	02.70
	E-222		Sand	01.30	01.32	00.60

3.2. Analysis of asphalt cement

Table 2 reflects the analysis and characteristics of the AC used in the tests was already carried out by the supplier of the material MPI, who provided its technical data sheet.

3.3. Maximum specific gravity

An asphalt mixture was prepared without compaction for each one of the percentages of asphalt, 4.5%, 5.0%, 5.5%, 6.0% and 6.5%, to determine, by means of the rice test, the maximum specific gravity (Gmm) INV-E735 of the mixtures, necessary data in the marshall design development.

Table 3 indicates the specific gravity in each percentage of asphalt for each of the materials extracted from the 3 water sources. Data necessary for the design of the asphalt mix, where it is determined that the less asphalt addition is applied to the mix, the greater will be its % of voids.

Table 2. Technical sheet asphalt cement manufacturing plant and industrial processes.

Characteristic	INV	parameter	Plant MPI		
			T	Z	P
Specific weight (km/m^3)	E-707	00 - 00	1011	0990	1011
Penetration (25°C,100 g.5 s),0.1 mm	E-706	60 - 70	0061	0063	0063
Softening point, (°C)	E-712	48 - 54	49.80	48.90	0050
Index of penetration	E-724	-1.2 - 0.6	-0.79	-0.90	-0.65
Absolute viscosity (60 °C), P, minimum	E-716	1500	2340	2120	2140
Brookfield viscosity (60 °C), P, minimum	E-717	1500	2006	2005	2352
Lost by heating thin film (%)	E-720	00.80	00.31	00.27	00.29
Ductility (25 °C, 5 cm/min) (cm), minimum	E-702	100.0	136.5	0140	0130
Solidity in trichlorethylene, (%) minimum	E-713	0099	99.47	99.99	99.29
Flash point (°C), minimum	E-709	0230	0298	0296	0304

Table 3. Maximum specific gravity per % asphalt.

Water source	Maximum specific gravity	Percentage of asphalt				
		4.5	5.0	5.5	6.0	6.5
T	Gmm	2.430	2.413	2.392	2.369	2.346
Z		2.477	2.457	2.437	2.416	2.403
P		2.452	2.426	2.406	2.389	2.373

3.4. Viscosity of asphalt according to temperature

A comparative table was made where the viscosity obtained by the AC was faced with respect to the exposure temperature. Table 4 shows the data supplied by MPI, where its viscosity determines the optimum compaction temperature of the mixture. The higher the temperature, the lower the viscosity of the mixture.

Table 4. Viscosity Vs temperature asphalt cement 60-70.

Temperature (°C)	Viscosity (cps)		
	T	Z	P
060	209000.0	212000.0	210000.0
080	019438.0	017021.0	018500.0
100	003227.0	003301.0	003282.0
135	000352.5	000323.7	000345.5
150	000170.0	000163.8	000165.8

3.5. Mixing and compaction temperature

With the help of the data described in Table 4, the optimum mixing and compaction temperature was determined for the elaboration of the mixtures for each of the aggregates extracted from the 3 WS. Table 5 shows the minimum and maximum working temperature for mixing and compacting. The mixing temperature must be higher than that required for compaction, in order to avoid heat loss in the mixing action by reaching the compacting activity at the optimum temperature.

Table 5. Working temperature for aggregates.

Activity	Temperature (°C) applied to each aggregate					
	T		Z		P	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Mixed	146	152	149	153	148	153
Compaction	137	142	138	144	137	141

3.6. Optimal percentage of asphalt cement

After performing the graphic interpretation of the marshall design and verify compliance with the hot asphalt mix design criteria of Table 450.10 [20] of INVIAS, the optimum percentage was determined for the mixtures of the aggregates extracted from the 3 WS. Table 6 shows the final results of the marshall process, data obtained through the projection of the tables above. The data is adjusted in order to comply with the parameters indicated in the INVIAS-13 looking for the lowest amount of AC, which reduces costs, while still complying with the regulations.

Table 6. Percentage asphalt cement marshall method.

Characteristic	INV	Parameter	Water source		
			T	Z	P
Optimal asphalt content (%)	E-782	00.00	05.20	05.40	05.20
Compaction, shock / face	E-748	75.00	75.00	75.00	75.00
Stability (N)		Minimum 9000	13100	13700	12000
Flow (mm)		2.0 - 3.5	02.98	02.80	02.60
Flow stability ratio (kN/mm)		3.0 - 6.0	04.40	04.89	04.62
Vacuum with air (Va) (%)	E-799	4.0 - 6.0	05.00	05.00	04.80
Empty mineral aggregates (%)		Minimum 14	14.54	14.08	14.60
Empty filled with asphalt (%)		65 - 75	69.00	65.00	68.00

4. Conclusions

The SA characterized fulfilled most of the tests that are necessary for the design of asphalt mixes HDM-19 except for the percentage to the wear of the aggregates result of the test in the machine of the angels since the WS Z had 0.02 below the parameter permitted. To ensure better compliance with each of the criteria established by the Colombian standard INVIAS-13, the stone material must be washed to remove any type of dirt that significantly affects the design of the asphalt mixtures. The asphalt mixtures designed in the laboratory when tested by means of the stability and flow test maintained a resistance within the specifications of the INVIAS-13 standard, which is consistent with the optimum percentage of asphalt used. The optimum content of asphalt according to the ideal dosage made in the laboratory was for the WS T of 5.2%, for the WS Z 5.4%, for the WS P 5.2% being these verified in each of the graphs of the marshall design to determine if It was within the criteria stipulated in the INVIAS-13 standard for asphalt mixtures HDM-19. The stability / flow ratio of the asphalt mixtures designed with the ideal dosage in the laboratory are within the range stipulated in the INVIAS-13 standard. When designing this mixture by means of the dosing process by the weight in each of the sizes of the screens, a uniformity in the asphalt mixture can be guaranteed regardless of the stony material with which it is worked since it is based on the normative INVIAS-13 and in this way reduce costs in terms of asphalt and the production of these mixtures. The temperature at which the mixing and compaction process of the asphalt mixes must be kept in order to prevent the asphalt from exceeding the temperature levels at which they are allowed and this will lose part of its physical properties affecting the strength and durability of the asphalt mixtures at the moment of being evaluated. With the research carried out there is an important reference as far as the design of HDM-19 mixes is concerned, information that can be consulted by road works contractors in order to select the best material to be used in the design of the asphalt mix to be implemented.

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