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RECYCLING OF POROUS BITUMINOUS MIXTURES

Teresa Dias
AENOR – Auto-Estradas do Norte, SA
Rua Antero de Quental, 381, 3º
4455-586 Perafita – Matosinhos
PORTUGAL
T: + 351.22 999 7490
tdias@aenor.pt

Paulo Pereira
Universidade do Minho – Departamento de Engenharia Civil
Campus de Azurém
4800 – 058 Guimarães
PORTUGAL
T: +351.253 510 200
F: +351.253 510 217
ppereira@civil.uminho.pt

Jorge Pais
Universidade do Minho – Departamento de Engenharia Civil
Campus de Azurém
4800 – 058 Guimarães
PORTUGAL
T: +351.253 510 200
F: +351.253 510 217
jpais@civil.uminho.pt

ABSTRACT

Once flexible pavements reach minimal bearing capacity, their structural rehabilitation is normally undertaken using bituminous mixture overlay. The number of layers and the thickness depend of the existing quality of the pavement and of the required quality determined by the rehabilitation program for a next life period.
The rehabilitation of a pavement with a porous bituminous mixture wearing course is usually undertaken without any treatment to increase its bearing capacity.
The bearing capacity of this type of mixture can be increased by the use of a grout to fill its voids, increasing its resistance. The new material is produced by spreading a grout over the pavement surface, with the help of rubber scrapers, penetrating the voids of the mixture until it reaches the bottom of the layer. The properties of this material are dependent on void connectivity, in order to allow the grout to flow through them. An adequate viscosity of the grout is essential so as to fill the voids completely.
The objective of this paper is to analyse the recycling of porous bituminous mixtures, studying the grout and evaluating new mixture properties in terms of stiffness, fatigue life and permanent deformation.

KEY WORDS

Recycling, rehabilitation, porous bituminous mixture, grout.

INTRODUCTION

The porous bituminous mixture of a wearing course essentially has a functional purpose, not providing it with a significant structural capacity. Its optimal functionality is directly related with the capacity to drain any water falling on the pavement. Thus, to ensure road safety it is essential that the drainability of the porous bituminous mixture be ensured at all times.

Throughout the years, the evolution of a porous bituminous layer, in addition to the surface wearing, resulted in the filling of its voids, which compromised its functionality.

In order to reestablish its porous bituminous capacity, functional rehabilitation can be carried out by suction and washing with appropriate equipment. Alternatively, the existing layer can be replaced with a new one, after milling.

One of the possible alternatives would be to maintain the existing porous bituminous layer after applying a treatment to provide it with structural capacity; thus contributing to the support for a new porous bituminous layer. The layer that initially offered reduced structural resistance would then provide a more significant contribution. This structural improvement is obtained by filling the porous bituminous mixture voids with a fluid material, which should contribute to a higher stiffness modulus to the mixture.

The main purpose of the project undertaken was to analyze the characteristics of the material to be used on the structural rehabilitation of an existing porous bituminous layer, as well as to verify its effective contribution to the pavement's bearing capacity.

Regarding the filling material, the study of alternative formulations was carried out at the laboratory, as well as its physical and mechanical characterization. Test specimens obtained from pavement slabs were carried out so as to define the optimal composition to be applied on a trial section.

THE POROUS BITUMINOUS MIXTURE FILLED WITH GROUT

Semi-flexible pavements (1) are characterized by the existence, on the surface, of a porous bituminous layer filled with hydraulic material – a semi-flexible layer. This layer combines the best qualities of bituminous pavements (flexible) and concrete (rigid), namely the flexibility and the absence of joints, which is a characteristic of flexible pavements, and high load capacity, which is a characteristic of rigid pavements.

The disadvantage of this type of pavement resides in the fact that it requires two construction stages with regard to the superficial layer: one, in which the bituminous mix is compacted upon the pavement and, the other, in which a filling material is set on the mix, filling its voids.

The semi-flexible layer is composed of a porous bituminous mix, with 25 to 35% voids, into which a grout is poured (Figure 1).

The high resistance of porous bituminous layer filled with the grout, reduces the strain level installed in the base layer. The time required for the construction of this layer as well as the time required for subsequent traffic operation constitutes a significant advantage in comparison with conventional concrete pavements. This type of wearing layer is usually applied with a thickness of between 30 and 60mm (2).

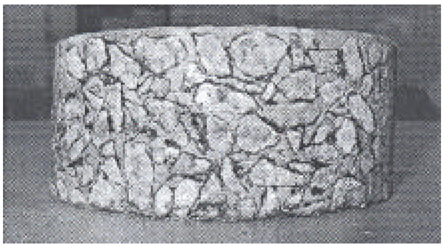

Figure 1 – Core withdrawn from a porous bituminous layer filled with grout

As previously mentioned, the construction of the porous bituminous layer, filled with grout, requires two stages, since it is necessary to allow the bituminous layer to cool down before pouring the grout through the voids. Thus, this process is usually carried out over two consecutive days.

The porous bituminous layer is applied using a normal asphalt paver and is then compacted using a steel roller, without vibration, to avoid the formation of cracks and tracks in the material. As soon as this layer is cold, its voids can be filled with fluid grout (3), which is applied on the surface with the help of rubber scrapers (squeegees).

Depending on the material used for the grout, and on the specifications of the producer, a light steel roller may be used in the vibration mode to make sure that the voids of the porous layer are completely filled with the grout. After filling the voids, the surface should be treated to improve its properties, such as skid resistance, durability and appearance (Figure 2).

Figure 2 – Application of the cement grout on the porous bituminous layer

This type of layer is applied in heavy duty areas, such as industrial pavements, warehouses, distribution centers, workshops, ports, roads, bus terminals, parking areas with heavy traffic, airport pavements, docks, hangar pavements, cargo centers and other areas subjected to slow and heavy loads (1) and (3).

LABORATORY STUDY

The objective of this study is to assess a possible solution for the rehabilitation of porous flexible pavements. The solution should maintain the existing porous bituminous layer, improving its structural capacity after treatment, so as to constitute a support for a new porous bituminous layer. Thus, the layer that initially provides reduced structural resistance will offer a more significant contribution to pavement resistance. Therefore, besides functional rehabilitation, due to the setting of a new porous bituminous layer, the pavement will also be structurally rehabilitated, due to the filling of the old porous bituminous layer.

Laboratory research was performed so as to find the best cement grout that maximizes resistance and minimizes costs.

Grout Formulation

The sequence of tasks concerning the grout formulation comprised the following stages:

1. Grout formulation (cement+fly ash+water+superplasticizer);
2. Measure of grout viscosity, with Marsh flow cone;
3. Grout test specimens and compression tests;
4. Penetrability on the slabs withdrawn “in situ”;
5. Impregnation of slabs withdrawn “in situ” and performing tests to determine the stiffness modulus, as well as fatigue tests.

In order to find the most suitable grout, several formulations were carried out, varying both the ratio water/cement (0,30; 0,35 and 0,40) and the ratio cement/fly ash (0% e 40%). These compositions were poured on the porous bituminous layer 20x20cm slabs withdrawn “in situ”, as shown in Figure 3. The superplasticizer was fixed on 1% of the binder, in compliance with formerly performed studies.

Figure 3 – Slabs filled with cement grout

For the various grout alternatives, viscosity tests were carried out using the Marsh flow cone and compression tests, on 5x5cm test specimens, on the 7^{th}, 14^{th} and 28^{th} days. Based on these tests, and on the penetrability of the grouts on the slabs of the porous bituminous layer, it was possible to select 4 grouts to be studied more thoroughly. The characteristics of these grouts are presented in Table 1.

Table 1 – Composition of the grouts

Ratio Water/Cement	Penetration time	% Fly Ash	Strength at 28 days (kN)	Designation of the study
0,35	70 seg	0%	˜110	F_35_0
		40%	˜100	F_35_04
0,40	45 seg	0%	˜105	F_04_0
		40%	˜95	F_04_04

The choice criteria for these grouts were:

- The penetration time on the slabs, in which, apparently, both grouts are possible;
- The compression resistance at 28 days, with 40% of fly ash, increases considerably, approaching the no-ash grout (0% fly ash).

Mechanical characterization of the rehabilitated porous bituminous mixture

The bituminous mixtures are characterized by their stiffness modulus, Poisson coefficient and fatigue law. In view of their viscous-elasticity, the knowledge of their phase angle, which is characterized by the gap between the material's response and load application, is also important.

Thus, for the characterization of the rehabilitated porous bituminous mix, test specimens were tested, in order to determine their stiffness modulus, phase angle, fatigue life and permanent deformation.

The stiffness modulus and phase angle were determined with four point bending tests, in prismatic beams at $100x10^{-6}$ strain level. These tests were performed under a frequency descending order (10, 5, 2, 1, 0.5, 0.2 e 0.1 Hz) at 20 ºC. The stiffness modulus and phase angle were determined by the average of 6 tests for each porous bituminous layer filled with the respective grout.

Figures 4 and 5 present the stiffness modulus and the phase angle as a function of applied test frequency, for the porous bituminous mixes filled with the four grouts and for the porous bituminous mix with no filling. It can be observed that, with regard to the four grouts, there is no significant variation in the stiffness modulus and the phase angle. The stiffness modulus rises from 3000 MPa (porous bituminous mix with no filling) to 10000 MPa (porous bituminous mix with grout filling). On the other hand, the phase angle at 10 Hz, decreases from 15º (porous bituminous mix with no filling) to 6º (porous bituminous mix with grout filling).

The bituminous mixes fatigue resistance is usually expressed by a relationship between the strain level and the number loads to produce the material failure. This relationship is usually established through laboratory tests.

The laboratorial test used in the study to characterize fatigue behavior was the four points bending beam test on prismatic specimens. This test was performed at several strain levels until the test specimen fails. In this case, the beams are subjected to pure flexion between two load points, as shown in Figure 6.

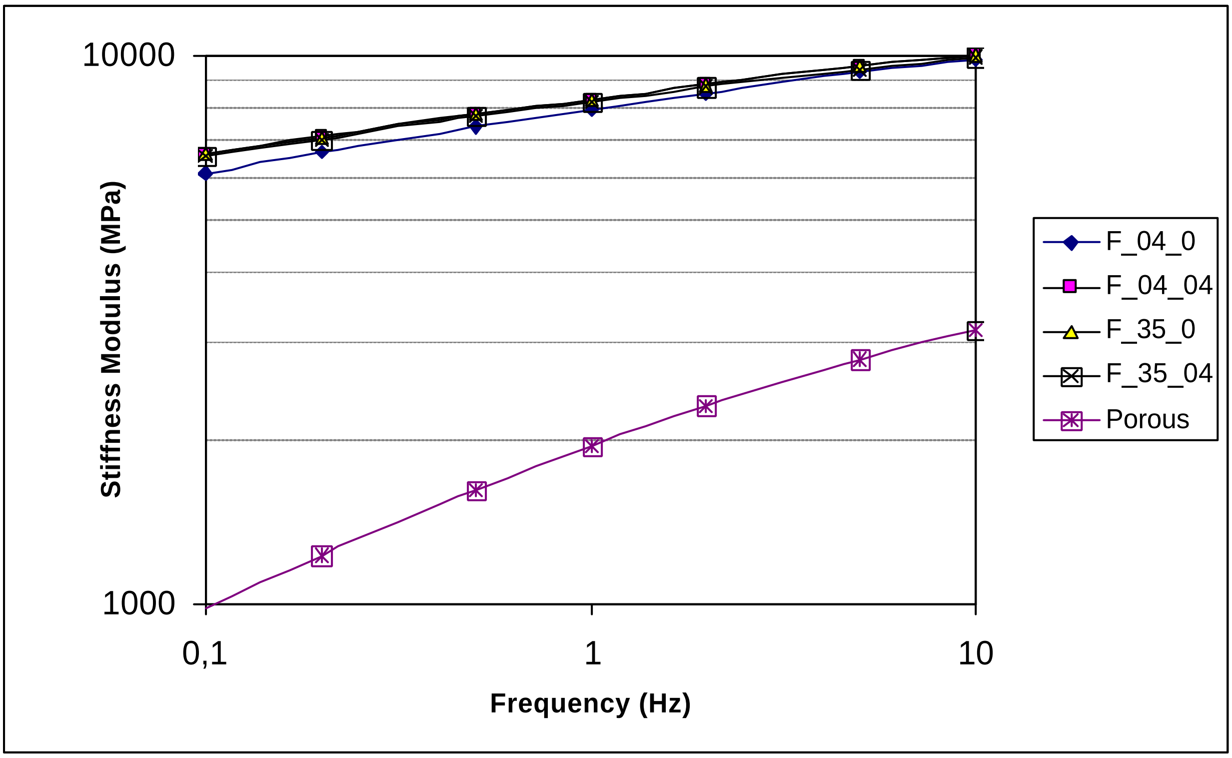

Figure 4 – Stiffness modulus of the bituminous mixes

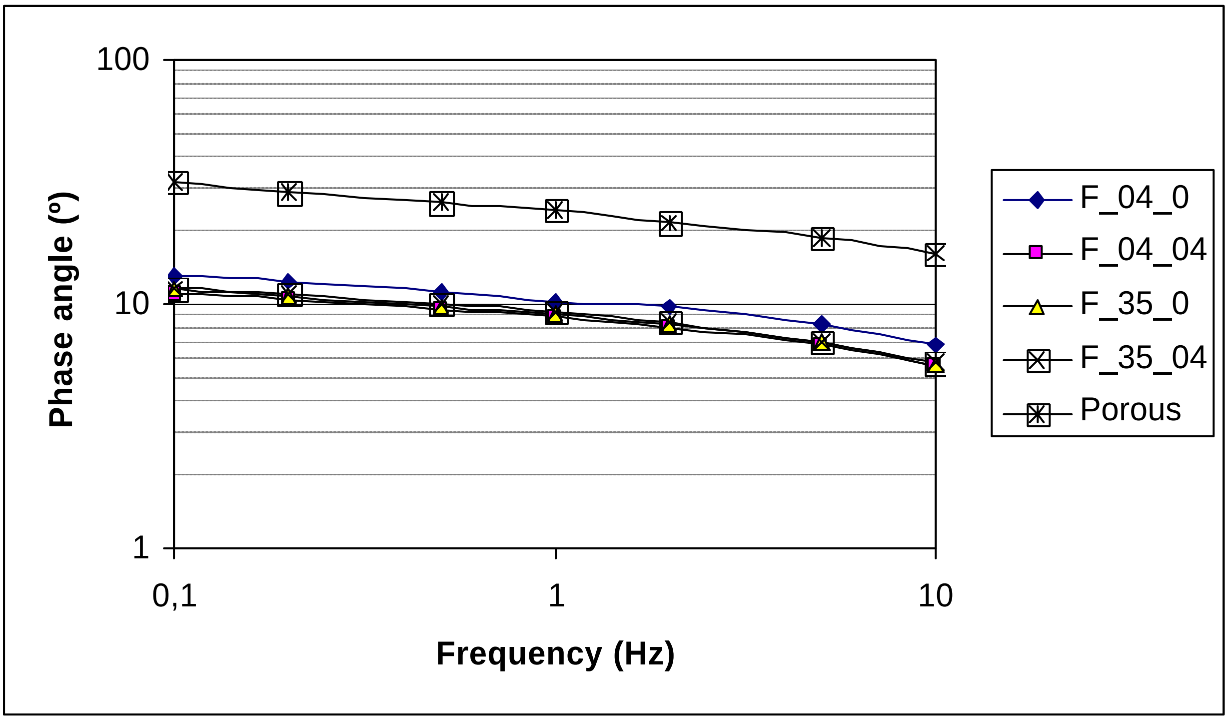

Figure 5 – Phase angle of the bituminous mixes

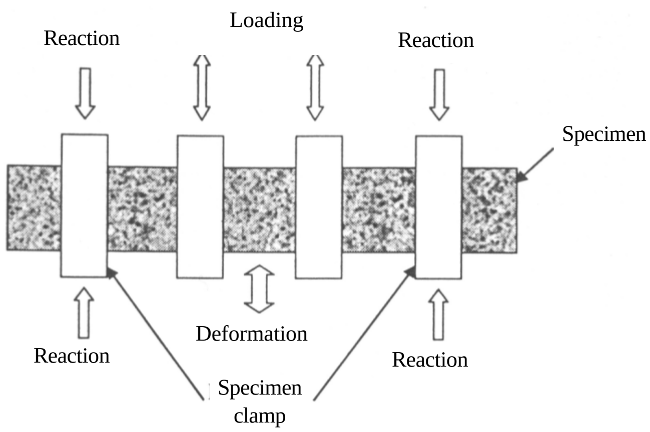

Figure 6 – Loading plan and structural functioning of the flexion test at four points

Figure 7 shows the results of the fatigue tests for the porous bituminous mixes filled with the 4 grouts and for the porous bituminous mix with no filling. Once again, it can be observed that there is no significant variation with regard to the fatigue behavior, which is slightly inferior to the one observed in the porous bituminous mix with no filling.

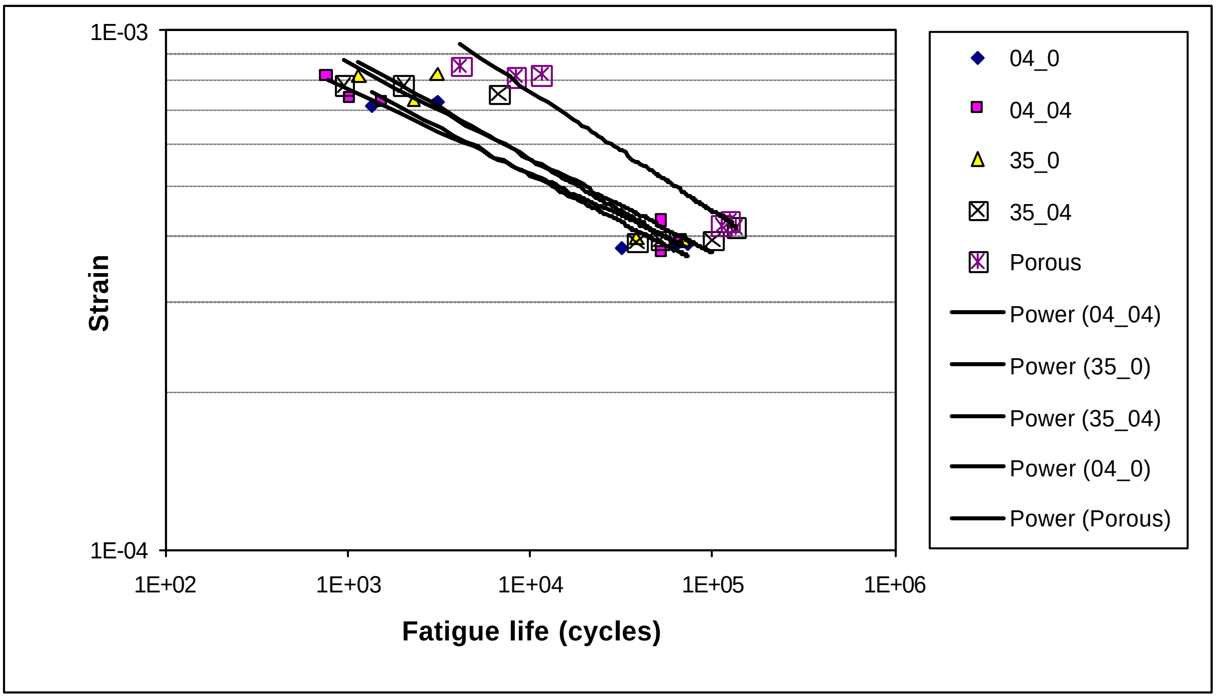

Figure 7 – Fatigue life for the porous bituminous mix filled with the four grouts and without filling

Permanent deformation is mainly due to two factors: (i) densification of the mix due to the heavy vehicles repeated application of load; (ii) action of the shear tensions occurring close to the pavement surface and under the tire flank (4).

The shear test at constant height enables the simulation of the "in situ" conditions, after the densification of the mix. Thus, this test should be carried out with test specimens possessing a void volume similar to the critical value for the mix to become unstable.

After achieving the densification of the mix, the best way to study the resistance to permanent deformation due to shear tensions, is to perform the test with no volume variations (densification or expansion). Thus, the Repetitive Simple Shear Test at Constant Height (RSST-CH) is used. In this test, the test specimens are glued to the machine dishes, as shown in Figure 8, in order to avoid lateral movements and consequent volume variations. This gluing is made with a specific press, which allows the lining of the two dishes and ensures that they are set in parallel.

Table 2 presents the shear test results concerning the porous bituminous mixtures filled with the 4 grouts. It can be observed that the number of load axles required for a 25mm permanent deformation shows very high values when compared with the fatigue life. This enables to conclude that the permanent deformation is not expected in this type of material.

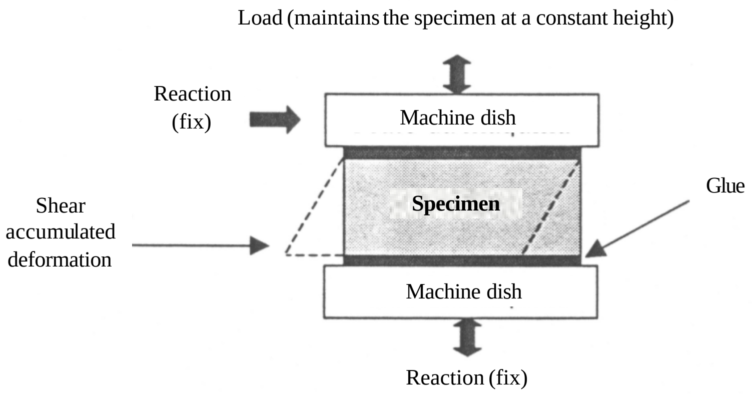

Figure 8 – Schematic representation of the repetitive simple shear test at constant height

Table 2 – Results of the repetitive simple shear test at constant height

Mix	ESALs (80 kN)
35-04	4.86E+12
04-0	9.46E+14
04-04	8.93E+10
35-0	5.63E+13

An economic study has also been carried out, by comparing rehabilitation solutions for the porous bituminous layer. A traditional solution, consisting of the old porous bituminous layer milling, application of tack coat and 4 cm porous bituminous layer, was compared with the solution under study, which consists of filling the old porous bituminous layer with cement grout and the placement of also 4 cm of a new porous bituminous layer.

Market research made it possible to obtain the cost of the traditional solution, which is about 6,5 €/m^2, whereas for the other solution, the value would be approximately 2 €/m^2. Therefore, it can be concluded that the solution under study is, at least, three times more economical, but has also environmental advantages, since the deposit of the material produced by the milling process is not required.

CONCLUSIONS

In this paper, a structural rehabilitation research of a porous bituminous mixture by filling its voids with cement grout, as well as the behavior of the rehabilitated bituminous mixture under 4 grout possibilities, was presented

The results obtained, enabled one to observe identical behavior for the mixtures with the 4 grouts. Yet this was different from the one observed for the porous bituminous mix, with no voids filling.

The stiffness modulus of the rehabilitated mixtures is about 10000 MPa (10 Hz); whereas for the no filling porous bituminous mixture, it was approximately 3000 MPa. The phase angle, at 10 Hz, decreases from 15º (no filling porous bituminous mix) to 6º (porous bituminous mixture with grout filling).

It was also observed that the grout filled mixtures show less fatigue life than the no filling mixtures, due the increase of the stiffness modulus. Thus, it can be concluded that the more economical grout, i.e., with a high water/cement ratio (0,40) and a higher percentage of fly ash (40%), leads to good results and can be used successfully in the structural rehabilitation of porous bituminous mixtures.

The economical study performed enabled one to conclude that the structural rehabilitation solution is, at least, three times more economical. Furthermore, it is environmentally more advantageous, since the deposit of the milled material is not required.

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