

Evaluation of the bond between mastic and coarse aggregates

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ABSTRACT: In the last decades, the flexible road pavements have been subjected to the action of a more intense traffic, which has often originated their premature degradation. Among others, to guarantee a better performance of the pavement, it is essential that the bituminous mixtures show an appropriate behaviour *in situ* for the high solicitations to which they will be submitted. The bituminous mixtures behaviour is evaluated through tests that allow the study of their properties. The bond between the mastic and the coarse aggregates may possibly influence the behaviour of a bituminous mixture in the pavement. Thus, the main aim of this work was the study of the bond between mastic and coarse aggregates, trying not only to contribute to a better knowledge of this property, but also to a better behaviour of the bituminous mixtures *in situ*. A proceeding to study the mastic composition was developed and mechanical tests were used in order to evaluate the bond between mastic and coarse aggregates, which is determined through the tensile and shear strengths. The results of the mechanical tests were used to evaluate the influence of the mastic binder content on the strength of the bond between mastic and coarse aggregates. In the same tests, it was also observed the main type of failure of the bond between mastic and coarse aggregates.

KEY WORDS: Bituminous mixtures, behaviour, tests, mastic, aggregate-mastic bond, failure.

1. INTRODUCTION

1.1. Thematic framing

The behaviour of the bituminous mixtures has a great influence in the performance of a flexible road pavement. Usually, the properties of the bituminous mixtures, evaluated in fundamental and simulation tests, are the fatigue and the permanent deformation resistances. Certain properties of the bituminous mixtures that influence their behaviour in service can also be evaluated. One of those properties (to be studied along this work) is the strength of the bond between mastic and aggregates of a bituminous mixture.

According to Scholz (1995), when the strength of the bond between mastic and aggregates is weak, the bituminous mixtures have a smaller stiffness, which corresponds to a lower capability for them of resisting to the stresses induced by the traffic.

As stated by the same author, the reduction of the strength of the bond between mastic and aggregates results in a more fragile structure of the bituminous mixture with a larger tendency

to disintegrate, which, as a consequence, increases the propensity for the incidence of cracking and permanent deformation (due to the smaller stiffness of the bituminous mixture).

A research (Hargreaves et al., 1985) related to the problems of premature degradation of bituminous mixtures applied in the wear layers of flexible road pavements showed that several cases of premature degradations were due to the failure of the bond between bitumen and coarse aggregates.

Curtis et al. (1993) refer that a bituminous mixture can be visualized as a system in which the larger, smaller and fine aggregates are either coated with bitumen or suspended within the bitumen. The bitumen can penetrate in the pores and interstices of the aggregates. The electrically active sites on the aggregates attract the most polar species of the bitumen, which have a greater bond capacity in the initial contact.

Each bitumen molecule is in contact with the surface of an aggregate or with other bitumen molecules that are in contact with or close to an aggregate surface. The fine aggregates are interspersed with the bitumen, forming a mastic, a medium in which it is difficult to distinguish between the bitumen and the aggregates.

The bond between the bitumen and the aggregates happens during the hot-mix processing, when the components of the bitumen contact and adhere to the interfacial surface of the aggregates, with the more polar constituents of the bitumen (the ones that contain heteroatoms of sulphur, nitrogen or oxygen) being most competitive for the active sites on the surface of the aggregates (the sites that contain metals or electrically charged species).

An evaluation of the interactions between bitumen and aggregates showed that the chemical composition of the aggregates is much more influential than the bitumen composition, either to guarantee an appropriate bond or to avoid the loss bond due to the presence of water in the bituminous mixture, except where cohesive bitumen failures occur (Curtis et al., 1993). Although the bitumen composition has a smaller effect, it is not insignificant.

The modes of failure of the bond between bitumen and aggregates are many and dependent on the character of the system consisting of bitumen and aggregates. The most important modes of failure are:

- 1) separation of the bond in the interface between bitumen and aggregates;
- 2) failure within the bitumen where its soluble components are removed;
- 3) cohesive failure within the aggregates;
- 4) phase separation of bitumen components, when the presence of water increases the solubility of polar compounds of the bitumen through hydrogen bonding.

The failure can be interfacial or cohesive, either in the bitumen or in the aggregates. Interfacial failures are originated by loss of bond in the interface between bitumen and aggregates. On the other hand, cohesive failures happen due to internal problems of union in the bitumen or in the aggregates, that cause the bond failure between bitumen and aggregates.

The factors that influence the strength of the bond between bitumen and the aggregates are numerous and complex. At Table 1 some of these factors are identified and it is considered that approximately 80% are controllable in the phases of bituminous mixture production and pavement construction.

1.2. Main aims

In this work the authors intended to evaluate the bond between mastic and aggregates in a bituminous mixture through fundamental tests that simulate the behaviour of the bituminous mixtures *in situ*, with the purpose of increasing the strength of that bond. This way, the behaviour of the bituminous mixtures would be improved to delay the incidence of premature degradations in flexible road pavements.

Table 1: Properties of the materials and external influences that affect the bond of bitumen to aggregates (Whiteoak, 1990)

Aggregate properties	Bitumen properties	Bituminous mixture properties	External influences
<ul style="list-style-type: none"> - Mineralogy - Superficial texture - Porosity - Dirtiness - Durability - Superficial area - Absorption - Water content - Shape - Wearing properties 	<ul style="list-style-type: none"> - Rheology - Electrical polarity - Constitution - Aging 	<ul style="list-style-type: none"> - Voids volume - Permeability - Binder content - Thickness of the bitumen layer - Type of filler - Grading of the aggregates - Type of bituminous mixture 	<ul style="list-style-type: none"> - Precipitation - Water - Water pH - Presence of salts - Temperature - Temperature cycles - Traffic - Spreading and compaction phase - Drainage

Thus, in the present work, tensile and shear mechanical tests were implemented to determine the strength of the bond between mastic and aggregates. The results of those tests will be used to achieve the following main aims:

- to evaluate in which way bituminous mixture compositions (mastic binder content) influence the strength of the bond between mastic and aggregates;
- to observe the zone where the failure of specimens happens, in order to verify if the implemented tests simulate the phenomenon that is intended to be studied;
- to compare the interfacial strength of the bond between mastic and aggregates with the internal cohesion strength of the mastic, in order to investigate which is the main cause of failure of the bond between mastic and aggregates (separation in the interface or cohesive failure of the mastic).

The application of mechanical tests to study the mastic-aggregate bond is justified by the need of determining the mechanical strength of that bond. Besides, the loss of bond of the bituminous mixtures in service can only be ascertained if the bituminous mixtures were submitted to a kind of load that represents the real solicitations of the traffic in the pavement that originate that phenomenon.

Specimens composed by different layers of mastic and coarse aggregates were used to determine the strength of the bond between mastic and aggregates (in the interface). Specimens composed only with bituminous mastic were also prepared, to evaluate the possibility of occurring loss of bond between mastic and aggregates due to a failure of internal cohesion of the mastic.

2. EXPERIMENT DESIGN

2.1. Used materials

In this work, as bituminous binder, it was used a pure 50/70 bitumen. The characterization of that bitumen was made through a penetration test (ASTM D 5), and it was verified that the bitumen had a penetration of 51 (10^{-1} mm). The softening point of the bitumen, determined by the ring and ball method (ASTM D 36), was 53 °C. The bitumen used in this work had a high thermal susceptibility (IP = -0.43), this means that its characteristics change a lot when temperature varies.

Concerning the aggregates used in this work, they have a granitic origin. The wear values measured in Los Angeles's machine (ASTM C 131) were always lower than 15% (aggregates with good wear characteristics).

According to a study done by Silva (2002), in this work the bituminous mastic was defined as being the material that involves and bonds the coarse aggregates, in a specific bituminous mixture (in this work, the mixture studied was a 0/14 bituminous wear mixture pointed out in the Portuguese specifications of APORBET (1998)). The same author states that the fine aggregates that compose the mastic are the ones that have dimensions lower than 2mm (sieve n°10) and that the coarse aggregates correspond to the aggregates retained in the 3/8 " sieve or in sieves above.

The aggregates required to prepare the mastic were obtained by sieving, so that the grading curve of the mastic presented in Figure 1 was obtain. The coarse aggregates used to prepare the specimens were also obtained by sieving, corresponding to the aggregates passed in 1/2" sieve and retained in 3/8" sieve (Figure 1).

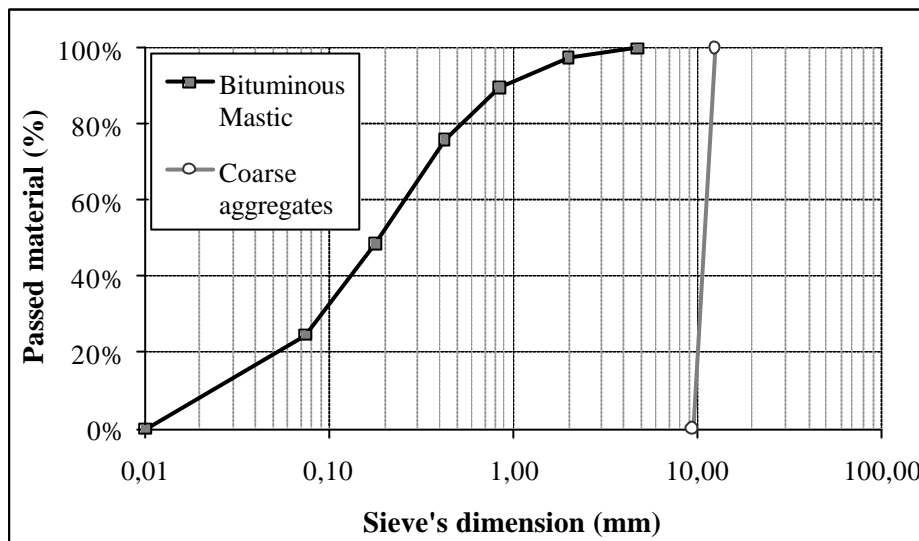


Figure 1: Mastic and coarse aggregate gradings used to prepare the specimens for the tensile and shear mechanical tests

The different binder contents used for preparation of the mastics used in the specimens with different layers of mastic and aggregates (determination of the strength of the bond between mastic and aggregates) were the following: 10.5%, 13%, 14% and 15%.

The composition of the mastics used in the specimens prepared only with mastic (determination of the internal cohesion of the mastic) was also the indicated in Figure 1, being the binder contents of the mastics the following: 13% and 15%.

2.2. Test configuration

The specimens used in the several tests were prepared in laboratory. The compaction of the specimens was made by using one of the methods recommended during the SHRP program (Harrigan et al., 1994) that consists of compacting slabs in laboratory, through the repeated passage of a light cylinder with vibration over the bituminous mixture.

In the specimens tested to tensile, a small incision was made in middle height of the specimen, to make easier the occurrence of the failure in the zone where the bond between mastic and aggregates should be evaluated. The specimens used in this study always had the same dimensions (in the tensile test they had $5 \times 5 \times 5 \text{ cm}^3$, while in the shear test they had $5 \times 10 \times 5 \text{ cm}^3$), although the form as they were prepared has varied. As a matter of fact, two different test configurations were used along the experimental work, which will be described forwards.

To study the strength of the bond between mastic and coarse aggregates, specimens had been prepared with a layer of coarse aggregates in the middle of other two layers of mastic. In these specimens, it is easily identifiable the bonding zone between mastic and aggregates (Figure 2). 16 specimens were tested in the tensile test and 12 specimens in the shear test.



Figure 2: Specimens used to evaluate the strength of the bond between mastic and aggregates

Some specimens were also prepared only with mastic (Figure 3) to evaluate the internal cohesion of mastic. Three specimens were tested in the tensile test and other three specimens in the shear test. The comparison of the results obtained with the specimens presented in Figures 2 and 3 allowed analyzing which is the main type of failure of the bond between mastic and aggregates (interfacial or cohesive failure).



Figure 3: Specimens used in the mechanical tests carried out to evaluate the internal cohesion of the mastic

2.3. Laboratorial procedure

In Figure 4 it can be observed the types of mechanical tests implemented to study the bond between the mastic and the coarse aggregates: i) simple direct tensile test; ii) shear test with constant confinement stress of 100 N.

A rising deformation of 2 mm/min was imposed. In the tensile test the specimens were glued to the base plates for load application, while in the shear test the specimen were just lean against those base plates.

In Figure 5 it can be observed the types of mechanical tests implemented to evaluate the internal cohesion of the mastic: i) simple direct tensile test; ii) shear test with constant height.

A rising deformation of 2 mm/min was imposed. The specimens used in the tensile test were the only ones that had been glued to the base plates for load application.

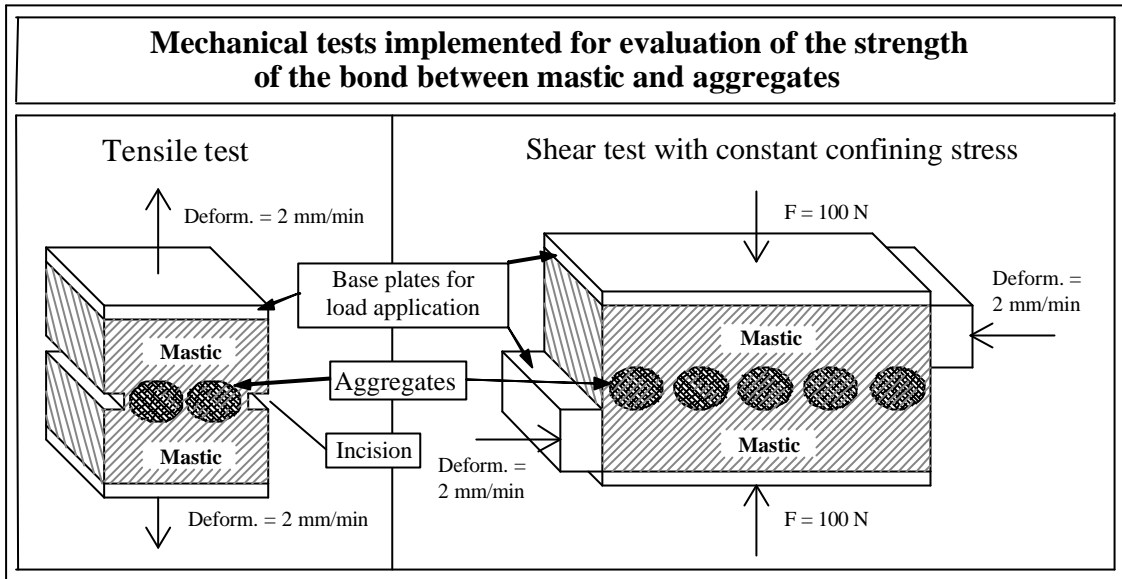


Figure 4: Configuration of the mechanical tests implemented to evaluate the strength of the bond between mastic and aggregates

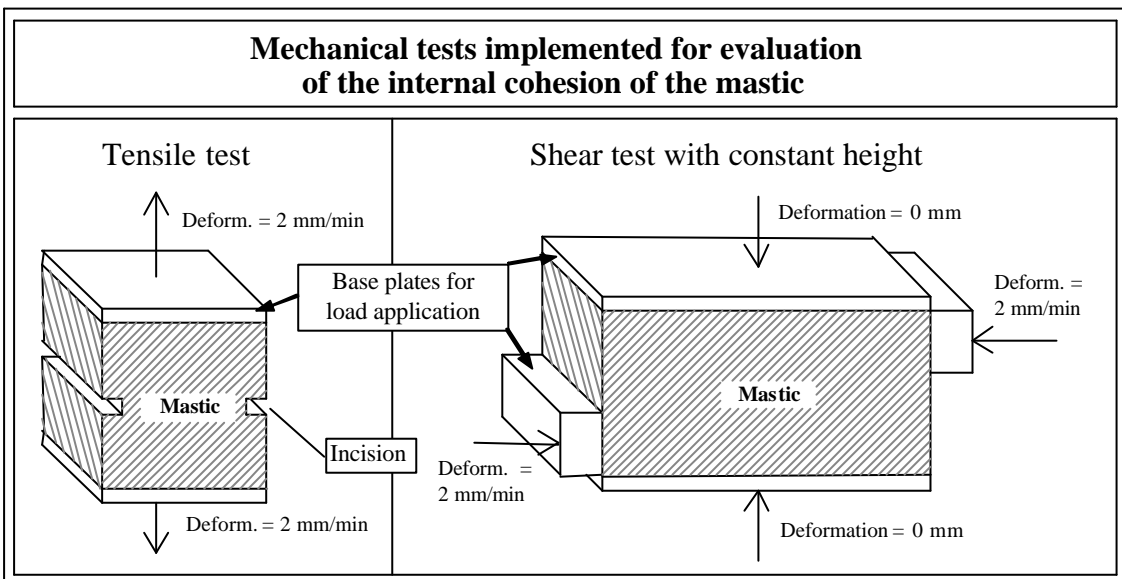


Figure 5: Configuration of the mechanical tests implemented to evaluate the internal cohesion of the mastic

3. TEST RESULTS

3.1. Strength of the bond in the mastic-aggregate interface

Examples of the results typically obtained in the tensile and shear mechanical tests accomplished to evaluate the strength of the mastic-aggregate bond in the interface are presented in Figure 6.

In both tests (tensile and shear) all the specimens reach failure in the zone where the mechanical strength of the bond between mastic and coarse aggregates is intended to be determined. This condition is fundamental to be possible to consider that the tests are capable to evaluate the bond between mastic and aggregates.

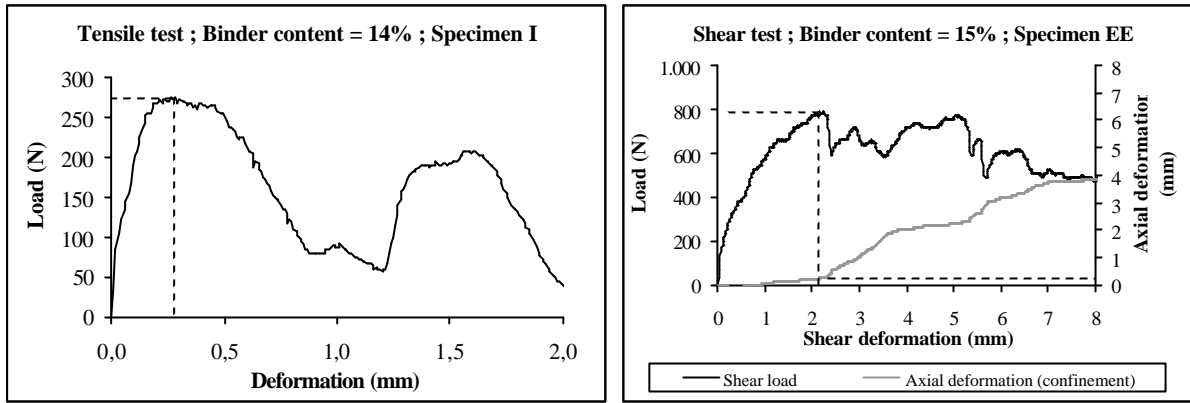


Figure 6: Typical results of the tensile and shear tests carried out to evaluate the strength of the interfacial bond between mastic and coarse aggregates

The variation of the tensile strength of the specimens tested in this phase of the work in function of mastic binder content is presented in Figure 7.

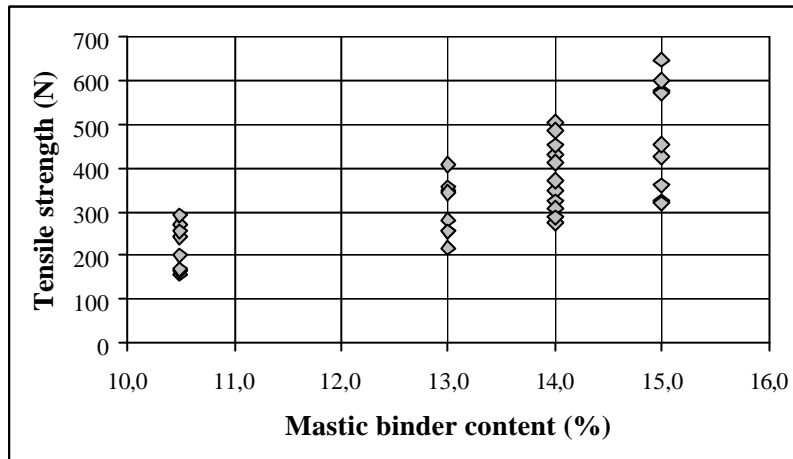


Figure 7: Influence of the mastic binder content in the tensile strength obtained in tests carried out to evaluate the interfacial bond between mastic and coarse aggregates

The variation of the shear strength of the specimens tested in this phase of the work in function of mastic binder content is presented in Figure 8.

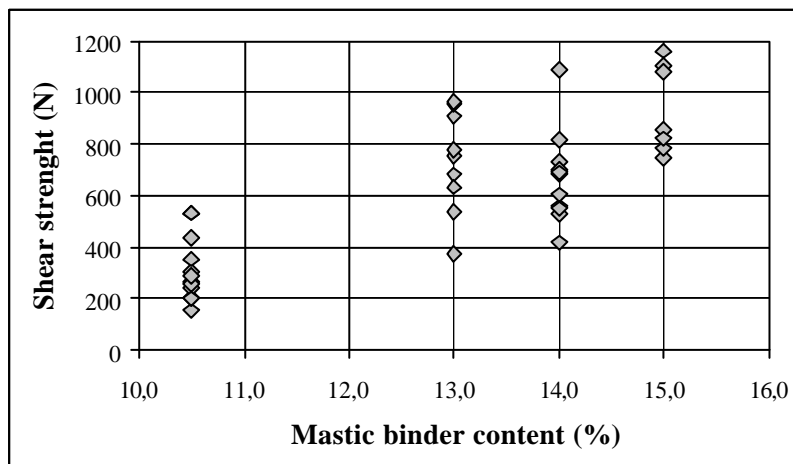


Figure 8: Influence of the mastic binder content in the shear strength obtained in tests carried out to evaluate the interfacial bond between mastic and coarse aggregates

Based on Figures 7 and 8 it was observed that the strength of the bond between mastic and coarse aggregates increases in function of the mastic binder content, either in the tensile tests whether in shear tests.

3.2. Cohesive strength

The results of the mechanical tests performed to evaluate the cohesive strength of the mastic allow evaluating the influence of the mastic binder content in its internal cohesion. The typical results obtained in the tensile and shear tests carried out to evaluate the internal cohesion of the mastic are presented in Figure 9.

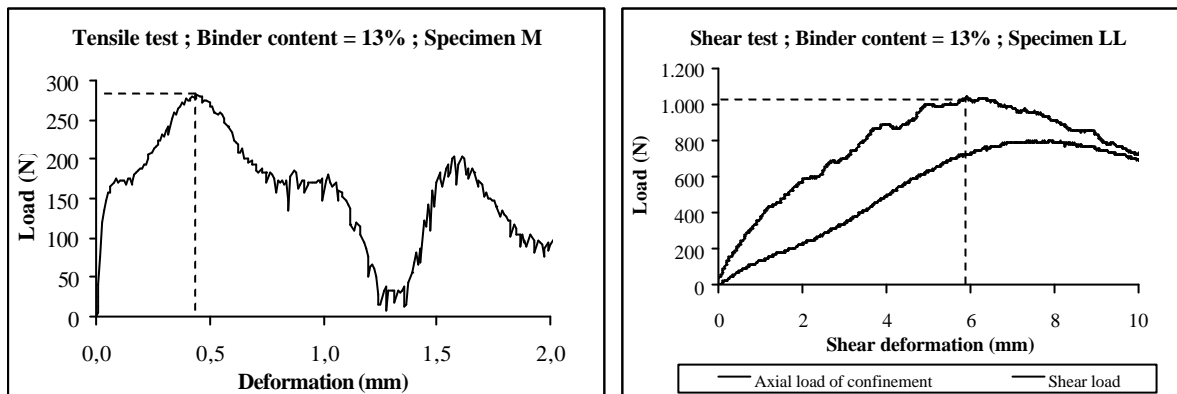


Figure 9: Typical results of the tensile and shear tests carried out to evaluate the internal cohesion of the mastic

The results of the mechanical tests performed to evaluate the internal cohesion of the mastic are presented in Figure 10, respectively, the tensile strength and the shear strength of each specimen in function of the mastic binder content.

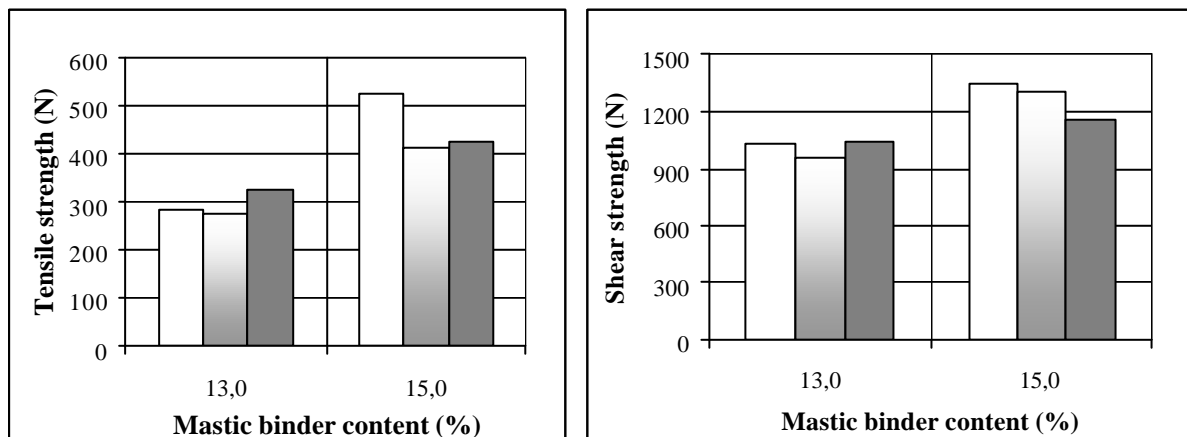


Figure 10: Influence of the mastic binder content in the tensile and shear strengths obtained in the tests performed to evaluate the internal cohesion of the mastic

4. RESULT ANALYSIS

Bases on the Figures 7 and 8, it was observed that the strength of the interfacial bond between mastic and coarse aggregates increases in function of the mastic binder content, either in the tensile tests whether in shear tests.

Thus, for the different mastic binder contents tested the wear mixture that had greater tensile and shear strengths (stronger aggregate-mastic bond) was the mixture with the highest mastic binder content (equal to 15%).

Concerning to the failure of the specimens used in the mechanical tests, this one happened preferentially in the bonding zone between mastic and coarse aggregates, either in the tensile tests (Figure 11) whether in shear tests.



Figure 11: Failure zone usually observed in the specimens used in tensile tests

Thus, it was verified that the mechanical tests implemented are really evaluating the strength of the bond between mastic and coarse aggregates.

Concerning to the mastic's internal cohesion, the mastic that exhibited better behaviour in the tensile and shear tests was the one with the highest binder content (15%). In Figure 10 it was observed that the tensile and shear strengths increased in function of the mastic binder content.

Finally, the results obtained for the strength of the interfacial bond between mastic and aggregates (specimens with different layers of mastic and aggregates) were compared with the results obtained in the mechanical tests performed on specimens only prepared with mastic (internal cohesion of mastic). By this means, it was intended to be analyzed which is the main type of failure that originates the loss of bond between mastic and aggregates:

- i) failure of bond in the interface between mastic and aggregates;
- ii) cohesive failure of the mastic in the bond with the aggregates.

It was observed that the average values estimated to the strength of the interfacial bond between mastic and aggregates and to the internal cohesion of the mastic are nearly the same. As the cohesion of the mastic is not superior to the strength of the interfacial bond between mastic and aggregates, it means that the failure of the specimens with different layers of mastic and aggregates (tested to evaluate the bond between mastic and aggregates) happened due to a loss of internal cohesion of the mastic.

Thus, when the tests implemented in this study were done, the main type of failure of the bond between mastic and aggregates was the cohesive failure of the mastic in the bond with the aggregates. For consequence, to improve the bond between mastic and aggregates it is fundamental to increase the internal cohesion of the mastic.

5. CONCLUSIONS

It was concluded that the strength of the bond between mastic and coarse aggregates is greater in the mixtures with higher mastic binder content.

It was also observed that the main type of failure of the bond between mastic and aggregates (stripping) is the cohesive failure in the mastic.

The mechanical tests used to evaluate the bond between mastic and coarse aggregates seem to simulate correctly the existent phenomenon, because the rupture of the specimens occurs in the bonding zone between mastic and aggregates.

In a future work it should be researched, by experimental means, other factors related with the study of the bond between mastic and aggregates of a bituminous mixture, namely:

- i) the capacity of the bituminous mixture keeps up the same strength of the bond between mastic and aggregates when submitted to adverse climatic conditions (for instance, the presence of water);
- ii) the influence of the bitumen aging in changing the “in service” strength of the bond between mastic and aggregates;
- iii) the advantages of using of harder bitumens and “anti-stripping” agents in the bituminous mixtures;
- iv) the strength of the mastic-aggregate bond influence in the bituminous mixture resistances to cracking and the permanent deformation.

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