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Pavement Recycling: an environmentally sustainable rehabilitation alternative

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Summary

The preservation of environment by reducing the use of material and natural resources together with important economic savings have led pavement recycling to be a prime solution for pavement maintenance/rehabilitation. It is based on sustainable development, by reusing materials reclaimed from the pavements and reducing the disposal of asphalt materials.

The present paper focuses on the analysis of a heavily trafficked urban road rehabilitation project. The original pavement design did not take into account the current traffic levels which are considerably above the initial values. The pavement was reaching failure in several areas and needed urgent measures to avoid complete failure. The pavement condition was a result of lack of structural strength and a deficient drainage.

A semi-rigid pavement structure was proposed in order to improve the bearing capacity of the pavement and minimize the maintenance operations in the future. The operations involved cold "in situ" recycling of part of the existing bituminous layers and the top part of the granular layers with the addition of cement, and the overlay with new bituminous mixtures incorporating a significant percentage of materials reclaimed from the surface course of the same pavement. This solution allowed the maintenance of the pavement level (without the need for footpath reconstruction) and minimized the use of new materials, contributing towards a sustainable development.

KEYWORDS: pavement rehabilitation; cold "in situ" recycling; hot in plant recycling; cement.

1. INTRODUCTION

Nowadays, local and international authorities and organisations are seriously concerned about the disposal of waste materials and its impact in environment. Therefore, its elimination (and any by-products) passes through the optimization of their use in the industrial processes. Existing deteriorated material can be reused; its characteristics can be rehabilitated, recycled and improved. The old material can be successfully reused for what it was initially intended, or as part of a new material [1]. If the recycling process is carried out in plant, only temporary deposits to store the old material will be needed before it is mixed with the new material. If the process is undertaken “in situ” no storage will be needed.

From a study about recycled material applied on surface courses [2], it was proved that the most conditioning factor in the production of recycled mixtures with at least 50% reclaimed material is the maximum temperature at which new aggregates are heated in plant. Besides, researchers did not verify any undesirable effect on the properties of the mixtures with a high percentage of recycled material.

Potter and Mercer [3] carried out a study including several trials on public roads and on full-scale accelerated load testing facilities. They evaluated the performance of recycled materials used in the construction of sections of these trials. One of the main conclusions of the study was that the performance of the recycled materials was as good as that of equivalent conventional materials.

Another research carried out by Servas et al. [4] included the assessment of the mechanical properties of hot bituminous mixtures after the incorporation of reclaimed material in different percentages (0, 30, 50 and 70%). In that study, no clear correlation was found between the percentages of recycled material and the properties of the resulting mixture. Therefore, given an adequate mix design, the amount of recycled material to be included depends upon other factors related to the material itself, the type of plant used and even economic and ecological policies.

The rate of reclaimed material to be used can be limited by several factors, which include [5]:

- Grading;
- Aggregate properties;
- Binder properties;
- Heating, drying and plant capacity;
- Moisture of the reclaimed material and new aggregates;
- Temperature at which new aggregates need to be heated;
- Ambient temperature of the recycling material and new aggregates;
- Other factors.

A research study carried out by Oliveira et al. [6], to assess the benefits of including recycled materials in pavement design, has shown that the costs of applying a recycled mixture (with up to 50% reclaimed material) as a base or binder course were reduced by more than half, when compared with the costs of applying a new bituminous mixture, for the same expected life. The authors emphasized that a high amount of reclaimed material was used to produce the recycled mixture. This is practicable only if the right batch plant is available. Nevertheless, the study showed that it is worth to invest in the right technology.

This paper presents a case study, which comprises a heavily trafficked urban road (approximately 3 km long) linking the city of Braga with the Portuguese highway network. The traffic assessed during this study showed an Average Annual Daily Traffic (AADT) value of about 50000 vehicles, 2000 of which were classified as heavy vehicles. The road cross-section comprises a dual carriageway, each with three traffic lanes, along 1 km, and two traffic lanes along the other 2 km.

Although the pavement has been in service for less than 15 years, several maintenance operations have already been carried out, including overlays and surface course replacements in some areas. Nonetheless, the pavement is reaching failure in a major part of the length. Visual observation of the pavement condition showed a high level of degradation for several distress types, namely rutting and alligator cracking.

The best solution to repair cracking is by eliminating it. A plausible and highly recommendable solution may consist of milling the cracked layers. The milled material could be reused in plant or recycled “in situ”. Control and elimination of cracking is one of the advantages of pavement recycling if compared with structural overlaying.

2. TYPES OF RECYCLING TECHNIQUES

Producing bituminous mixtures by using reclaimed materials may be carried out using hot or cold production methods. Both alternatives may be undertaken in plant or “in situ”.

In hot recycling processes, in general, the recycling ratio may vary between 10% and 40% depending on the type of procedure and on the type of plant used. These values are generally lower than those observed in cold recycling, which reaches nearly 100% in most cases.

The differences among the various in plant recycling processes reside in the type of plant used, fixed or portable, continuous or batch production, and in the production processes which may be diverse. On the other hand, “in situ” recycling techniques differ from each other essentially on the type of binder used. For instance, the same equipment can be used for cold “in situ” recycling using bituminous emulsion, foamed bitumen or cement as binder.

In general terms, hot in plant recycling involves the following stages:

- storage and preparation of the reclaimed asphalt pavement material (RAP), whose size needs to be reduced through fragmentation, and make it more homogeneous;
- study the mix design of the final mixture (including the reclaimed material);
- production of new bituminous mixtures using old and new materials ;
- application of the resulting bituminous mixture by using traditional methods and equipments.

Cold recycling is a rehabilitation technique generally used to solve structural problems in flexible pavements. Thus, it may be used for rehabilitating either one or more bituminous layers in poor condition or even including part of the granular layers underneath. This type of operation is usually finished by overlaying the recycled layer by one or more traditional bituminous mixtures.

Lately, “in situ” cold recycling with cement has been widely used in Europe, especially in Germany, France and Spain, where it has been applied successfully. This development owes its success to three main factors:

- a better knowledge of the mechanical characteristics of the material modified with cement;
- the development of a more powerful equipment that provides more efficiency and working depth;
- an ecological aware attitude which promoted this technique in view of the benefits for the environment.

The cement used in pavement recycling develops the bearing capacity of the layer more rapidly and allows pavement recycling of deeper layers in contrast with recycling with bituminous emulsion. Thus, it is an adequate way for situations in which a considerable increase in the pavement bearing capacity is intended by using the less number of new layers. The cohesion and resistance of cement-recycled layers increase throughout time, what means a higher stability and bearing capacity under variable moisture conditions, allowing the use of materials with lower quality. On the other hand, recycling with cement does not require a so long curing time as emulsion recycling mixtures do. Therefore the surface course may be applied more rapidly. The main inconvenient of recycling with cement is the natural appearance of surface cracking, due to shrinkage of the recycled layer (transversal cracks spaced from 5 to 30 m).

The cement may be mixed through different processes: i) spread as powder over the pavement before the action of the recycling equipment, which will mix it with the milled material and will add the necessary hydrating moisture; (ii) spread as powder by the recycling equipment, just before the milling/mixing chamber; (iii) placed directly in the milling/mixing chamber as a cement slurry through the spraying nozzles (Figure 1).

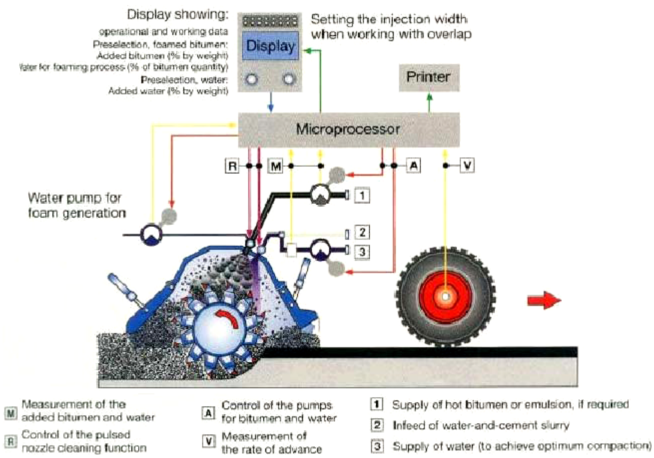

Figure 1. System for the injection of the binder and water in the milling/mixing chamber of the recycling equipment [7]

Compaction should immediately follow the mixing process. It is carried out by several passes of a roller compactor with vibration over the new layer and/or a pneumatic cylinder. After the first passes of the roller compactor, the surface level shall be corrected by means of a grader over the compacted layer and then further passes of the compacting equipment shall be made, [8]. The entire process needs to be carried out immediately after recycling because of the limited manoeuvring time, before the cement starts to set, which should not exceed 2 to3 hours under good conditions. Under high ambient temperatures, a water tank should be available “in situ” to moisten the surface of the recycled material in case of excessive evaporation. In order to prevent the evaporation, a layer of tack coat should be sprayed over the surface. This allows the hydration of the cement and an adequate curing of the recycled material.

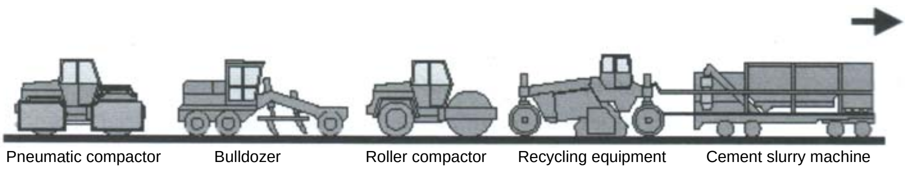

Figure 2. Equipment used in the recycling operation [8]

Amongst other reasons, the success of recycling with cement depends on the mechanical characteristics of the reclaimed materials and on a correct mix design study of the layer that is to be recycled.

3. MIX DESIGN STUDY OF RECYCLED MATERIALS

In order to obtain good results with recycling processes, it is essential to carry out a prior study to assess the thickness and the characteristics of the existing materials, in order to determine the type and quantities of new materials that should be added to the final mixture. When recycled “in situ”, the pavement may present a variable behaviour depending on the constitution of the original pavement (thicknesses of each layer and variability of the material within each layer), emphasizing the need for an adequate mix design study. Furthermore, that study will lead to establishing homogeneous sections which will conduct to eventual modifications of the mixture for certain sections of the pavement. The mix design will necessarily be different if recycling involves only bituminous layers or if it also involves part of the granular layers. The mix design study should be carried out by using materials preferably milled by the equipment that will be used in the recycling works. This will avoid obtaining a different aggregate grading, what would compromise the design study.

Independently from the mix design method used for hot recycled mixtures (Hveem, Marshall or Superpave), special attention needs to be paid to the heterogeneity of the material. Some segregation or contamination may appear when materials are stockpiled. Therefore, it is recommendable not to collect all the material from the same pile so that the sample of reclaimed material can be representative.

In order to predict the behaviour of the final recycled mixture, it is essential to study the characteristics of the reclaimed material. These characteristics can be obtained by extracting and recovering the existing bitumen, separating it from the aggregates and testing both. Thus, it is possible to know the quantity and characteristics of each constituent and decide which materials should be added to make the final mixture.

One of the issues that needs further study when investigating recycled mixtures is related to the possible mix between the old binder of the reclaimed material and the new binder which is to be added. McDaniel & Anderson (1997) (cited in [9]) carried out some tests in material reclaimed from three different sources. They used two types of new bitumen and two different recycling ratios (10 and 40%), so that they could study the mix between the old and the new bitumen. They concluded that the reclaimed material is not a simple “aggregate”. According to the same researchers, it is not reasonable to consider that the mixture between old and new bitumen is complete but partially achieved.

Another factor to consider in the mix design study is moisture in the recycling material. A high percentage of moisture may oblige to devote a higher quantity of time and energy while heating. It also may originate an incorrect value regarding the amount of material weighted (it will include water).

In hot recycled mixtures, the bitumen content is one of the most important parameter that needs to be controlled. Pereira et al. [10] studied some of the fundamental properties (stiffness, fatigue and permanent deformation) of bituminous mixtures produced with 50% reclaimed material at a range of bitumen contents. A conventional mixture of identical gradation and material composition, made of 100% virgin aggregates, was also studied to be compared with the behaviour of recycled mixtures. In that study, the authors concluded that an increase in the binder content does not necessarily means an improvement on the fatigue life of the recycled mixtures, since there is an optimum value above which the properties of the mixture do not improve any longer. It was also concluded that the recycled mixtures present a better performance to permanent deformation and a worse performance to fatigue than the conventional mixture (produced with 100% new materials).

4. CASE STUDY: THE REHABILITATION OF A HEAVILY TRAFFICKED URBAN ROAD

4.1. Project

The rehabilitation project of this case study resulted from a previous study carried out by Oliveira et al. [11] on a heavily trafficked urban road. The original pavement design did not take into account the current traffic levels which are well above the initial values. The pavement is reaching failure in several areas and needs urgent measures to avoid complete failure. The pavement condition is also a result of lack of structural strength and a deficient drainage. Different pavement rehabilitation alternatives were assessed in order to choose the best solution, which should improve the bearing capacity of the pavement, through the rehabilitation of the existing layers and the improvement of the drainage systems, in order to minimize the maintenance operations in the future. The rehabilitation alternatives were also analysed in terms of the impact of the maintenance operations in the environment.

The rehabilitation project comprised the recycling of part of the existing materials, in order to improve the bearing capacity of the pavement without significantly increasing the need for new materials and the disposal of construction waste. In order to reduce the influence of the structure variability throughout the road length, this project included the milling of the surface course material (30% of which should be included in the production of the bituminous mixture for the new binder course) and the recycling of the remaining bituminous material with part of the granular layers (in a thickness of about 200 mm) with the addition of cement. This should be the main structural layer and the pavement will become semi-rigid. The thickness of the new binder and surface courses were designed in accordance with the expected future traffic. The project also included the construction of a subsurface drainage system. This should increase the stiffness of the subgrade and granular layers and reduce the thickness of the new bituminous bound layers. A Stress Absorbing Membrane Interlayer (SAMI) was also considered in the project, to be applied between the cement recycled layer and the new bituminous layers, in order to reduce the crack propagation phenomenon, which is usually observed in pavements with cementitious base courses due to shrinkage of the base.

According to the results presented in this paper, the main conclusions to be drawn are as follows:

- Significant savings can be obtained by choosing rehabilitation strategies that include recycled materials in the new layers (overall cost savings of up to 24% in the present project);
- Significant environmental cost savings can be obtained when using recycled materials, (reductions of more than 55% in the consumption of new resources and of more than 45% in the disposal of construction by-products were calculated for the present project);
- CO2 emissions can be greatly reduced by using rehabilitation strategies comprising “in situ” recycled materials.

4.2. Mix Design Studies

4.2.1. Cold “in situ” recycling with cement

The mix design of this type of mixtures consists essentially on the assessment of the optimum water content for several cement ratios. In order to characterise the final mixture and to assess if it would meet the specifications, in terms of compressive strength and indirect tensile strength, several samples of material were collected after the top bituminous layers were milled off and several specimens were produced on the laboratory. According to the Portuguese specifications for hydraulically bound mixtures applied on base and or sub-base layers, the minimum requirements for this type of mixtures are those presented in Table 1.

Table 1. Minimum requirements for hydraulically bound materials

Curing Time	**Indirect Tensile Strength (MPa)**
7 days	0.2
28 days	1.0

4.2.2. Hot in plant recycling

At the present stage of the mix design study, the batch mixing plant that will be used for the production of the hot recycled mixture is being adapted for allowing the incorporation of reclaimed material into new bituminous mixtures. Meanwhile, the final composition of the mixture is being studied at the laboratory, in order to meet the specifications and to determine the optimum binder content. As stated above, the first step in the mix design study of hot recycled mixtures is to assess the characteristics of the reclaimed material.

In order to characterise the components of the recycled mixture it is necessary to separate the aggregates from the bitumen of the reclaimed material. This can be achieved by using a solvent that will reduce the bitumen viscosity until it becomes liquid, allowing its separation from solid elements (aggregates and filer). This process is known as bitumen recovery and it is carried out in two phases: (i) bitumen-aggregate separation by means of a solvent, in a conventional centrifuge for coarse aggregates (Figure 3-a) and in a high rotation centrifuge for the finer elements that can not be separated in the first equipment (Figure 3-b); (ii) bitumen-solvent separation through a rotary evaporator (Figure 4).

a) b)

Figure 3. Centrifuges (University of Minho) used to separate the aggregates from the bitumen-solvent solution: a) for coarse aggregates; b) for fine aggregates and filler

Bitumen recovery is carried out following the European Standard EN 12697-3 [12]. This procedure can also be used to verify if the properties of the bitumen present on the final mixture meet the requirements set for the mix design. If the bitumen presents a very low penetration value, becoming too hard, it may be necessary to change the penetration grade of the new binder added to the mixture in order to make the final blended bitumen more flexible and, therefore, more resistant to fatigue.

Figure 4. Rotary Evaporator (University of Minho) used to recover the bitumen

Although this process is still being carried out and no results are available regarding the properties of the binder, it was already possible to study the grading of the aggregate that was separated from the bitumen. As can be observed in Figure 5, the grading of the reclaimed material did not meet the specification limits in some parts of the curve. This was corrected by manipulating the grading of the new aggregate added to the recycled mixture as shown in Figure 5.

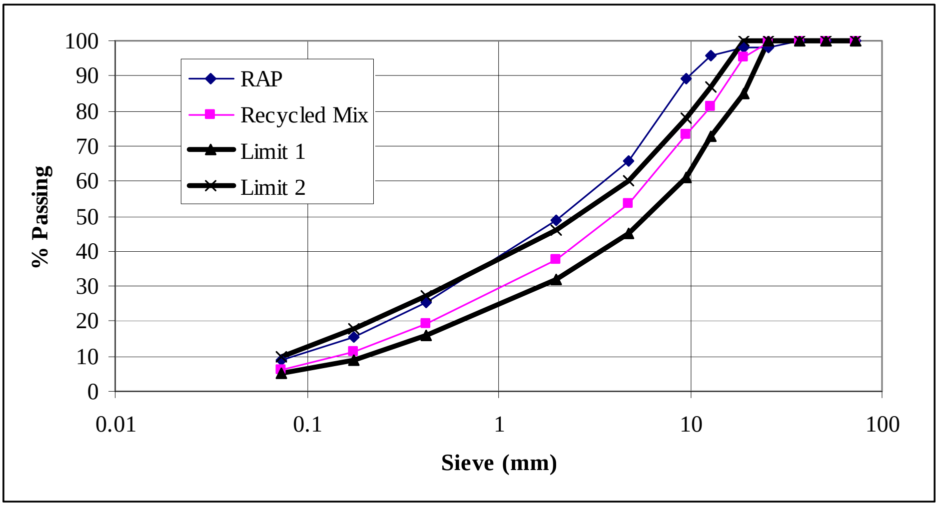

Figure 5. Grading of reclaimed material, recycled mixture and specification limits

The tests carried out during the mix design study for both types of mixture produced some results that are presented in the following section.

4.2.3. Laboratory Results

The first recycling operation that would take place in the rehabilitation of the pavement is the cold "in situ" recycling. Therefore, in the mix design study of that mixture the optimum cement ratio was determined by the results of indirect tensile strength tests carried out over laboratory prepared cylindrical specimens with different percentages of cement. The study started with 3% cement (by mass of mixture) and stopped after the results obtained fulfilled the minimum requirements of the specification. The results of this study are presented in Table 2.

Table 2. Results of the mix design study for the mixture recycled with cement

Cement ratio (%)	**Indirect Tensile Strength at 7 days (MPa) (average of 3 specimens)**
3	0.13
4	0.26

According to the results obtained it was decided to carry out the recycling operation with 4 % cement.

For the hot recycled mixture, the specifications were more restrict since the properties of the final mixture are more susceptible to variations in its composition. Therefore, after the collection of a representative sample from the stockpile and prior to the evaluation of the final mixture properties, the binder content of reclaimed material was determined by the ignition method (ASTM Standard D6307 – 98) [13] and was estimated to be of 4.99% (by mass of mixture). Therefore, the amount of new binder, to be added to the recycled mixture to obtain the optimum binder content, must be calculated taking into account that about 30% of the material already has 5% bitumen.

In the present project, the mix design procedure should not only consist on the verification of the optimum binder content (using the Marshall mix design method), but also on the study of the stiffness moduli and fatigue resistance of three mixtures (one with the optimum binder content and the other two with a binder content of, respectively, 0.5% above and below the optimum). This process is still being done and the results obtained so far are relative to the optimum binder content and to a traditional bituminous mixture applied on binder courses (produced with 100% virgin materials).

The stiffness moduli obtained for the recycled mixture and for the traditional bituminous mixture are presented in Table 3. Figure 6 shows the results of fatigue tests carried out on a 4-point bending test equipment, at the University of Minho, for the studied mixtures.

Table 3. Stiffness moduli of the studied hot bituminous mixtures, at 20 ºC and 10Hz

Specimen	Stiffness Moduli (MPa)	
	Recycled mixture	**Traditional mixture**
A	5327	5703
B	5339	5594
C	5440	5072
D	5406	5775
E	5371	5412
F	5367	4961
G	5623	5348
H	5784	5349
I	5741	5466
Average	**5489**	**5409**

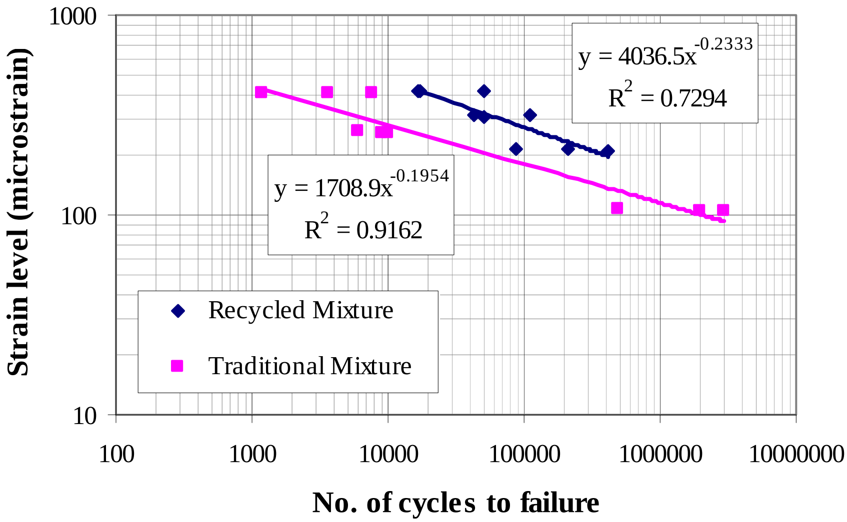

Figure 6. Fatigue life of the studied bituminous mixtures, at 20 ºC and 10Hz

As it can be observed from Table 3 and Figure 6, the recycled mixture shows results that point towards a better performance than that of the traditional mixture. Nevertheless, the stiffness moduli of both mixtures are slightly below the value of 6000 MPa expect on the pavement design stage. Therefore, the next step is to verify if, by reducing the binder content of the recycled mixture, the behaviour of the mixture will not be compromised in terms of fatigue and the stiffness modulus will increase to the expected value.

4.3. Trial Section and Pavement Rehabilitation Operations

Due to limitations in the closure of the road to perform the rehabilitation works, the layer recycled with cement will have to withstand the traffic passing on this busy urban road. Therefore, to assess the influence of the traffic on the properties of the recycled layer a trial section was defined. In this trial, all the procedures were verified and the equipment calibrated for a correct performance on the reminder of the rehabilitation works (Figure 7).

Figure 7. “In situ” recycling with cement on the trial section

After 7 days of curing, the trial section was opened to traffic in order to verify if it would damage the recycled material. The bearing capacity of the pavement was periodically measured by Falling Weight Deflectometer (FWD) tests. The results of these tests can be observed in Figure 8.

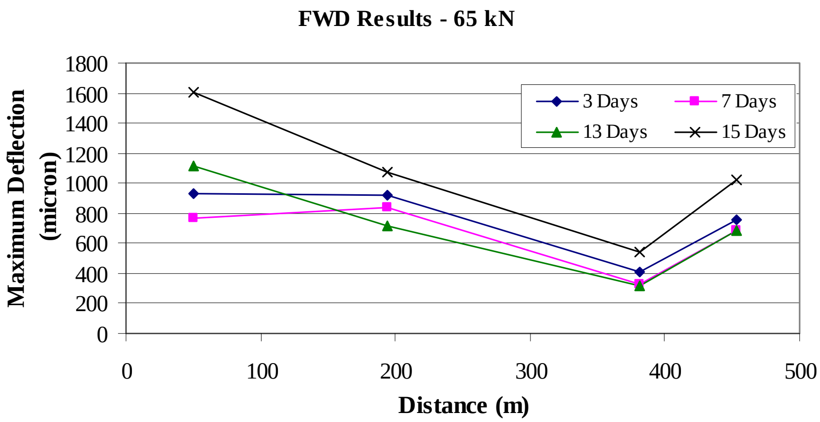

Figure 8 – FWD results obtained over the recycled material in the trial section for a standard load of 65 kN

The results presented in Figure 8 clearly show that severe damage was imposed in the recycled material by the traffic loads. Initially, the bearing capacity was increasing, as it can be interpreted from the reduction in the maximum deflection measured for a load of 65 kN, verified in all points up to 7 days, after which the trial was opened to traffic. However, one week after the opening, not only the positive evolution of the bearing capacity had stopped, but also some damage was imposed to the material. The results presented in the previous figure are complemented with visible damage of the material (disintegration of the top part of the layer) as can be observed in Figure 9.

Besides studying the effects of opening to traffic after 7 days of curing, the trial section was used to extract some cores of the recycled material and to compare the results of indirect tensile strength tests carried out on them with those obtained during the mix design study. Due to unexpected circumstances, the cores were only tested after 10 days of curing time and the average strength obtained was 0.38 MPa, which is perfectly in line with the results obtained in the mix design study for 7 days of curing.

Figure 9 – Visible damage in the recycled material 8 days after opening to traffic

5. CONCLUSIONS

Based on literature review and on the authors' previous experience in this subject, it can be stated that recycling of pavements is highly recommendable, not only in terms of improvement of pavement characteristics, but also for the purpose of saving scarce resources and reducing construction waste.

Before proceeding to any rehabilitation operation, a prior study needs to be carried out to apply the most adequate technique. In that prior study it is essential to define homogeneous sections, not only as for degradation, but also in relation to the geometric characteristics of the pavement and of existing materials. Thus, when using recycling techniques, it is possible to carry out a more adequate mix design study of the new recycled layer and of the final pavement design, namely recycling depth and number of new layers to be applied.

While works are being undergone, it might be necessary to revise the recycling process if significant variations occur in the materials or in external conditions, such as water in the recycling material when dealing with cold recycling. This factor demands a more rigorous control and supervision of works to obtain satisfactory results.

When using milled materials that have been stored for the manufacturing of new bituminous hot mixtures, special attention must be paid to their characteristics, i.e., binder variability, grading or moisture. All these factors need proper consideration in the mix design study in order to obtain a mixture with similar characteristics to those of a conventional bituminous mixture.

In the case study presented in this paper, the main conclusions and recommendations that could be drawn are the following:

- the results obtained in the mix design study for the cold "in situ" recycling with cement pointed towards a minimum of 4% cement ratio (by mass of mixture);
- the curing time of the cement recycled material before opening to traffic (7 days), was clearly insufficient, as it can be observed by the damage obtained in the trial section;
- cold "in situ" recycling with cement should not be used in situations where it is predicted that traffic will be passing over the material before the application of at least one bituminous overlay (which should only be applied after a curing period of the hydraulic bound layer of at least 7 days);
- the results obtained for the hot recycled mixture showed that it is possible to obtain mixtures whose fatigue performance is as good as traditional bituminous mixtures, using less virgin materials;
- the behaviour of the whole pavement will be continuously monitored in the near future and further publications shall be made about this rehabilitation project.

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