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Feasibility of using asphaltites from Pesca Boyacá in flexible pavement structures

Factibilidad de uso de asfaltitas de Pesca Boyacá en estructuras de pavimento flexible

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Abstract
The use of unconventional materials has been a widely studied and used technique around the world. The results of the comparative analysis of a dense cold mix of aggregates with the addition of asphaltite from a technical and economic point of view is reported. The study was carried out using the methods developed by Marshall and Ramcodes, which characterized the aggregates first, in order to make an accurate comparison between the specifications and volumetric properties obtained and determine if asphaltite can be used in the construction of layers of flexible pavements in Colombia. The mix designed for the gradation of the central limit of the specifications using asphaltite meets the design criteria for a cold dense mix used in patching work except for flow. These mixtures can have a better performance than conventional mixtures while remaining economic. The use of Pesca, Boyacá asphaltites as a fine aggregate in a dense cold mix with asphalt emulsion is promising. This is due to its increased stability at an initial manufacturing cost which is lower than the cost of a conventional mix.
Keywords*: Asphaltite; cold dense mixture; stability; unconventional materials; fine aggregate.*

Resumen
La utilización de materiales no convencionales ha sido una técnica ampliamente estudiada y utilizada en el mundo. Se reporta los resultados del análisis comparativo desde el punto de vista técnico y económico de una mezcla densa en frío con la adición de asfaltita. El diseño se realizó por las metodologías Marshall y Ramcodes, previa caracterización de los agregados, esto con el fin obtener puntos de comparación en el cumplimiento de las especificaciones y propiedades volumétricas obtenidas y determinar si la asfaltita puede ser utilizada en la construcción de capas de estructuras de pavimentos flexibles en nuestro país. La mezcla diseñada con asfaltita, para la gradación del límite central de las especificaciones, cumple los criterios de diseño para una mezcla densa en frio usada en labores de bacheo, con excepción del flujo. Estas mezclas, pueden llegar a tener un mejor comportamiento que las mezclas convencionales, a un costo no muy alto. Es prometedor el uso de las asfaltitas de Pesca Boyacá, como agregado fino en una mezcla densa en frio con emulsión asfáltica, una vez que aumenta su estabilidad a un costo de fabricación inicial, inferior al costo de una mezcla convencional.
Palabras clave: Asfaltita; mezcla densa en frío; estabilidad; materiales no convencionales; agregado fino.

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1. Introduction

The requirements of the road infrastructure in Colombia and growing environmental issues create the need to investigate new materials and/or improve the quality of existing ones to make pavement structures have a longer useful life.

In Colombia, deposits of natural asphalt are known in Departments such as Boyacá, Caldas, Caquetá, Cesar, Cundinamarca, Santander, and Tolima and at least five of them are currently in operation, facilitating the use of asphaltite in road projects (Caro and Caicedo, 2017).

Asphaltite is a hydrocarbon poor in oxygen and paraffins, its a solid derived from petroleum, a mineral product, light, brittle, with few impurities and high caloric value, endowed with a high melting point, higher than 110°C (Alarcón, 2014).

Several investigations have been carried out to evaluate asphaltite behavior; among them: regarding the improvement of secondary and tertiary roads in Colombia with the use of natural cold asphalt mixture (asphaltite) (Peña, 2017); an analysis of the use and behavior of asphaltite as a granular base and sub-base in pavements (Bustamante et al., 2019); in hot dense mixtures (MDC2) (Higuera et al., 2012); cold dense mixtures (Manrique, 2013); as an alternative at the time of construction or to rehabilitate road infrastructure (Ruiz et al., 2017); modified asphalt mixtures with asphaltites (Rondon and Reyes, 2012); asphaltite-modified asphalts during aging (Themeli et al., 2017); modified asphalt with recycled rubber from disused car tires and asphaltite in the same mixture, at different temperatures and frequencies (Mantilla and Castañeda, 2019).

There are many benefits to the use of asphaltite in a pavement layer, as long as these layers are designed and built technically. This study aims to contribute to the proper use of asphaltites from Pesca (Boyacá) as an integral part of a layer of a flexible pavement structure.

2. Discussion and development

2.1 Characterization of the materials

Both the granular material and the asphalt emulsion were physically and chemically characterized and compliance was determined in light of the general construction specifications of the National Institute of Roads (INVÍAS, 2013) for the design of cold dense mixtures with asphalt emulsion and the addition of asphaltite, for a traffic level NT-1. Said characterization is shown in (Table 1) (Table 2), (Table 3) and (Table 4).

***Table 1.** Characterization of asphaltite*

ENSSAY	RESULT	SPECIFICATION	
Sand equivalent of soils and fine aggregates (%) (INV E-133-13)	67	50% Min	
Specific gravity and adsorption of fine aggregate (Gsb) (INV E-222-13)	2.50	% Adsorption	2.86%
Specific gravity and adsorption of fine aggregate (Gsb-sss) (INV E-222-13)	2.57	% Adsorption	2.86%
Specific gravity and adsorption of fine aggregate (Gsa) (INV E-222-13)	2.70	% Adsorption	2.86%
Qualitative asphalt extraction (%) (INV-E-732-13)	4.0	N.A.	
Liquid limit (%) (INV-E-125-13)	15.27	≤40	
Plastic limit	N.P.	N.P.	
Penetration 0,1 mm (INV E-706-13)	224	200 - 250	
Ignition point and flame through the open Cleveland cup °C (INV E-707-13)	95 °C	≥ 200 °C	

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2.2 Granulometric analysis

It is determined that the behavior of the granulometric curve of the coarse aggregate does not comply with the gradation of a cold dense asphalt mixture (MDF-19). Its granulometry is shown in (Figure 1).

Table 2. *Characterization of the granular material*

ESSAY	***RESULT***	***SPECIFICATION***	
Percentage of fractured faces (2 folds) (INV E-227-13)	*100%*	*60 % mín.*	
Flattening index (INV E-230-13)	*27.90%*	*≤35*	
Elongation rate (INV E-230-13)	*26.50%*	*≤35*	
Specific gravity and absorption of coarse aggregate (Gsa) (INV E-222-13)	*2.69*	*% Adsorption*	*1.24%*
Specific gravity and absorption of coarse aggregate (Gsb) (INV E-223-13)	*2.60*	*% Adsorption*	*1.24%*
Specific gravity and absorption of coarse aggregate (Gsb-sss) (INV E-223-13)	*2.63*	*% Adsorption*	*1.24%*
Wear resistance of aggregates Los Angeles machine (INV E-218-13)	*21.22%*	*< 35%*	
Liquid limit (INV-E-125-13)	*16.0%*	*≤25*	
Plastic index (INV-E-125-13)	*0.58%*	*≤3*	
Loss in soundness and solidity test in sodium sulfate (I.N.V. E–220 -13)	*8%*	*< 12%*	

Table 3*. Chemical analysis of asphaltite*

ESSAY	***METHOD***	***RESULT(%)***
Ash content	*ASTM D3174*	*92.5*
Humidity content	*ASTM D3173*	*0.4*
Volatile matter content	*ASTM D3175*	*7.1*

Source: Own elaboration based on results from the Metallurgy Laboratory, UPTC.

Table 4*. Emulsion characterization*

ESSAY	***RESULT***	***SPECIFICATION***	
		Min.	***Max.***
Saybolt Furol Viscosity at 25 °C, s (INV E 763 13)	*25*	*20*	*200*
Stability during storage (24 hours), % (INV E 764-13)	*0.8*		*1*
Sedimentation at 5 days, % (INV E 764-13)	*1.6*		*5*
Distillation: Residual asphalt content, % (INV E 762-13)	*60*	*57*	
Sieving: Retained sieve No. 20 (850 m), % (INV E 765-13)	*0.014*		*0.10*
Particle charge (INV E 767-13)	*Positive*	*Positive*	
PH (INV E 768-13)	*2.81*		*6*
Tests on the distillation residue			
Penetration (25º C ,100 gr, 5 s), 0.1 mm (INV E 706-13)	*83*	*60*	*100*
Ductility (25º C ,5 c/min) cm (INV E 702-13)	*46*	*40*	

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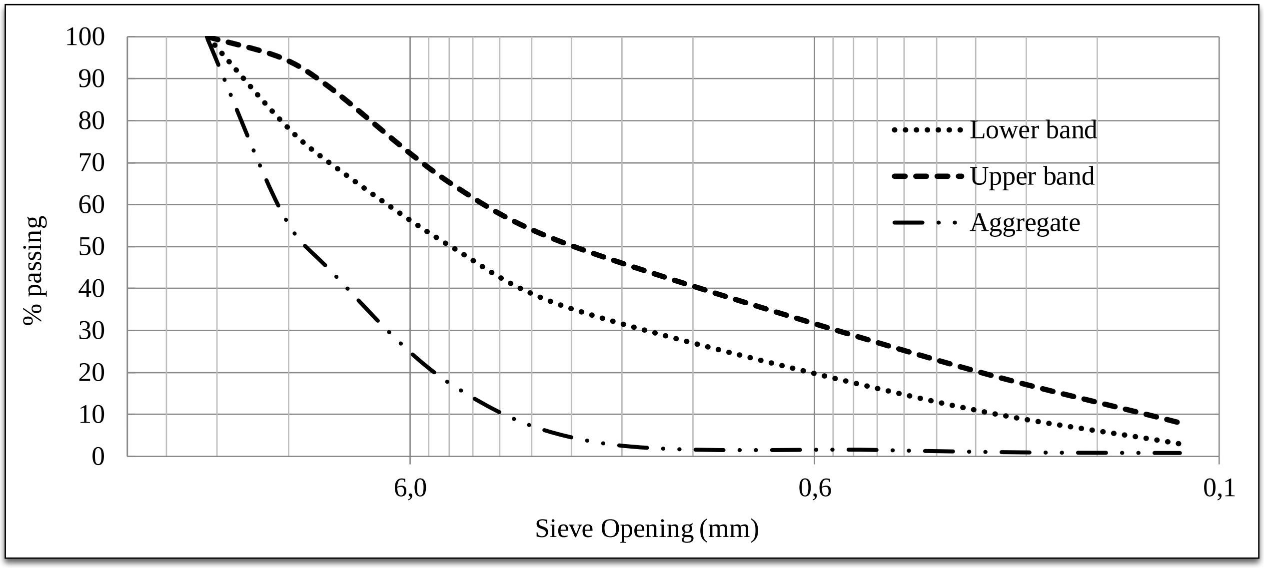

Figure 1. *Coarse aggregate granulometries and specification for an MDF-19 mixture.*

The granulometry of the fine aggregate (asphaltite) is poorly graded and does not meet the requirements for fine aggregate. Its granulometry is shown in (Figure 2).

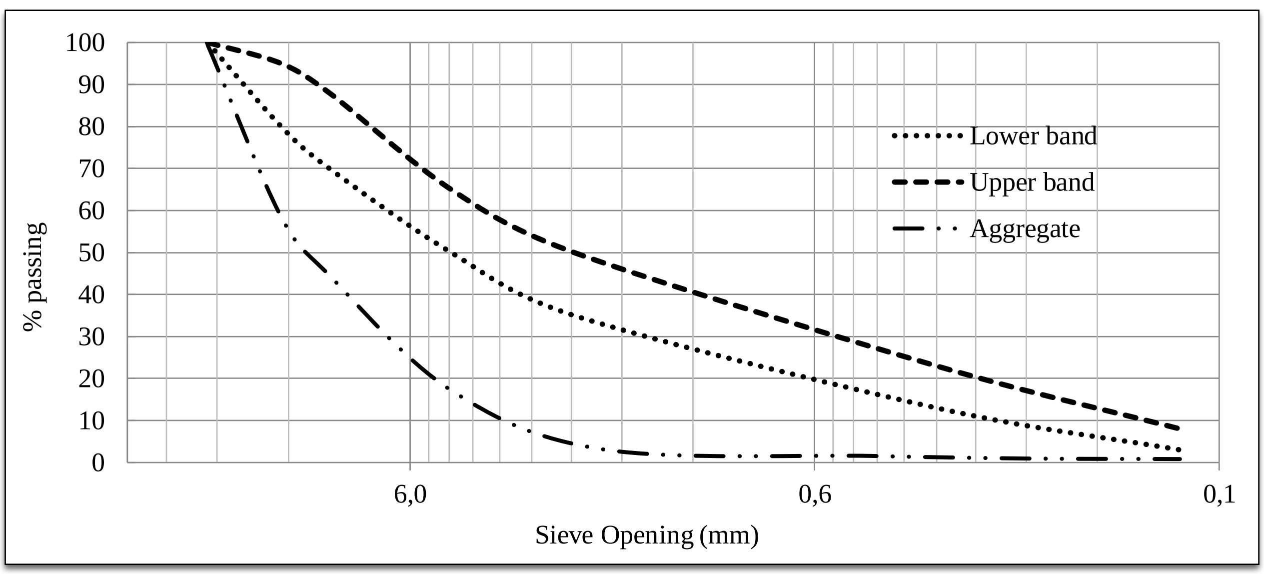

Figure 2*. Asphaltite granulometry and specification for an MDF-19 mixture.*

The stone aggregates must comply with the specified gradation to be considered appropriate in the design of an asphalt mixture. Given the gradations of the materials available to design an asphalt mixture MDF-19, the granulometric stabilization was carried out. (Figure 3) shows the result of the mixture, central strip, which combines 49% coarse aggregate and 51% fine aggregate (asphaltite).

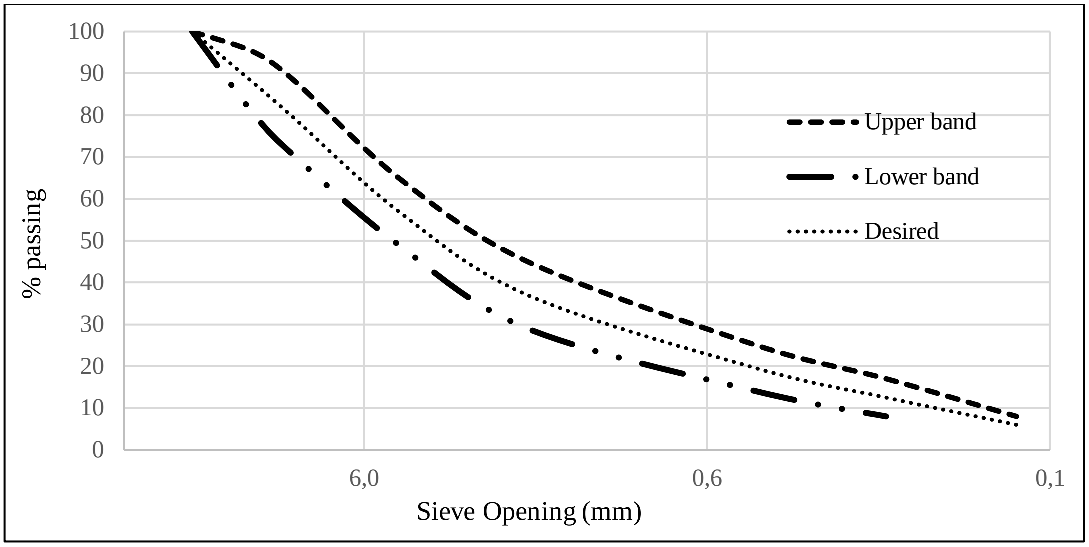

Figure 3. *Particle size adjustment, central strip, of the mixture of coarse aggregate and asphaltite*

2.3 Experimental design

Using the Marshall methodology, three mixtures were designed with a two-factor factorial experiment: the variable asphalt content in 1% for each mixture and the variable gradation according to the location in the granulometric strip. The procedure for preparing the briquettes was the one proposed by the University of Illinois using the modified Marshall method for cold dense mixtures with any degree of asphalt emulsion and dense granulometry aggregates (FUNDALANAVIAL, 2003).

Likewise, the design of three mixtures was carried out using the Ramcodes methodology with constant asphalt percentages for each granulometry according to Ramsoft. Through Arizada, the mechanical behavior of the different mixtures designed was analyzed within the mathematical and statistical framework of Ramcodes analysis (Sánchez Leal, 2009).

3. Result analysis

3.1 Influence of the granulometry in the volumetric properties of the mixture

The use of cold mixtures and their classification depends largely on the granulometry and surface texture (Jiménez, et al., 2019). Both the origin of the granular material and the granulometry affect the mechanical and dynamic properties of asphalt mixtures (Reyes et al., 2013).

The resilient modulus of modified asphalt mixtures is impacted by the granulometry of the aggregate mixture and by the variations that may occur in the volumetric and gravimetric properties of the asphalt mix (Kaa et al., 2016).

Dense granulometries are desirable in the preparation of asphalt mixtures because they mitigate rutting effects and have mechanical and dynamic properties greater than other mixtures. (Reyes and Camacho, 2008) determined the incidence of rutting in asphalt mixtures by varying their granulometry in the upper, lower and middle band, and concluded that the permanent deformation is directly related to the granulometric bands and the compaction energy.

Factors influencing the volumetric and mechanical properties of a mixture have been investigated in the past, including gradation and asphalt emulsion content (Yang, et al., 2020). Current practices for asphalt mix design and acceptance testing are based on volumetric properties (Gashi, et al., 2017). The parameters that affect the performance of a cold asphalt mixture are, among others, compaction method and level, additives, and gradation (Dash, 2013).

To analyze the influence of the granulometry on the volumetric properties of the mixture in this study, four volumetric parameters and the emulsion content were taken into account with two points above and two below the one obtained in the coating calculations, for the different gradations of the top, middle, and bottom bands.

3.2 Voids with air (Va)

A good gradation for an asphalt mix is the one that provides the densest packing of particles, improves stability by increasing the number of contact points between particles, and reduces air voids (Al-Mosawe, et al., 2015).
The Va values for the mixtures of the middle and lower bands show a similar behavior, while the values are higher than those specified for the upper band's mixture, which is a normal result once a coarse gradation has less surface area, translating into a greater need for asphalt compared to a finer mixture. In this particular case, to comply with the design ranges, the percentage of residual asphalt must be between 5% and 6.2%, as shown in (Figure 4).

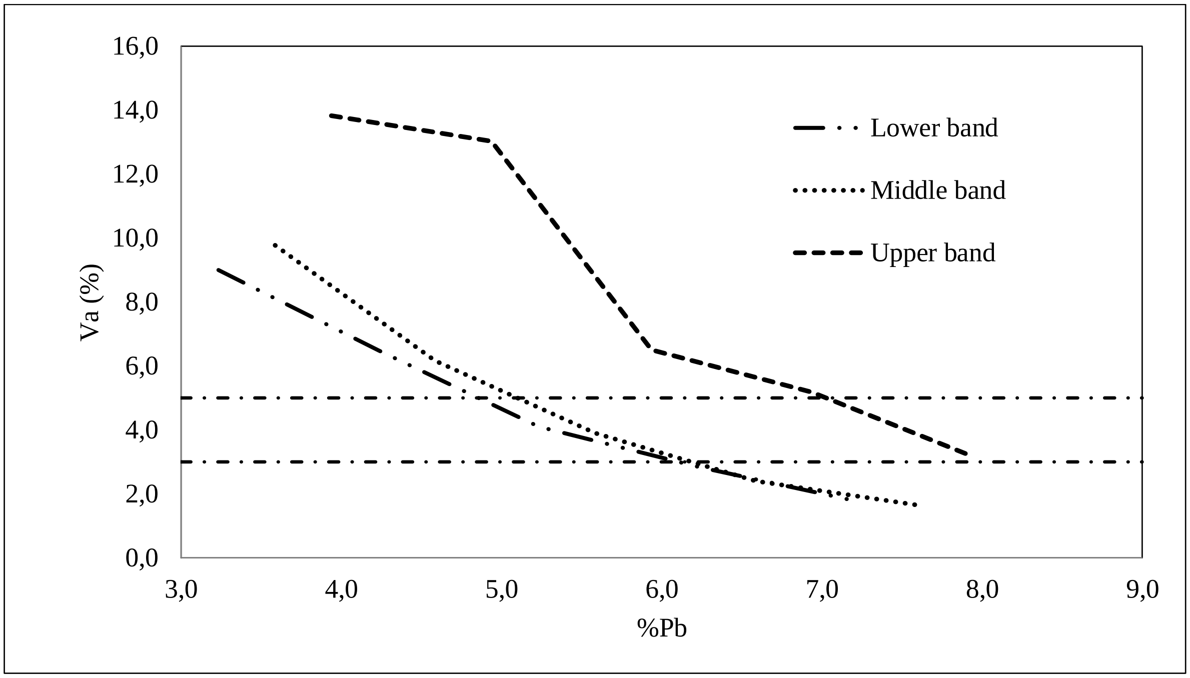

Figure 4. *Behavior of voids with air for different granulometries*

*According to (**Booth Cooper III,** 2011), the variability of air voids in the laboratory is lower than in the field. High air voids can cause moisture damage to the mix, while low air voids could improve durability by making the mix less permeable to air and water. However, if they are too low, they could generate exudation of the mixture under the passage of traffic (Razzaq et al., 2018).*

3.3 Voids in mineral aggregates (VMA)

In Minnesota, the influence of the VMA was investigated and significant differences were found between those designed and those after construction, potentially due to low durability and the degradation of the aggregates during construction, which tends to decrease the VMA and increase the surface area of the aggregates and thus the absorption of asphalt (Chadboum, et al., 1999).
The mixtures designed in this study meet the specification in this parameter, however, and given that the higher the percentage of VMA, the higher the percentage of asphalt required and the greater the possibility of exudation under high temperatures, percentages of residual asphalt higher than 5.5% are not recommended. (Figure 5) shows the results obtained.

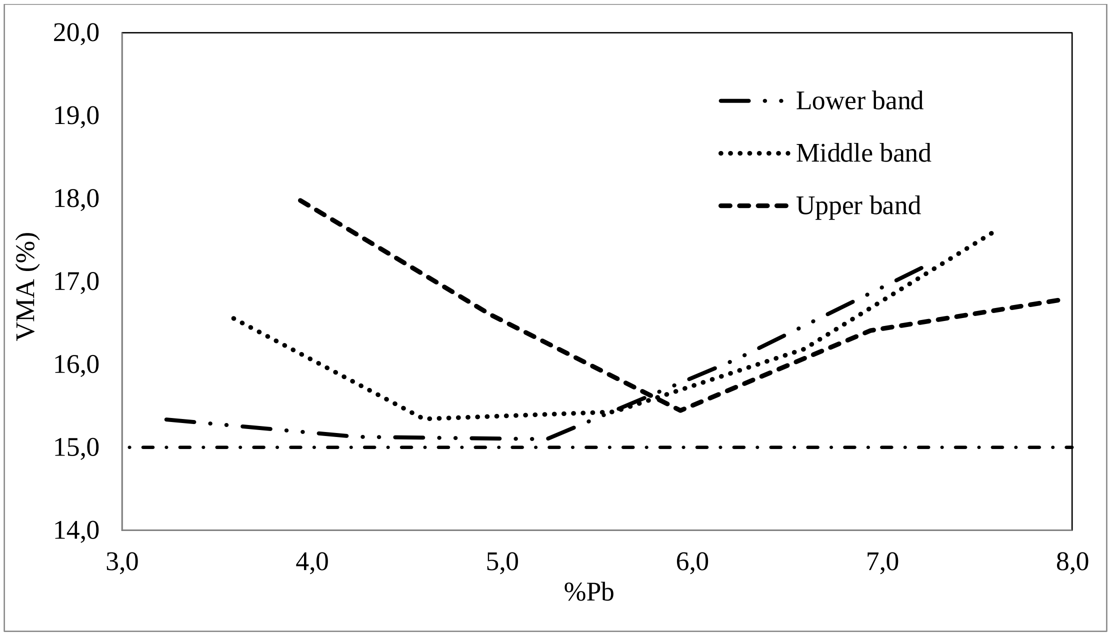

***Figure 5**. VMA behavior for different granulometries*

3.4 Voids filled with asphalt (VFA)

In this study, if the residual asphalt content for the mixtures with the granulometry of the middle and lower bands is less than 5%, they could present brittle pavements, premature cracking, wear, and detachment since the residual asphalt would not cover the totality of its surface and thus the voids with air. (Figure 6) shows the results obtained.

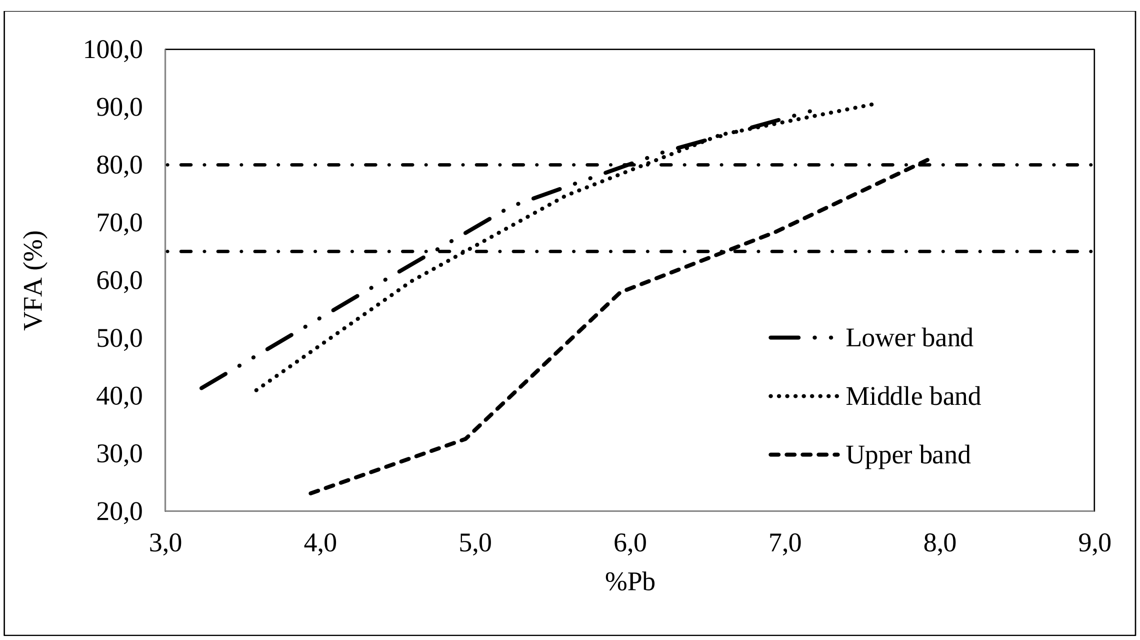

***Figure 6**. Behavior of the VFA for different granulometries*

3.5 Net bulk specific gravity of the asphalt mixture (Gmb).

Density behavior is very similar for the granulometries of the lower and middle bands, but not so for the upper band; the highest density is achieved with percentages of residual asphalt in the range of 5.4% to 6.4%. (Figure 7) shows the results obtained.

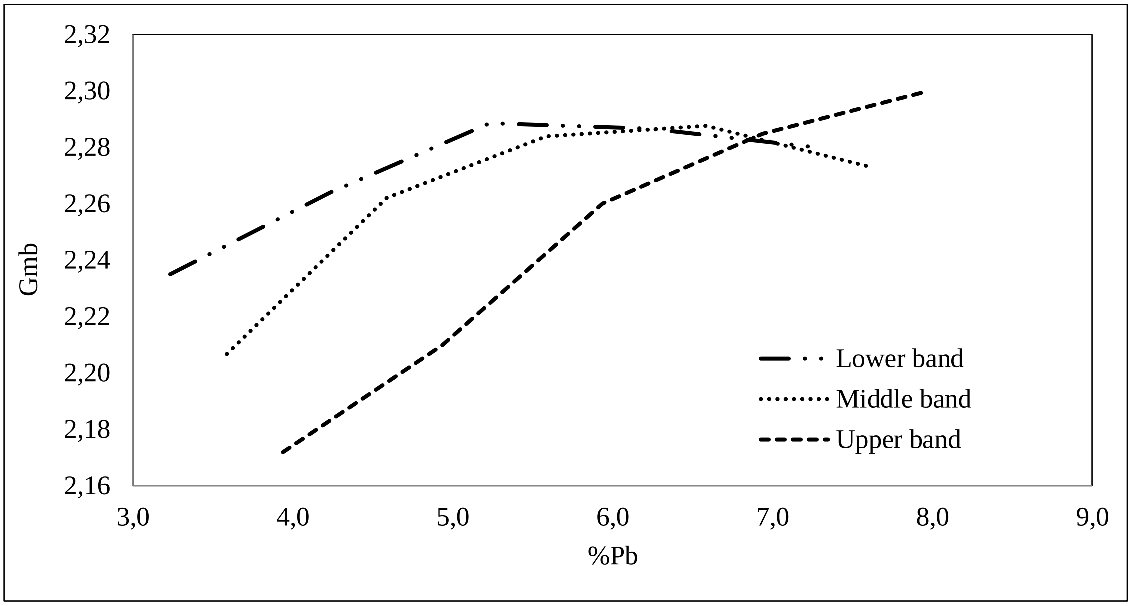

***Figure 7**. Behavior of the net bulk specific gravity (Gmb) for different granulometries.*

3.6 Bitumen content

The influence of the aggregates on the volumetric parameters of the mixtures was analyzed by means of the void polygon obtained by Ramcodes. There is proximity of the polygons of the mixtures designed with the granulometry of the central and lower bands, while the mixture designed with the granulometry of the upper band has a different void polygon according to the difference in the behavior of their densities, as shown look at (Figure 8).

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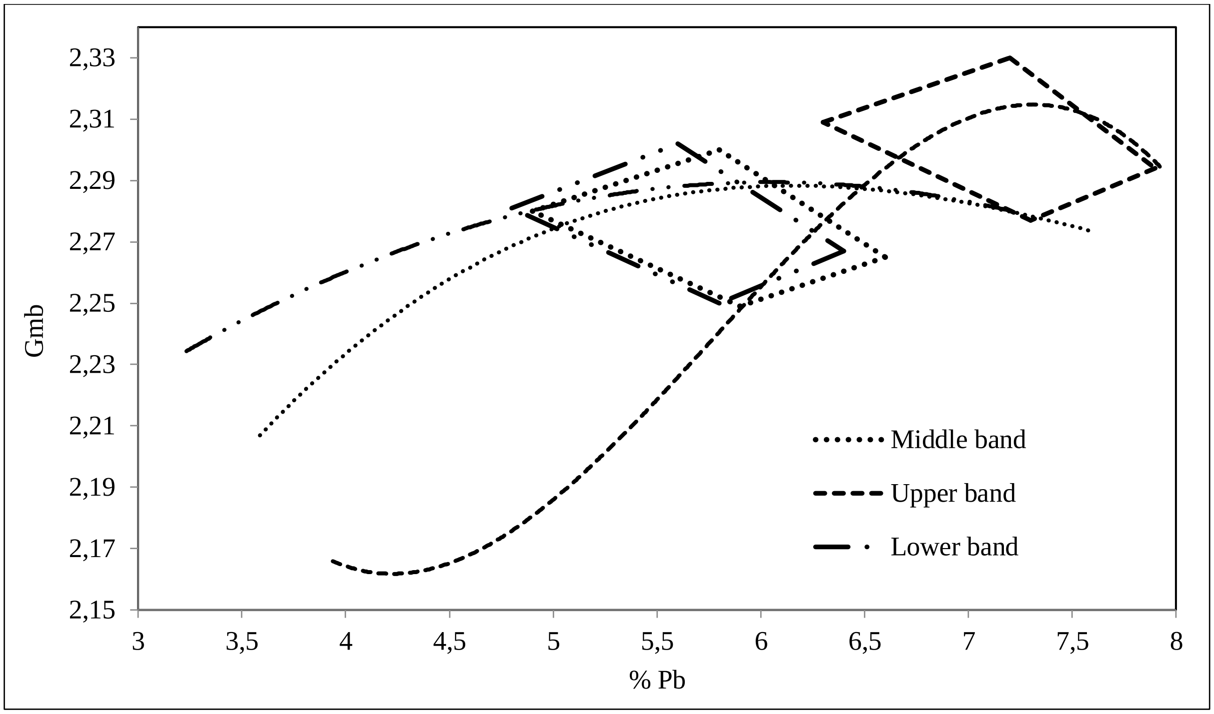

Figure 8. *Ramcodes void polygon for the different granulometries.*

3.7 Obtaining the bitumen content in the mixture by the Marshall method

The optimal percentage of asphalt was determined following the procedure of the American Asphalt Institute and the methodology of the National Asphalt Pavement Association (NAPA). A bitumen percentage of 5.5% and 5.6% is obtained by the IDA and NAPA methodologies, respectively. A similar procedure was conducted for the middle and upper bands. The results and mechanical behavior are presented in (Table 5).

Table 5*. Mix design results with asphaltite*

MIXTURE	*FINE BAND*		*MIDDLE BAND*		*THICK BAND*	
	M1	*R1*	*M2*	*R2*	*M3*	*R3*
% Residual asphalt	*5.4*	*5.7*	*5.5*	*5.8*	*7.0*	*7.2*
Gmb gr/cm³	*2.286*	*2.280*	*2.284*	*2.279*	*2.311*	*2.308*
Stability (Lb)	*453,0*	*482,4*	*570,0*	*595,4*	*515,0*	*544,3*
Flow (mm)	*6,0*	*6,0*	*6,5*	*67*	*10,4*	*10,1*
% Va	*4,0*	*3.9*	*4,0*	*3.9*	*4,0*	*3.9*
% VMA	*15.3*	*15.8*	*15.3*	*15.8*	*15.5*	*15.8*
% VFA	*74.2*	*75.4*	*73.8*	*75.5*	*72.0*	*75.4*

According to the results obtained, the mixtures prepared for the central and upper strip meet the specifications except regarding flow. Table 6 shows the requirements for a conventional cold dense mix designed by Marshall (Ministry of Communications, Infrastructure and Housing, 2001). (Table 6)

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Table 6. *Requirements for a conventional cold dense mix*

Design method	***Limit Values***	
MARSHALL (AASHTO T 245, ASTM D 1559 y MS-14)	*Minimum*	*Maximum*
Number of compaction blows at each end of the specimen	*50*	*75*
1. With asphalt emulsion	*75*	*75*
2. With liquid asphalt		
Stability according to the use of the mixture		
1. For patching	*2.224 N (500 pounds)*	
Stability/Flow Ratio (lb/0.01 inch.)	*3,336 N (750 pounds)*	
Flow in 0.25 mm (0.01 inches)	*8*	*16*
	120	*225*
Percentage of voids with air in the compacted mixture	*3*	*15*
Moisture Sensitivity AASHTO T 283 Retained Strength		
1. With asphalt emulsion	*50%*	
2. With liquid asphalt	*75%*	
Percentage of voids filled with asphalt	*65*	*80*

3.8 Analysis of results obtained by the Ramcodes and Marshall methodologies

A sensitivity study was carried out based on the statistical techniques of analysis of factorial experiments, in which the behavior of bulk specific gravity (Gmb) and percentage of asphalt (% Pb) in an asphalt mixture is studied (Ramcodes, 2009). The stability for the central strip with residual asphalt in the range of 6.25% and 7% was between 550 and 600 lb; for the lower strip with residual asphalt ranging from 5.75% to 6%, between 470 to 480 lbs; and for the upper strip with residual asphalt ranging from 6.5% to 6.75%, between 500 to 510 lbs. In the three strips, the higher the residual asphalt content, the higher the flow values.

3.9 Analysis by means of contour maps for stability and flow

The statistical system takes into account the level of on site risk and protects against the acceptance of a defective mixture or the rejection of acceptable mixtures. This response is obtained by superimposing the void polygon on the response surfaces (contour maps) obtained using the Origin statistical package, which increases the quantity and quality of information to establish realistic designs (Jiménez et al., 2009). The values obtained in the laboratory for the Marshall design are similar to the response given by the contour map (Ramcodes), which statistically suggests a more accurate response for stability and flow of each mix. In the same way, it is evident that the results obtained by the Marshall methodology for each mixture are within the acceptable range in the Ramcodes polygon.

3.10 Design and control criteria

(Figure 9), (Figure 10), and (Figure 11) show the void polygons and the quality control criteria, representing the acceptable control regions in the space established between %Pb and Gmb for the mixtures. This procedure is possible by superimposing the control polygon on the response surfaces and the void polygon, formed by the minimum allowed density level with respect to the laboratory density, and the minimum allowed density level of the theoretical maximum density (RICE %, Vv = 0). In addition, the typical ranges of acceptable variation for optimal %Pb were established at ±0.30% and ±0.45%.

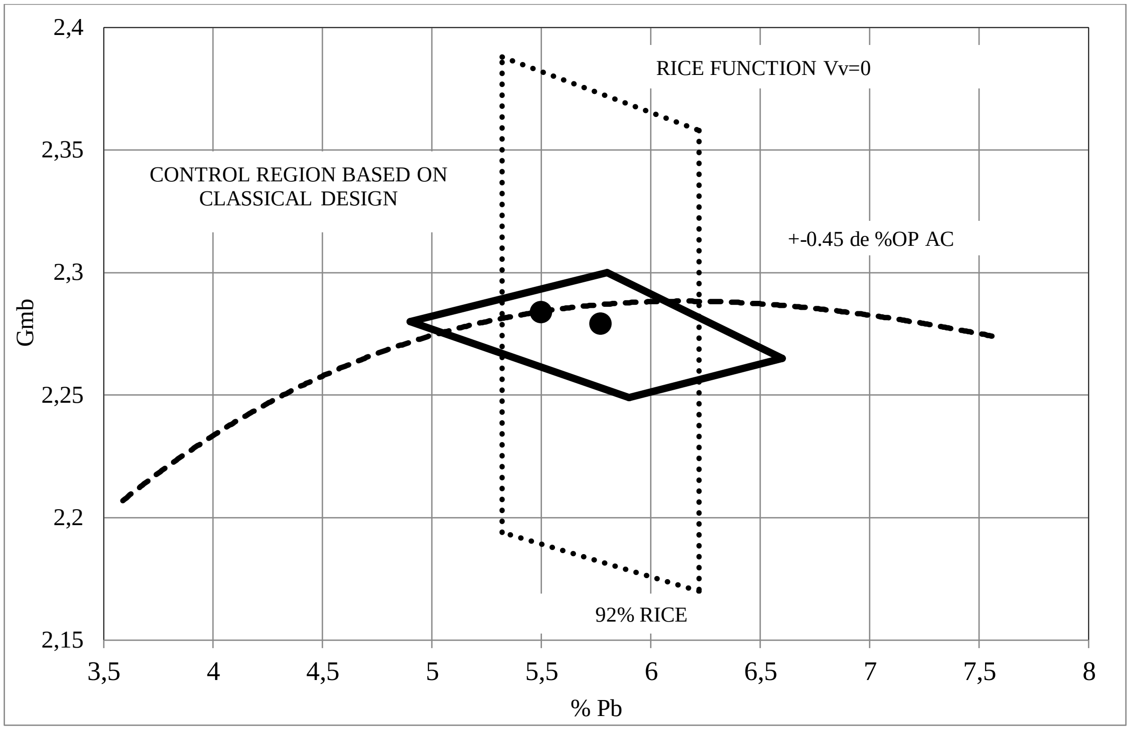

Figure 9. *Quality control and design criteria for the central strip mixture.*

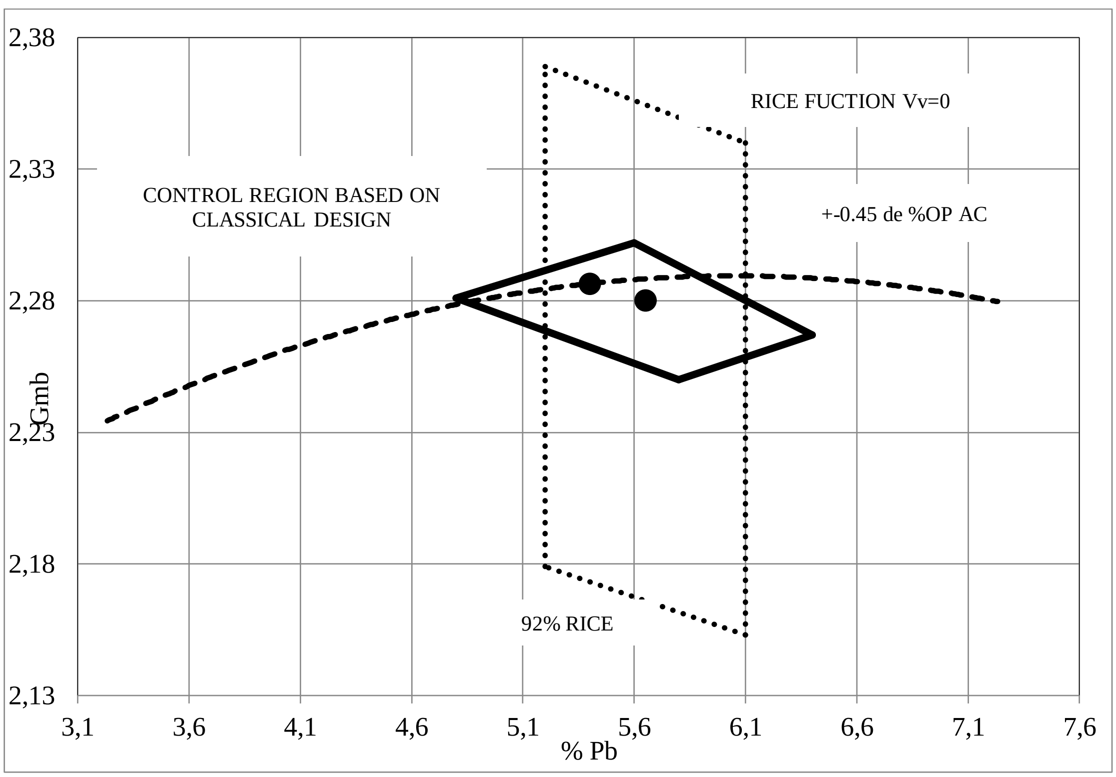

Figure 10. *Quality control and design criteria for the mixture of the lower strip.*

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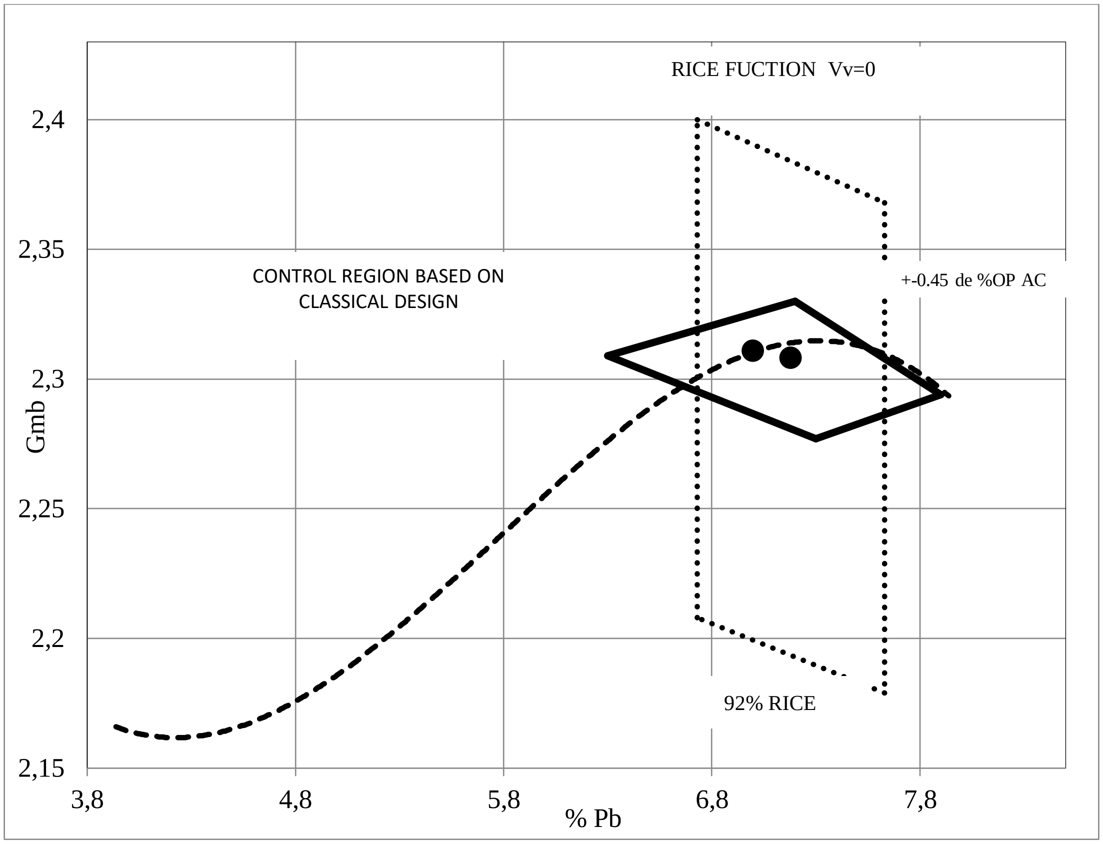

Figure 11. *Quality control and design criteria for the mixture of the upper strip.*

As can be seen, the three mixtures meet the design and control criteria, in addition to having a wide margin of tolerable ranges within the control polygon and the maximum regions where the specifications for the acceptance of the mixtures are met according to the % of residual asphalt that ranges between 5.2% and 7.63% in general.

4. Conclusions

The three mixtures meet the design and control criteria, in addition to having a wide margin of tolerable ranges within the control polygon and the maximum regions where the specifications for the acceptance of the mixtures are met according to the % of residual asphalt that ranges between 5.2% and 7.63% in general.
The mixes designed in this study with the addition of asphaltite were of high stability, ergo, more rigid and at the same time more brittle because their flow is also greater. Thus, they would have a better behavior in hot climates.
The behavior of modified asphaltite designed mixtures can have better behavior than conventional mixtures, at a not very high cost and without generating requests or different manufacturing requirements according to their normal process.

According to the design methodologies used, the bituminous mixtures with asphaltite, for the gradation of the central limit of the specifications, would have a better performance throughout their useful life because they have a closer relationship with the construction specifications of roads of INVÍAS 2013 for traffic level one (NT–1).
From the statistical analysis carried out with the contour maps, similarity is observed in the results obtained by the two Marshall and Ramcodes methodologies, where flow and stability data do not vary by more than 1 and 4%, respectively.

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