# THE INFLUENCE OF FINE AGGREGATE ON THE BITUMINOUS MIXTURE MECHANICAL BEHAVIOUR

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Abstract
The mechanical behaviour of a bituminous mixture is influenced by its composition. One of the compositional parameters that can change the bituminous performance in a pavement is the gradation of the fine aggregates. This paper presents the stiffness, fatigue and permanent deformation results of bituminous mixtures used in wearing and base courses. For each type of mixture, five mixtures were defined, by changing the gradation curve (from more to less fine aggregates). All mixtures were produced and compacted in laboratory. Specimens for tests were obtained by cored and sawed from compacted slabs. For stiffness and fatigue, tests were executed on four point bending beam on controlled strain, whereas for permanent deformation tests were the repetitive simple shear test at constant height.

## 1. Introduction

One of main objectives of this paper is to understand in which way the fines gradation influences the bituminous mixture properties, namely the tensile fatigue and permanent deformation resistances of the whole bituminous mixture.

So, to evaluate the bituminous mixtures behaviour, standard fatigue and permanent deformation tests were executed on bituminous mixtures with different aggregate gradations.

## 2. Experiment design

### 2.1 Materials

In this study two types of bituminous mixtures were used. A dense graded bituminous mixture for base courses and a bituminous mixture for wearing courses, following the


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Portuguese normalization. Based on each aggregate gradation, more four mixtures were defined. Two mixtures where the gradation curve is below and two mixtures where the gradation curve is above the gradation curve defined by the Portuguese normalization. These four gradation curves were defined changing the amount of aggregates in the sieves #20, #40, #80 and #200.

Thus, the gradation curve proposed by the Portuguese normalization for wearing courses was used to produce mix number 1 (more fines) to 5 (less fines), as presented in Figure 1, and the gradation curve proposed by the Portuguese normalization for base courses was used to define mixes 6 (more fines) to 10 (less fines), as presented in Figure 2.

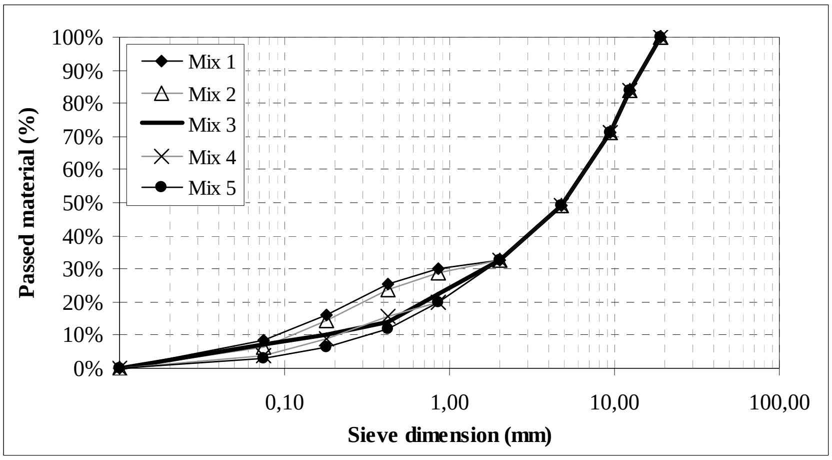


Figure 1. Aggregate gradation curve for wearing course bituminous mixtures

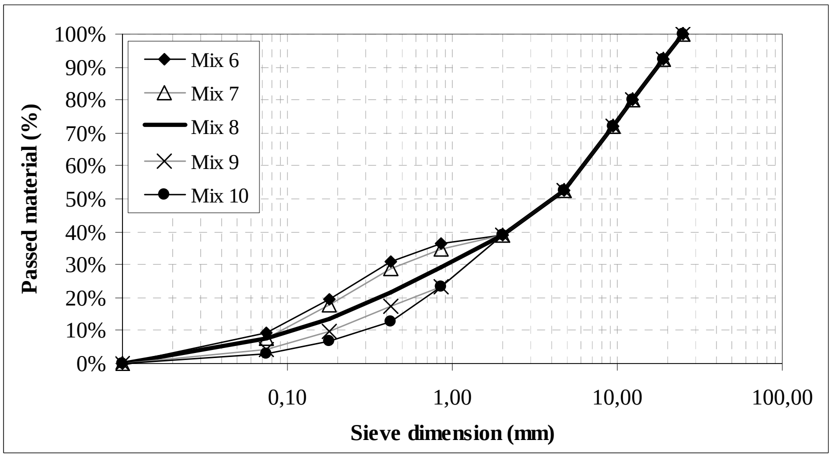


Figure 2. Aggregate gradation curve for base course bituminous mixtures


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For each mixture studied, the optimum binder content was calculated using the formula based on the specific surface of the aggregates developed by Duriez (1950):

$$t_b = \alpha \times k \times \sqrt[5]{\Sigma} \quad (1)$$

where $t_b$ = binder content; $\alpha$ = ratio between the bulk density of reference (2.5) and the real bulk density of the aggregates; k = function of the binder content of the mixture and $\Sigma$ = depends on the grading curve of the aggregates. Table 1 presents the binder content for each mixture, given in percentage of aggregate weight.

Table 1. Binder content for the mixtures used in this study

| Mix | Binder content | Mix | Binder content |
|---|---|---|---|
| 1 | 6.0% | 6 | 6.0% |
| 2 | 5.8% | 7 | 5.8% |
| 3 | 5.8% | 8 | 5.8% |
| 4 | 5.4% | 9 | 5.3% |
| 5 | 5.2% | 10 | 5.1% |

**2.2 Specimen preparation in the laboratory**

To produce the specimens, the aggregates were heated at 178 ºC and for the bitumen (PEN 50/70) the temperature was 150 ºC. After mixing, the mixtures were placed in an oven at 135 ºC during 4 hours to be subjected to the conditioning recommended by SHRP-A003A to simulate the aging during manufacturing (Tayebali, et al. 1994). The compaction was made with a lightweight vibratory steel roller. The air-void content was measured in all specimens and the average for each mixture is presented in Table 2.

Table 2. Average air-void content for the mixtures used in this study

| Mix | Air-void Content | Mix | Air-void Content |
|---|---|---|---|
| 1 | 1.3 % | 6 | 4.9 % |
| 2 | 2.9 % | 7 | 7.4 % |
| 3 | 1.2 % | 8 | 4.0 % |
| 4 | 5.0 % | 9 | 6.6 % |
| 5 | 7.7 % | 10 | 10.8 % |

## 3. Stiffness modulus and phase angle

The bituminous mixtures exhibit linear-viscoelastic behaviour as such that their response is time of loading and test temperature dependent. The material stiffness measures the ability to spread the traffic loads over an area.

The stiffness modulus and the phase angle were measured using a frequency sweep test. All the frequency sweep tests of this study were executed at a strain level of 150 micro mm/mm, and at 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz.


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In Figure 3 the stiffness modulus at 10 Hz is plotted to show the ranking of studied mixes and it can be concluded that the increase of fines increases the stiffness modulus. The horizontal lines represent the average value for each type of mix.

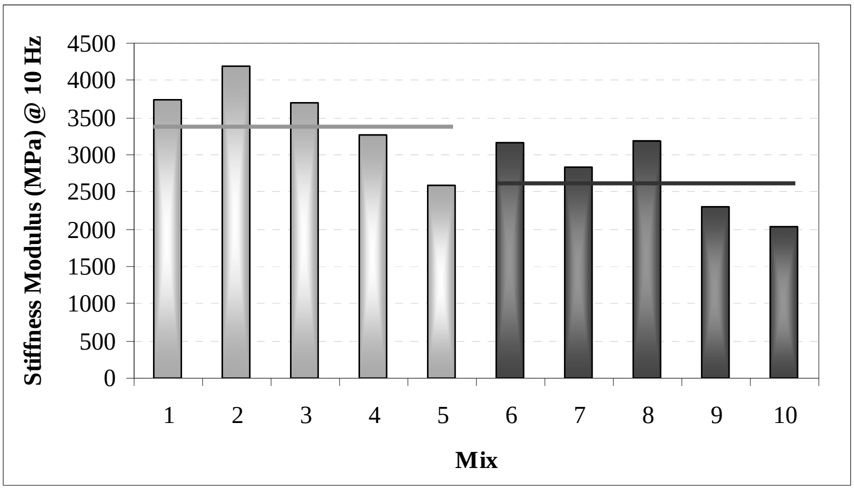


Figure 3. Stiffness modulus at 10Hz (temperature = 25 ºC)

Figure 4 presents the phase angle at 10 Hz is plotted to show the ranking of studied mixes and it can be concluded that the increase of fines decreases the phase angle. The horizontal lines represent the average value for each type of mix.

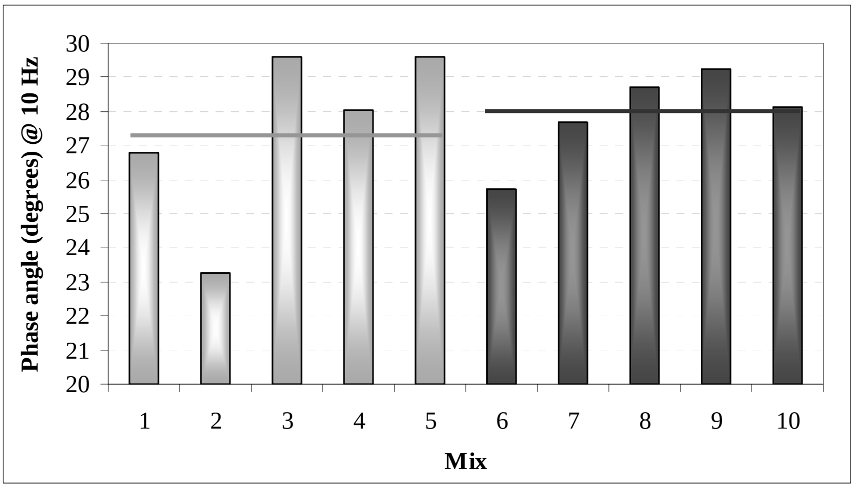


Figure 4. Phase angle at 10Hz (temperature = 25 ºC)


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## 4. Fatigue life

One of the major modes of distress considered in the asphalt concrete pavement design is the fatigue cracking. When an asphalt pavement layer rests on an untreated aggregate base layer, the passage of a wheel load causes the pavement to deflect.

The resistance to fatigue of a bituminous mixture is the ability to withstand repeated bending load without failure. This form of distress manifests itself by the appearance of cracking in the pavement surface. The fatigue of a bituminous mixture has been directly associated with the repeated application of tensile stresses or strains and it is generally accepted that it can be very well evaluated by a four point bending test (Pais, 1999). Fatigue tests are performed imposing strain or stress repetitively until failure occurs. The fatigue life is characterized by the relationship between the strain level and the number of repetitions to reach the failure. The fatigue life of bituminous mixtures is influenced by several factors such as test temperature, frequency of applied loads. Aggregate gradation has an important effect on fatigue life as demonstrated by Sousa et al (1998).

To evaluate the bituminous mixture fatigue resistance, flexural fatigue tests were conducted according to the AASHTO TP8-94 (Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending). They are intended to simulate pavement distress due to traffic loads during its expected design life. Fatigue Life is defined as the number of cycles until a 50% decrease of the initial stiffness of the test beam is achieved. Tests were executed at 25ºC and at 10 Hz frequency rate of loading. Six fatigue tests were performed for each mix, three at a strain level of $800\times10^{-6}$ and other three at $400\times10^{-6}$.

The ranking of the bituminous mixes in the fatigue tests can be found in Figure 5 where the fatigue life at $100\times10^{-6}$ (value obtained by extrapolation) is presented. The analysis of this figure shows that the decrease of fine aggregates increases the fatigue life.

## 5. Permanent deformation

Permanent deformation in bituminous mixtures is primarily a plastic shear flow phenomenon at constant volume, occurring near the pavement surface, caused by the shear stresses occurring below the edge of the truck tires.

Also, intrinsically linked to this procedure is the assumption that most of the permanent deformation occurs on the hottest days with the heaviest trucks. This assumption stems from observations in the laboratory that bituminous mixtures exhibit strong plastic behaviour described by a plasticity function that exhibits kinematics hardening. This hardening seems to be associated with the capability of the mixture to develop better particle-to-particle contact as it develops shear strains, and with the capability of the aggregate skeleton to develop dilatancy forces that in turn are capable of developing stabilizing confining stresses (Sousa, 1994).


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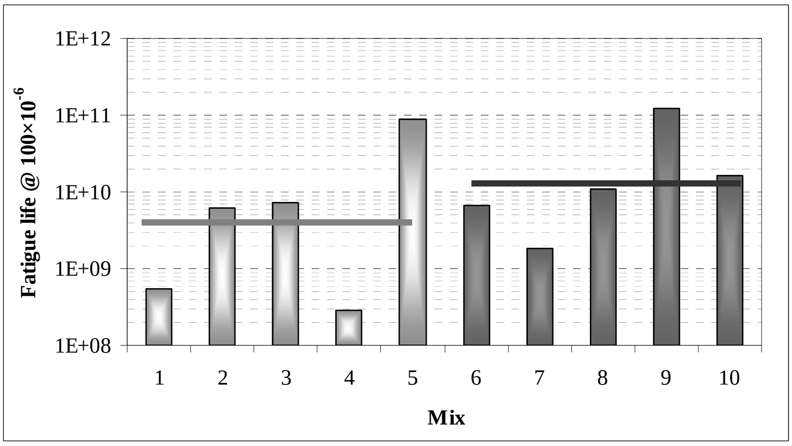


Figure 5. Fatigue life at a strain of $100\times10^{-6}$ (temperature = 25 ºC)

This phenomenon appears to be best captured by the RSST-CH executed at the highest 7 day pavement temperature at 5 cm depth. One of the advantages of this test is that it does not cause any change in volume in the specimen during testing. This is particularly important because a mix's resistance to shear deformation should be measured with a test that does not cause any change in volume (densification or dilation) (Sousa, 1994).

The SHRP A-698 permanent deformation methodology to predict the accumulation of rut depth in asphalt concrete mixes was used and adapted, yielding the selection of adequate loading times, eventually to be used in the Repetitive Simple Shear Test at Constant Height for the prediction of rut depth.

RSST-CH testing was undertaken with 0.1 seconds loading times, plus a rest period of 0.6 seconds. For each bituminous mixture, 3 replicates were tested at 50ºC. The magnitude of the loading pulse was set at 70 kPa. The test temperature was chosen to be representative of the maximum average seven day temperature at 5 cm depth.

A procedure to estimate the permanent deformation of asphalt concrete pavement based on the RSST-CH test was presented in the nomograph of the Figure 6. It is composed of four quadrants and it should be followed clockwise starting in Quadrant 1.

The procedure to estimate the permanent deformation starts by defining the rut depth level to be considered. The permanent shear strain, which is used to obtain the number of cycles in the RSST-CH, is calculated as following:

$$\text{Rut depth (mm)} = 279 \times \text{Permanent Shear Strain} \quad (2)$$

The number of ESALs is calculated using the following model:

$$\log(\text{\# of cycles}) = -4.36 + 1.24 \log(\text{\# of ESALs}) \quad (3)$$


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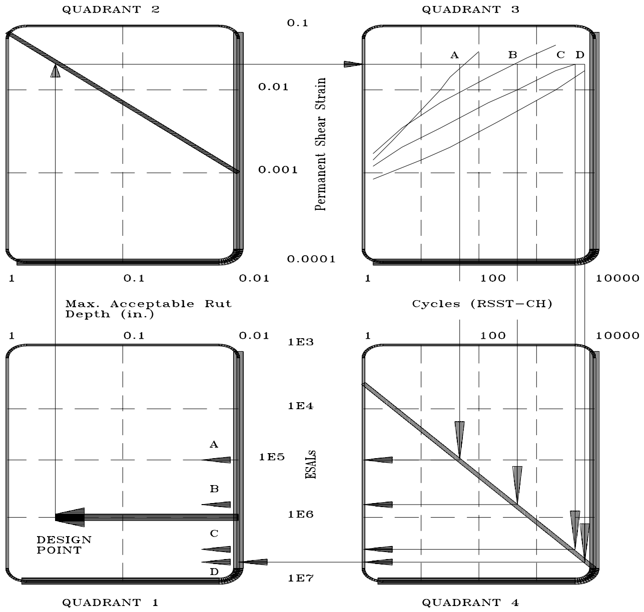


Figure 6. Nomograph procedure to estimate rutting performance

The permanent deformation results for all bituminous mixtures, expressed in number of ESALs to reach 12.5 mm rut depth, are presented in Figure 7. It can be concluded that, in this case, the permanent deformation was influenced by the air-void content. The increase of the air-void-content increases the permanent deformation.

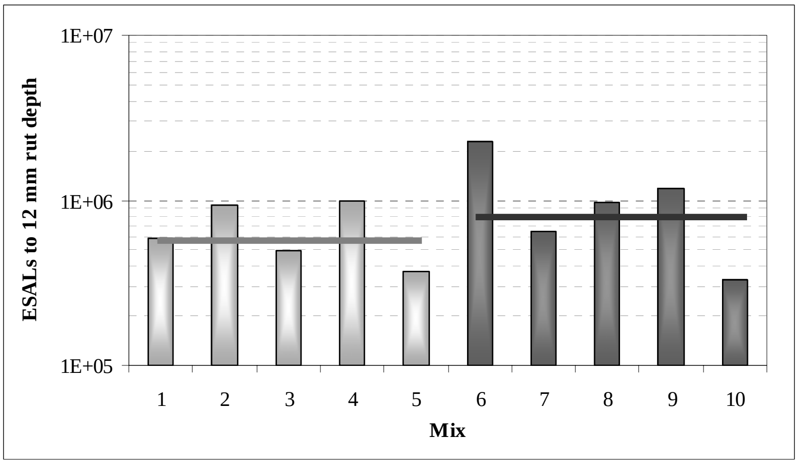



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Figure 7. Permanent deformation test results

## 6. Conclusions

This paper presented an evaluation of the stiffness, fatigue and permanent deformation performance of bituminous mixtures with different gradation of their fine aggregates based on the gradation proposed by the Portuguese normalization for wearing course and base courses.

From this analysis, the following conclusions can be made:

- The increase of fine aggregates increases the stiffness modulus and decreases the phase angle. So, the fines improve the performance and reduce the viscous behaviour of a mixture in the pavement.
- The decrease of fine aggregates increases the fatigue life;
- The results of the tests are dependent on the air-void content of the mixtures: usually the reduction in the air-void content implies a better behaviour of the bituminous mixture;
- The air-void content depends on the workability of the mixture. The binder and the fines contents change the workability properties of a mixture. So, the air-void, the binder and the fines contents are parameters very interdependent

## 7. References


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