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Performance of Bituminous and Hydraulic Materials in Pavements, Zoorob, Collop & Brown (eds)

Evaluation of mastic in bituminous mixtures

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ABSTRACT: The efficiency of the asphalt-aggregate bond is one of the key factors which affects the mechanical resistance of bituminous mixtures and a better understanding of its performance allows the behaviour of mixture to be more accurately predicted.

The asphalt-aggregate bond depends on the properties of the mastic and the mixture of fine aggregate and bitumen which bonds itself to the larger sized particles within the bituminous mixture. This mastic plays an important role in the asphalt-aggregate bond because failure occurs in this part of the bituminous mixture.

For the development of an adhesion test (at the University of Minho), a study was conducted to evaluate the mastic part of bituminous mixtures. A physical evaluation of the mastic was performed by sieve analysis. The material retained on each sieve was characterized by evaluating the binder content and the gradation of the fine aggregate fraction.

The results of this study allow the mastic part of a given mixture to be characterized as a function of aggregate gradation and binder content. The reverse process, where the type of mixture is defined by knowing the mastic, is also being studied, but this is not an easy process and it only allows some mixture variables to be defined.

1 INTRODUCTION

A new adhesion test is being developed at the University of Minho. This test evaluates the tensile and shear properties of the mastic component of a bituminous mixture and correlates the results with tensile fatigue cracking and permanent deformation resistance of the whole bituminous mixture.

The mastic used in this laboratory test, and evaluated in this work, is defined as the material that is bonded to the coarse aggregate component of a bituminous mixture. This is a different material from the usual stone mastic asphalt which is commonly reported in the literature.

The mastic characterization (sieve analysis and binder content of the fine material bonded to the coarse aggregate) was performed on each coarse aggregate fraction present in the bituminous mixture.

Moreover, the goal of this study was to understand in which way the mastic gradation and binder content varies as a function of the dimension of the coarse aggregate. In this study the mixture was divided into different fractions (one fraction for each aggregate size) and the characterization was carried out on each different coarse aggregate gradation.

For this study two conventional bituminous mixtures were produced (a wearing course and a base course). For each mixture type three binder contents were used. One was the optimum binder content, which was obtained using the Marshall method of mix design. The other two corresponded to binder contents 0.5% above and below the optimum.

2 COMPOSITION AND PERFORMANCE OF THE ASPHALT MASTIC

There are not many authors who refer to this subject. However, there are some authors (including writer of the Belgian standards), who have dedicated themselves to this study.

Analysing the existing literature concerning the mastic, both in conventional mixtures and in mixtures richer in mastic revealed that the main mastic characteristics are the proportional relation of filler to bitumen and the rheological properties of the bitumen. The optimization of these characteristics has been shown to improve the bituminous mixture performance.

Some authors report on the specific structure of the mastic mixtures. For small amounts of filler (application in hot mixes), the differences in rheological properties are not very important. On the other hand, when the filler content reaches high values (application in mastic asphalts), the rheological behaviour changes dramatically and this should be taken into account in performance prediction (Durand et al. 1997).

The next stage in the study of the constituents interaction consists of looking in more detail at the binder/stone interaction. This should be undertaken to create a better understanding of the products performance and a more effective prediction for road applications.

In the Belgian analytical mix design method, a bituminous mix is considered to be formed by a group of mineral coarse aggregates filled with mastic. Initially, the maximum volume available for mastic is determined, which is the same as the voids in mineral aggregates plus the volume of filler that exist in the aggregate. Since the filler component of the mineral aggregate will be used to produce the mastic, the volume available for mastic includes the filler volume. This volume should lie within pre-determined limits proposed by the Belgian standards. These limits are a function of the road type (i.e. highway, other roads, etc.) and layer type (i.e. wearing course, base course, etc.) and should be between 15.5% and 28.5%.

The next step is the determination of the mastic composition. The mastic composition must have thermal consistency and susceptibility so as to provide mixes with cohesion and stability adequate to the course used in the pavement as well as to the expected road traffic conditions. Its properties are influenced by the bitumen mechanical characteristics, the filler stiffness and by the ratio of filler to bitumen (Luminari & Fidato 1998).

The Belgian method demonstrates the importance of the mastic characterization and of the knowledge of its proportion in a bituminous mixture for mix design. By playing that role in the mix design, obviously, the mastic composition must be known to improve its performance in order to achieve not only a better adhesion between the mastic and the coarse aggregates but also an overall improved bituminous mixture behaviour.

Finally, referring to the study made by Cupo-Pagano et al. (1997), Rigden percentage voids is very important for the mastic characterization and for the mastic stiffening potential. The production of the mastic consists of a variation in the binder physical properties (an increase in the consistency and viscosity and an increase in the mixture stiffness) that can be measured by an application of a strain under static or dynamic conditions.

The influence of the mastic on the mechanical properties of bituminous concretes indicates that the main factors to be considered should be the type and content of the material, in order to avoid undesirable phenomena in road pavements.

3 CHARACTERIZATION OF THE USED MATERIAL

In order to develop a new fundamental test of adhesion, based on the principle that the mechanical behaviour of a bituminous mixture depends on the bond between the coarse aggregates and the bituminous mastic (which involve and link the mineral skeleton), it was first necessary to study the composition of the asphalt mastic.

This mastic, as explained earlier, is composed of bitumen and fine aggregates. The main objective of this laboratory work is to determine the grading curve

Table 1. Aggregate gradation for the wearing course bituminous mixtures (0/14) – granulometric curves.

		Percentage of material passing						
		Stock pile				Wearing bituminous mixtures		
Sieve	Diameter (mm)	0/4 mm	4/11 mm	11/16 mm	16/25 mm	Minimum	Obtained	Maximum
1″	25.000	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4″	19.000	100.0	100.0	100.0	59.7	100.0	100.0	100.0
1/2″	12.500	100.0	100.0	65.6	3.4	80.0	86.4	88.0
3/8″	9.500	100.0	97.4	16.5	0.5	66.0	66.5	76.0
no. 4	4.750	99.6	27.4	2.5	0.4	43.0	47.5	55.0
no. 10	2.000	81.6	5.8	1.4	0.4	25.0	35.5	40.0
no. 20	0.850	56.6	2.9	1.3	0.4	16.7	24.5	27.8
no. 40	0.425	39.8	1.9	1.2	0.4	10.0	17.3	18.0
no. 80	0.180	22.6	1.0	1.1	0.3	7.0	10.0	13.0
no. 200	0.075	11.7	0.5	0.8	0.3	5.0	5.3	9.0
Rest	0.010	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Used material (%)		41.5	19.0	39.5	0.0			

and the related bitumen content of the mastic that surrounds an aggregate with a certain dimension in a defined bituminous mixture.

The mastic that surrounds the retained aggregates on various sieves (3/4″, 1/2″, 3/8″, no. 4, no. 10 and no. 20) was studied for two bituminous mixtures proposed by the Portuguese standards for wearing and base courses. For each mixture, three binder contents were used (the optimum obtained from the Marshall method and 0.5% above and below optimum) in order to analyse how the composition of the mastic varies with the binder content.

The material used for this study was the most commonly utilized in the North of Portugal. The binder was an unmodified bitumen with a penetration grade of 51 dmm and a softening point (using the ring and ball method) of 53°C.

The aggregates used were the most commonly utilized, being raw materials from that region. They are mechanically crushed granitic rocks (both fine and coarse aggregates) and were stored in four stock piles according to the aggregate's dimension. This material has good wearing properties.

The aggregates stored in the stock piles were combined in order to obtain the gradation curve for the two bituminous mixtures used in this study. Tables 1 and 2 show how the stored materials were combined in order to obtain the 0/14 bituminous mixture for the wearing course and the 0/19 bituminous mixture for the base course, both indicated in the Portuguese standards.

The binder content and the void content were optimized by the Marshall mix design method. Other binder contents were tested specially to confirm the results obtained at the optimum binder content and to understand how the composition of the mastic varies as a function of the binder content.

4 LABORATORY PROCEDURE AND TEST METHODS

The first step in the laboratory procedure consisted of applying the Marshall mix design method (the most commonly used and specified in Portugal) in order to determine the optimum binder content for both mixtures investigated.

The optimum binder contents for both mixtures were 5.6% for the wearing course bituminous mixtures and 5.8% for the base course bituminous mixtures.

Three mixtures (three binder contents) for each aggregate gradation were prepared and, immediately after the mixing, were laid on a large table in order that the largest particles would not agglomerate but only be surrounded by mastic.

Some care was taken to avoid pollution by dust, and to ensure that the moisture level was not changed.

When the material was cold, it was then sieved in order to divide the mixture into different fractions as a function of the coarse aggregate dimensions. The sieves used to separate the mixtures are indicated below, both for the wearing course and base course mixtures.

Each fraction of the sieved material was burnt to remove the bitumen and measure the binder content.

After the bitumen had been removed, the aggregate gradation of each fraction was also determined.

The gradation of these fractions were always discontinuous. In this way, two distinct dimensions of aggregates can be observed: the coarse aggregates and the fine aggregate.

These fines have a much larger specific surface than the coarse aggregates and, because of this, it can be considered that all the bitumen (which existed in each fraction), together with the fines, compose the bituminous mastic for each coarse aggregate fraction.

Table 2. Aggregate gradation for the base course bituminous mixtures (0/19) – granulometric curves.

		Percentage of material passing						
		Stock pile				Base course bituminous mixtures		
Sieve	Diameter (mm)	0/4 mm	4/11 mm	11/16 mm	16/25 mm	Minimum	Obtained	Maximum
1″	25.000	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4″	19.000	100.0	100.0	100.0	59.7	85.0	92.5	100.0
1/2″	12.500	100.0	100.0	65.6	3.4	73.0	80.0	87.0
3/8″	9.500	100.0	97.4	16.5	0.5	65.1	75.7	79.3
no. 4	4.750	99.6	27.4	2.5	0.4	45.0	52.5	60.0
no. 10	2.000	81.6	5.8	1.4	0.4	32.0	37.7	46.0
no. 20	0.850	56.6	2.9	1.3	0.4	23.2	25.8	35.5
no. 40	0.425	39.8	1.9	1.2	0.4	16.0	18.1	27.0
no. 80	0.180	22.6	1.0	1.1	0.3	9.0	10.3	18.0
no. 200	0.075	11.7	0.5	0.8	0.3	5.0	5.4	10.0
Rest	0.010	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Used material (%)		43.75	31.76	5.88	18.61			

As the aim of this work is the development of a method in order to evaluate the mastic for different mixtures and for any binder content, the composition of the mastic was analysed for both mixtures investigated and for the indicated binder content.

5 RESULTS

In Tables 3 and 4 and in Figures 1 and 2, the results of the mastic composition analysis can be observed, which was the main objective of this work. All

Table 3. Analysis of the mastic composition (gradation and binder content) as a function of the size of coarse aggregate for wearing course bituminous mixture (0/14) – granulometric curves.

		Wearing bituminous mixtures (binder content = 5.6%)								
		Retained percentage							Cumulative passing %	
			Fractions burned after being retained in sieve							
Sieve	Diameter (mm)	Mix before burned	1/2″	3/8″	no. 4	no. 10	no. 20	Rest	Mix before burned	Mix after burned
3/4″	19.000								100.0	100.0
1/2″	12.500	18.8	74.8						86.4	85.5
3/8″	9.500	20.2	14.9	68.6					66.5	68.3
no. 4	4.750	24.4	0.0	17.6	65.4				47.5	48.5
no. 10	2.000	22.1	0.2	0.4	11.9	39.5			35.5	37.0
no. 20	0.850	12.4	0.6	1.0	2.6	23.7	38.1		24.5	26.5
no. 40	0.425		1.4	1.9	3.4	7.7	25.8	52.7	17.3	19.2
no. 80	0.180		2.9	3.8	6.5	12.1	16.5	30.7	10.0	11.2
no. 200	0.075		2.6	3.3	5.7	9.6	10.6	8.2	5.3	5.1
Rest	0.010	2.1	2.6	3.4	4.5	7.3	9.0	8.3	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0		
Binder content for all fraction			2.6	3.2	5.3	10.5	10.9	11.1		
Mastic binder content			10.3	10.3	15.4	17.3	17.7	23.6		
Average of mastic binder content			14.3							

Table 4. Analysis of the mastic composition (gradation and binder content) as a function of the size of coarse aggregate for base course bituminous mixture (0/19) – granulometric curves.

		Base course bituminous mix – (binder content = 5.8%)									
		Retained percentage								Cumulative passing %	
			Fractions burned after being retained in sieve								
Sieve	Diameter (mm)	Mix before burned	3/4″	1/2″	3/8″	no. 4	no. 10	no. 20	Rest	Mix before burned	Mix after burned
1″	25.000									100.0	100.0
3/4″	19.000	10.1	57.7							92.5	93.9
1/2″	12.500	11.1	36.4	84.4						80.0	80.4
3/8″	9.500	5.3	0.0	6.7	61.9					75.7	76.2
no. 4	4.750	27.3	0.0	0.2	25.8	64.6				52.5	57.0
no.10	2.000	31.4	0.0	0.2	0.2	14.0	37.8			37.7	41.5
no. 20	0.850	12.5	0.3	0.6	0.9	2.4	24.9	40.6		25.8	28.3
no.40	0.425		0.8	1.1	1.7	3.1	9.3	26.4	49.7	18.1	19.9
no. 80	0.180		1.9	2.5	3.5	6.1	12.1	15.8	33.6	10.3	11.1
no. 200	0.075		1.6	2.3	3.1	5.6	9.1	9.2	9.0	5.4	4.9
Rest	0.010	2.5	1.3	2.0	2.9	4.2	6.7	8.0	7.7	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
Binder content for all fraction			1.8	2.3	3.2	5.1	8.8	11.3	7.7		
Mastic binder content				4.2	14.5	8.5	14.3	14.2	19.0	15.3	
Average of mastic binder content			13.6								

these correspond to mixtures made with the Marshall optimum binder content, although other binder contents were studied and similar results were obtained.

Table 3 presents the percentage of each fraction of the retained bituminous mixture in each sieve before being burned. In the next columns, the gradation curves of each fraction after being burned are given as well as the binder content of each fraction and the mastic binder content.

The binder content of each fraction was calculated by dividing the binder weight by aggregate weight.

The mastic binder content was defined as the percentage binder content of each fraction excluding the largest aggregate size of that fraction.

Finally, in the last two columns, the gradation curve of the entire mix in the beginning and after the whole process is shown.

Figure 1 graphically illustrates the gradation curves presented in Table 3.

Table 3 and Figure 1 correspond to the analysis of the bituminous mixture for the wearing courses. The same results are presented in Table 4 and Figure 2 for the base course mixtures.

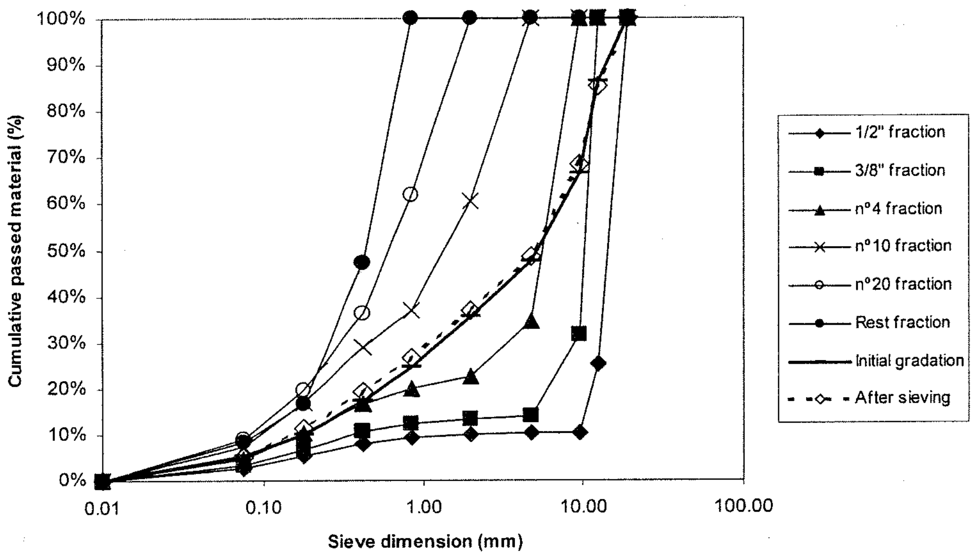

Figure 1. Gradation of a wearing course bituminous mixture (0/14) before and after sieving in different sieves and gradation of the retained material in each sieve after being burned.

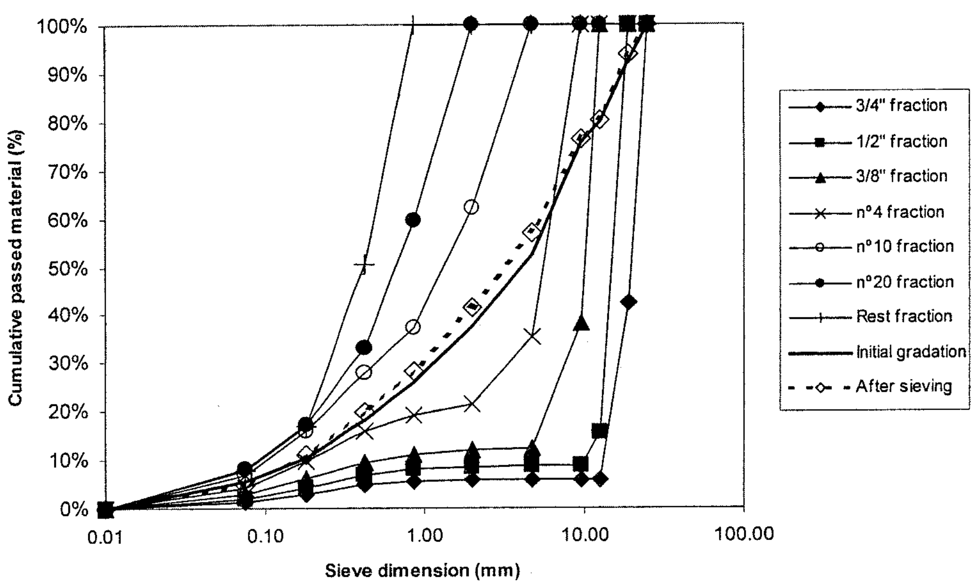

Figure 2. Gradation of a base course bituminous mixture (0/19) before and after sieving in different sieves and gradation of the retained material in each sieve after being burned.

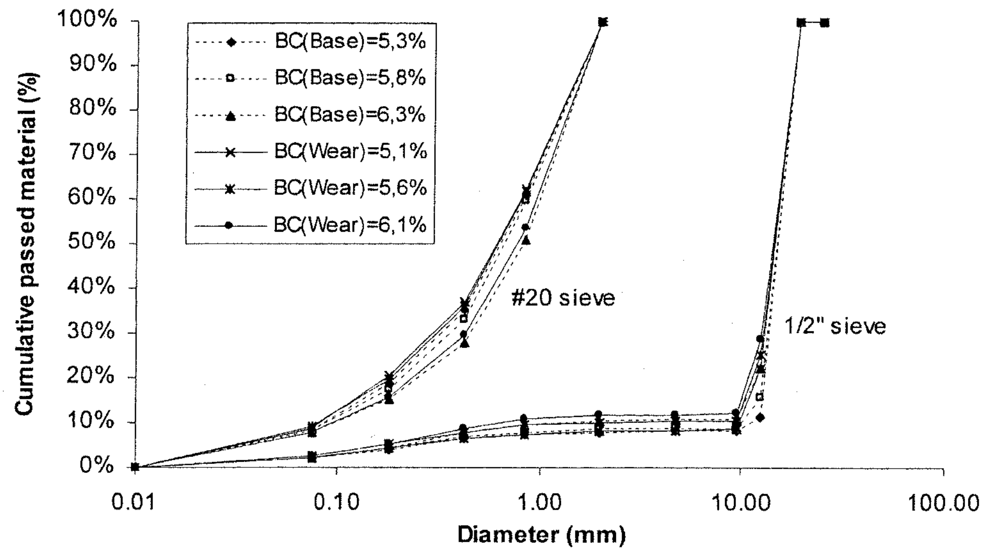

Figure 3. Influence of binder content on aggregate gradation of material retained in the 1/2″ and #20 sieves.

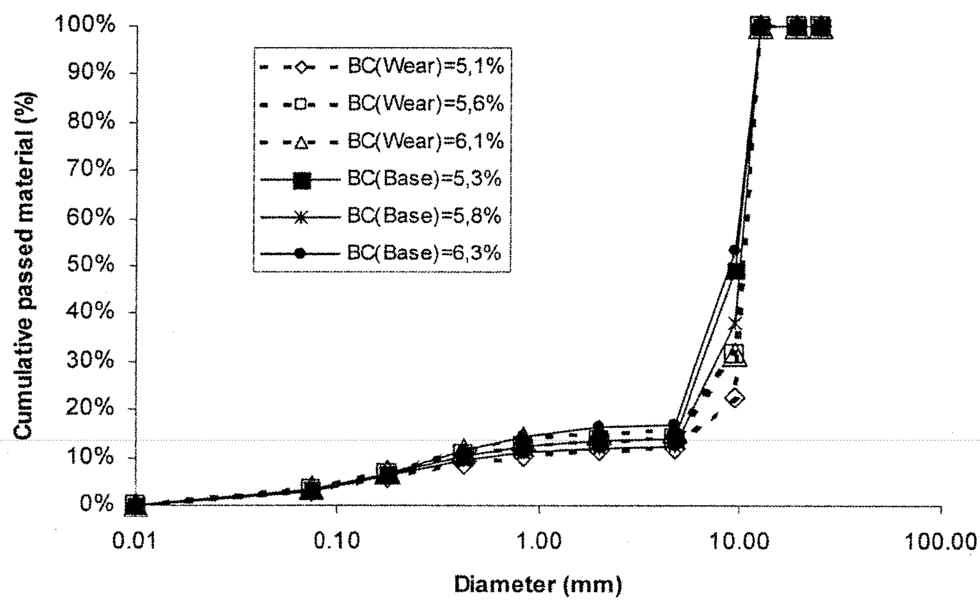

Figure 4. Influence of binder content on aggregate gradation of material retained in the 3/8″ sieve.

It would be important to analyse how the composition varies for the same fraction (for coarse aggregates with the same dimension), when the binder content varies for each mixture investigated (wearing or base course). Two different results were observed as a function of the dimension of the coarse aggregate.

In Figure 3 it can be observed how the composition varies (according to the binder content) when the coarse aggregate has a big dimension (no. 4, 3/8″, 1/2″ and 3/4″ fractions) for wearing courses and base courses. In this case the example shows the results for 1/2″. The results of the smaller dimensions (no. 10, no. 20 fractions) are also presented. In this case the #20 sieve was chosen.

Figure 4 shows the composition of the 3/8″ fraction for both mixtures and for all binder contents in order to allow a comparison of both mixtures.

The gradations of all fractions are shown in Figure 5 for both bituminous mixtures at all binder contents.

6 ANALYSIS OF RESULTS

Firstly, the process to evaluate the mastic composition of a bituminous mixture was simple and it showed

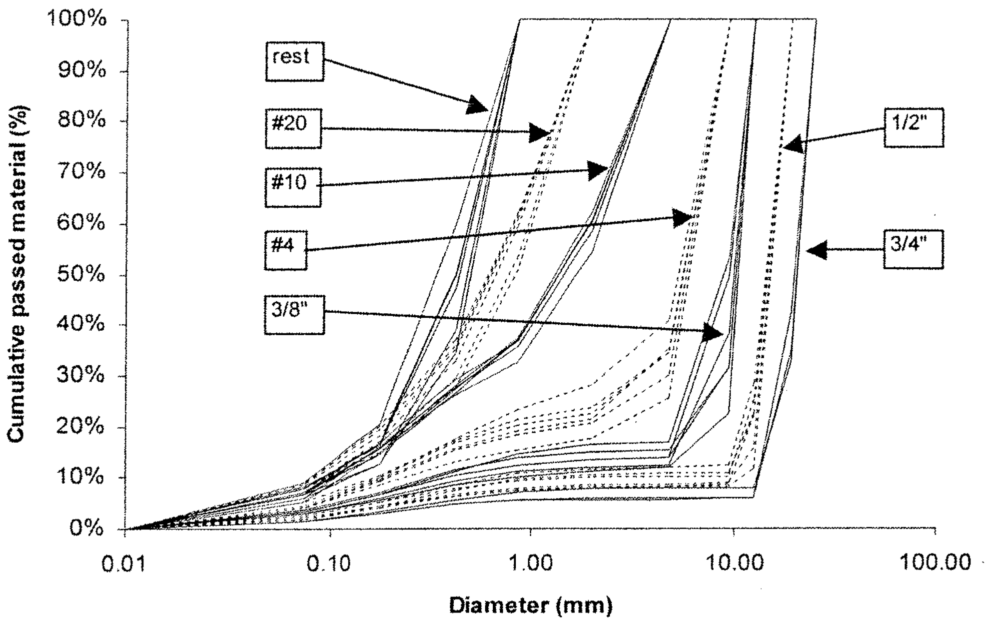

Figure 5. Influence of binder content on aggregate gradation of material retained in all sieves.

good results. In order to confirm the repeatability of the results, the procedure was repeated and it was shown that the process is always reproducible.

Moreover, in order to confirm that there was no loss of material whilst carrying out the procedure, it can be observed in Figures 1 and 2 that the gradation curves, before and after the whole process, are almost equal.

Any differences that might occur in the whole process are negligible and depend on the experience of the operator. Any loss of fines in the muffle furnace was also found to be insignificant.

The analysis of each fraction shows that the granulometric curves are similar to each other. They are discontinuous and consist of coarse aggregates (the two biggest dimensions of each fraction) and of fines (the remainder of the material). The fines, together with the bitumen of the fraction, compose the mastic, as defined in this work. The granulometric curves of this mastic are approximately linear, although the percentage retained on the smaller sieves is slightly greater. The bigger the coarse aggregate top size of the fraction is, the smaller the associated mastic binder content is. This is due to the smaller fines content in those fractions.

Comparative analysis between the different binder contents in the same fraction (both for wearing and base courses) shows that for #10, #20 fractions and the fraction of the rest (passing #20 sieve) the quantity of fines (for each fraction, the fines are defined as all aggregates excluding the largest aggregate size) decreases in the mastic composition, when the binder content increases. The gradation curves of these three fractions (which have got the smallest coarse aggregates) lie above the gradation curve of mix.

In the other fractions (#4, 3/8″, 1/2″, 3/4″), this situation is completely reversed. When the binder content increases, the quantity of fines (see earlier definition) increases in the mastic composition too. The gradation curves of these four fractions (which contain the larger coarse aggregates) lie below the gradation curve of the mix.

Concerning the comparison between the bituminous mixture for wearing courses and for base courses, when the same fraction size was analysed, a similar mastic composition was observed, in terms of aggregate gradation and binder content. However, the composition of the mastic of the bituminous mixture for the base courses was richer in fines (at the same binder content).

7 CONCLUSIONS

In conclusion, the executed procedures in this work were revealed to be a good option for the characterization of mastic composition. In fact, the lack of standardization and works, which allow mastic characterization, justifies the need of this effort.

The characterization was a reproducible method and allows easy observation and, in a quick process, obtains mastic composition.

One of the difficulties using this method consisted of defining the fines and the coarse aggregates in a certain fraction. Thus, a method must be developed regarding the definition of the fines which compose the mastic, and the determination of the mastic binder content.

An increase in the binder content in a mixture implies an increase in the fines content in the composition of the mastic of the larger coarse aggregates. This implies that there is a larger amount of mastic surrounding the bigger coarse aggregates, when the binder content is higher. When the binder content is lower, there is a bigger quantity of mastic surrounding the smaller coarse aggregates.

However, the same method should be used on a larger scale in order to draw further conclusions. Other mixtures and materials should be studied as well as different binder contents.

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