Asphalt Cold Mixtures for Pavement Rehabilitation: Curing and Mechanical Characteristics

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ABSTRACT: This paper presents the main results achieved in a research study concerning pavement rehabilitation using asphalt cold mixtures, specifically the application of "new" asphalt cold mixtures as overlays and *in situ* cold recycling of existing pavement layers with bitumen emulsion. In the frame of this research project, a study was performed comprising the characterization of the materials used in the production of selected cold mixtures (both "new" materials and old materials used for recycling), and the mixtures produced. Studies were performed about the most appropriate methods for representation of the *in situ* conditions in the laboratory. Furthermore, the effects of the curing process in the mechanical behaviour of the bituminous mixtures were also studied through laboratory testing. A comprehensive laboratory test programme was established, with the purpose of assessing the mechanical characteristics of dense graded asphalt cold mixtures, especially those related to pavement performance.

KEY WORDS: Road pavement rehabilitation, asphalt cold mixtures, *in situ* recycling, stiffness modulus, fatigue and permanent deformation resistance.

1 INTRODUCTION

This paper presents the main results achieved in a research study that was carried out at the Portuguese Laboratory of Civil Engineering (LNEC), concerning pavement rehabilitation using asphalt cold mixtures, specifically the application of "new" asphalt cold mixtures as overlays and *in situ* cold recycling of existing pavement layers with bitumen emulsion. In the frame of this research study, a PhD thesis was developed, under the theme "New techniques for pavement rehabilitation – Asphalt cold mixtures" (Batista, 2004).

Asphalt "cold mixtures" are those whose bituminous binder is incorporated in the mixture in the form of bitumen emulsion (emulsion of bitumen in water), allowing the mixture to be produced and placed at ambient temperature. This type of mixtures can be produced either using "new" aggregates or using reclaimed asphalt pavements, in the case of cold recycled mixtures.

Generally, the materials used in the production of asphalt cold mixtures are aggregates, bitumen emulsion and water. This last material is used in order to provide a satisfactory degree of coating of the aggregates by the bitumen emulsion, to improve the mix workability and the layer compaction.

The fact that no heating is necessary for the production and placement of asphalt cold mixtures provides some advantages to this technique in relation to the use of traditional hot mixtures, among which the following ones are listed:

- Reduction of energy costs;
- Reduction of pollutant emissions;
- Possibility of using lower complexity asphalt plants, that can easily be installed close to the job site, providing:
  - Reduction of time and costs of materials transport;
  - Flexibility in using local aggregates.

Furthermore, *in situ* asphalt cold recycling provides the following benefits:

- Savings on raw materials by reusing the existing pavement materials;
- Reduction of waste materials to be deposited in landfill.

When asphalt hot mixtures are used, the pavement can be trafficked almost immediately after laying and compacting and the mixture has the "final" characteristics for which it was designed. However, this is not the case for asphalt cold mixtures. In fact, after their application in the pavement, cold mixtures undergo the so-called "curing" process. This is mainly because one of the main constituents of this type of mixtures is water, both added to the aggregate mixture and present in the asphalt emulsion. After manufacture and application of the asphalt cold mixture, the water starts to be eliminated, mainly through the compression induced by the rolling compactors and later by evaporation. At the end of this process, referred to as curing, a continuous cohesive film that holds the aggregate in place with a strong adhesive bond must be achieved (Asphalt Institute MS14, 1990). Therefore, cold mixtures will only reach its "final" characteristics when the curing is concluded, which can take several months. Nevertheless, there is an intermediate phase, before curing is completed, when the pavement can already be trafficked, but it is necessary to ensure that no damage occurs in the layer, which could affect pavement performance, either in the short or in the long term.

Curing of asphalt cold mixtures has a great influence on the evolution of the mixture properties and therefore on the performance of pavements incorporating these materials.

2 WORK PROGRAMME

In order to evaluate the influence of curing on mechanical characteristics of asphalt cold mixtures, the following work program was developed:

- Follow-up of pavement rehabilitation works of Portuguese National Roads sections, where this type of materials was used either through the application of a new overlay or through *in situ* cold recycling of existing pavements.
- Laboratory studies comprising:
  - Development of methods for laboratory test specimen preparation and curing, which can adequately simulate the field conditions.
  - Mechanical characterisation of asphalt cold mixtures for specimens with different ages in order to evaluate the effects of the curing process in the mechanical behaviour of the mixtures and to assess pavement performance related properties. The tests performed made it possible to characterise the mixtures from the point of view of their stiffness, fatigue and permanent deformation.

It is worthwhile mentioning that from *in situ* monitoring of cold mixtures properties it was possible not only to get more information about the *in situ* behaviour of the mixtures but also to provide data on the evolution of the layer properties to support laboratory studies, such as test-specimen preparation and curing.

Most of the work described in this paper concerns the pavement of the National Road EN 120 in the South of Portugal, where a dense-graded asphalt cold mixture was used as overlay (Antunes *et al.*, 2000). Other rehabilitation works concerning *in situ* recycling of two existing pavements, namely the EN 260 and de IP2 in southern and central Portugal were also followed up by LNEC (Antunes *et al.*, 1999) (Batista *et al.*, 2002).

There are several documents available, which report these construction works. Some of the earlier results concerning the evolution of curing *in situ* and its effect on FWD layer moduli have already been presented in a previous conference (Batista & Antunes, 2002). This paper focuses mainly on the laboratory studies, specially those concerning asphalt cold mixtures mechanical characterization.

3 REPRODUCTION OF *IN SITU* CONDITIONS IN THE LABORATORY

3.1 Mix composition

For a systematic study about the evolution of asphalt cold mixtures with time, a unique mix composition was selected and tested for variable specimen's age and curing conditions. As the materials used in the laboratory study were the ones used in the production of the dense-graded asphalt cold mixture applied in a stretch of the National Road EN 120, the mix composition selected was the same that was used in this work site. This allowed for a direct comparison between *in situ* materials and laboratory samples.

The dense-graded asphalt cold mixture job-formula (in percentage with respect to the aggregate weigh) was:

- 25 % of 12/20 mm aggregate
- 25 % of 6/12 mm aggregate
- 50 % of 0/6 mm aggregate
- 6.5 % of a slow-setting cationic bituminous emulsion (ECL-1h).
- 2.5 % of added water

3.2 Compaction

The compaction method used in the laboratory should simulate as much as possible, the compaction achieved *in situ* when good construction practices are used. Figure 1 shows some results of the work that was undertaken, concerning compaction methods. In this figure, one can compare the densities obtained by different laboratory compaction methods with the *in situ* compaction obtained at the EN 120 (Antunes & Batista, 2002; F.A. Batista, 2004). The following methods were addressed:

- Static compaction with double plunger action (based on the Spanish Specification NLT161 or on the ASTM D1074). In earlier studies it had been found that the standard static compression of 21 MPa led to specimen densities well above the field densities (Batista & Antunes, 2002). Based on previous studies, two values were selected in this case for the static compression: the standard 21 MPa and 8 MPa.
- Modified Proctor compaction (based on LNEC's Specification E 197);
- Kneading compaction (based on the ASTM D1561).

Figure 1 presents two ranges of results regarding *in situ* compaction. The first range of values was obtained using the "sand replacement method" immediately after compaction in 13 sites, and the second one, with higher values, corresponds to the compaction achieved after one year and a half of trafficking.

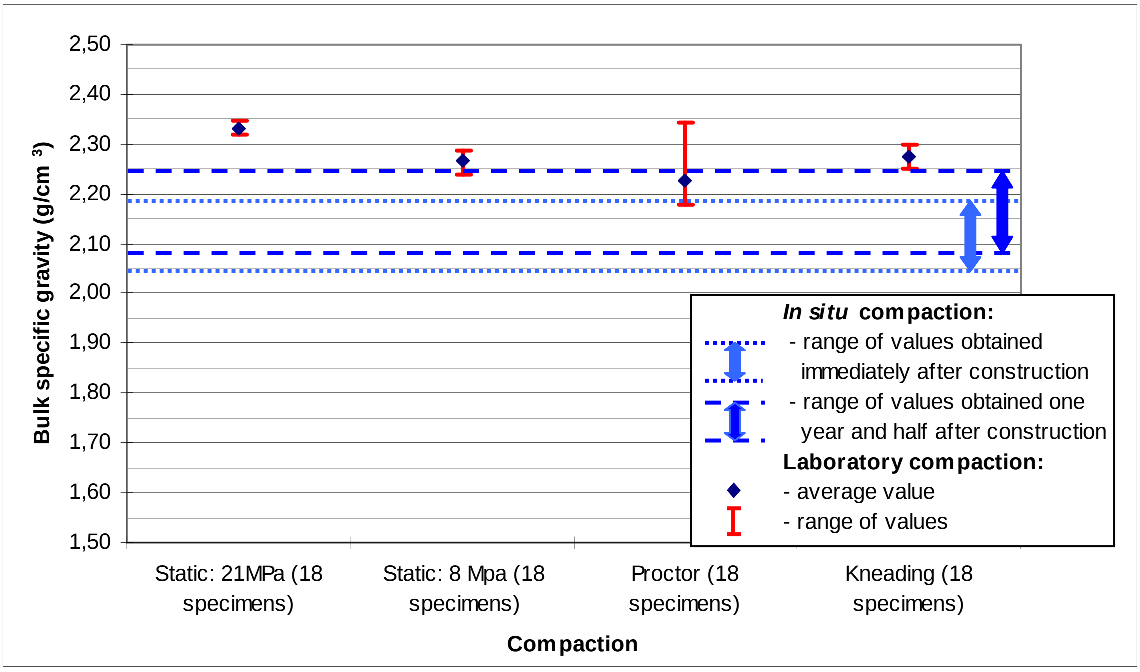

Figure1: Bulk specific gravity of mixtures compacted using different methods and/or load compaction.

The specimens compacted according to the ASTM D1074 have a bulk specific gravity well above the *in situ* values, if the specified compressive pressure is used. The specimens compacted by the Proctor method, by static compaction with a pressure of 8 MPa or by the kneading compactor are in the order of magnitude of the field densities obtained after one year and half of trafficking. However, the Proctor specimens have higher variability. The kneading compaction method seems to be the one which more adequately simulates the effect of rollers in the *in situ* compaction, and for that reason, it was the one used for the preparation of specimens for repeated load tests with the Nottingham Asphalt Tester (NAT) (see section 4). However, the static compaction at 8 MPa is also considered as an interesting method, especially for mix design, since the kneading compactor is not available in most field laboratories, and static compaction is easily performed in any laboratory.

3.3 Curing of asphalt cold mixtures

In order to assess the field cold mixture curing process, the water content evolution of the cold mixture was monitored after laying and compaction on site. In particular, *in situ* tests were performed in selected sites (13) at different ages of the cold mix layer. Figure 2 shows the evolution of water content with the cold-mix layer age during a period of around 2 months after the laying operation.

Figure 2 also presents the water content evolution of laboratory prepared specimens. These specimens were prepared using the kneading compaction method and were allowed to cure at room temperature. Taking into consideration that in the field, only the pavement surface is directly exposed to air, some of the specimens were covered with a plastic film around the lateral face, allowing only the water evaporation through the top surface.

Coupled with this, core specimens were extracted from the compacted layer, assuming that the depth until which it would be possible to extract the cores was a good indicator of the mixture cohesion and thus an indicator of its "curing" (Batista & Antunes, 2002). The thickness evolution with the cold mix layer age is also presented in Figure 2.

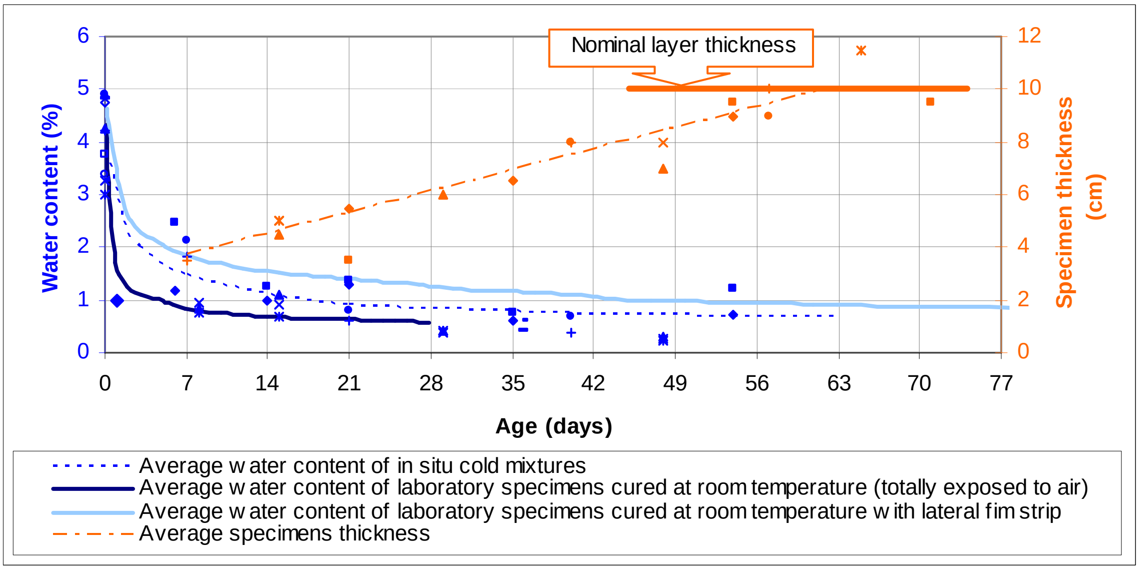

Figure 2: Evolution of the cold mixture water content and evolution of intact core specimen's thickness with age.

From the results presented in Figure 2 it seems that the *in situ* water content evolution is somewhat between the two groups of laboratory specimens (with and without plastic film).

The asphalt cold mixture under study was laid in the summer, in the south part of Portugal, which means that the weather conditions were certainly favourable to promote the mixture curing. From the results presented, one can conclude that for this particular case (dense-graded mixture using cationic slow setting emulsion, and placed under good weather conditions) the water content stabilized around 1% two to four weeks after laying (Figure 2).

However the water content stabilization does not necessarily mean that curing is fully completed. In fact, full thickness specimens (≈10cm) could only be extracted about eight weeks after laying (Figure 2).

4 MECHANICAL CHARACTERISTICS OF THE ASPHALT MIXTURES DURING THE CURING PROCESS

4.1 Introduction

In order to investigate the influence of curing on the mix performance and to get input for the analytical design of pavement structures comprising this type of materials, a laboratory testing program, was undertaken, concerning the following issues:

- Evolution and sensitivity to temperature of asphalt cold mixtures stiffness modulus under controlled curing conditions;
- Fatigue and permanent deformation of asphalt cold mixtures during curing.

Most of the tests were performed using the Nottingham Asphalt Tester (NAT) from the Technical University of Lisbon (IST), Geotechnical Laboratory. This equipment was used both for the assessment of the stiffness modulus and the fatigue resistance of the asphalt cold mixtures through indirect tensile tests and for the assessment of the permanent deformation through repeated load uniaxial tests (Figure 3). The tests were carried out on 100 mm diameter cylindrical specimens, both compacted on laboratory (see section 3.2) and extracted from the field (EN120).

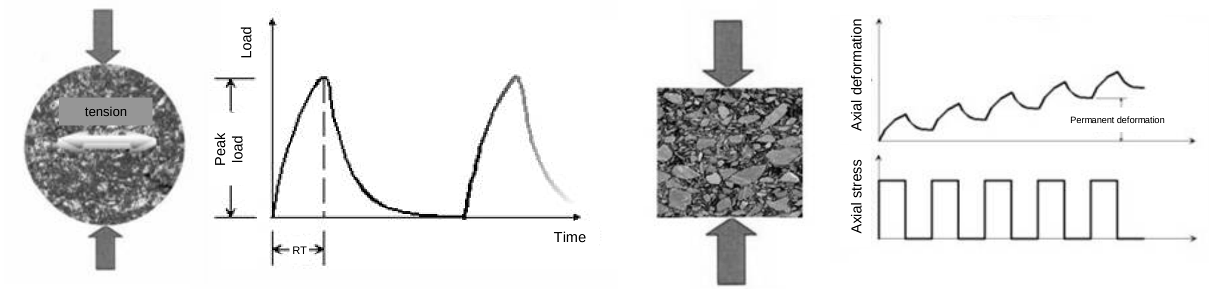

Figure 3: Assessment of fatigue and permanent deformation resistance using the NAT

In order to compare asphalt cold mixtures behaviour with a reference material, tests were also carried out on asphalt hot mixture specimens with a composition similar to the one used in this study, referred as “Grave-bitume” (GB). Specimens extracted from an *in situ* cold recycled layer (IP2) were also tested.

Other tests were also performed, namely wheel-tracking tests in order to provide extra information about asphalt cold mixtures resistance to permanent deformation (Batista, 2004).

4.2 Laboratory specimen preparation

More than 100 specimens were prepared in the laboratory, using the kneading compactor. These test specimens were later cured at room temperature in different conditions (see section 3.3), in order to study the effect of the curing process on the mixture properties. Some specimens were also cured in the oven, in order to evaluate the accelerated curing process used in mix design methods. Table 1 presents a summary of the curing conditions considered.

Table 1: Test specimens curing conditions

Specimens storage temperature	Specimens storage conditioning	Specimens age
Room temperature	Lateral film strip	1 day; 2 days; 1 week; 2 weeks; 1 month; 2 months
	Totally exposed to air	2 months
	Lateral film strip (1st phase) + Totally exposed to air (2nd phase)	4 months (2 months with film + 2 months without film)
Room temperature + oven at 60ºC	Totally exposed to air	4 days (1 day at room temperature + 3 days at 60ºC)

4.3 Stiffness modulus and resistance to fatigue

4.3.1 Test method

The stiffness modulus was determined after 100 load cycles, with a rise time (RT) of 124 ms, at a normal peak stress of 100 kPa. The fatigue resistance was determined using the same type of loading, but varying the peak load.

4.3.2 Asphalt cold mixtures stiffness modulus

The tests for determination of the indirect tensile stiffness modulus addressed the following issues:

- Evolution of the stiffness modulus at 20ºC temperature with the curing process;

- Variation of the stiffness modulus with temperature, using specimens cured for two and four months.

The results obtained for the variation of the stiffness modulus with the curing process are presented in Figure 4. This Figure shows the variation of stiffness modulus with age, for the specimens cured at room temperature as well as the stiffness modulus obtained for specimens submitted to an accelerated curing process (see Table 1) and field specimens cored from the site after one year and half of trafficking (specimens tested in laboratory after 2 years of construction).

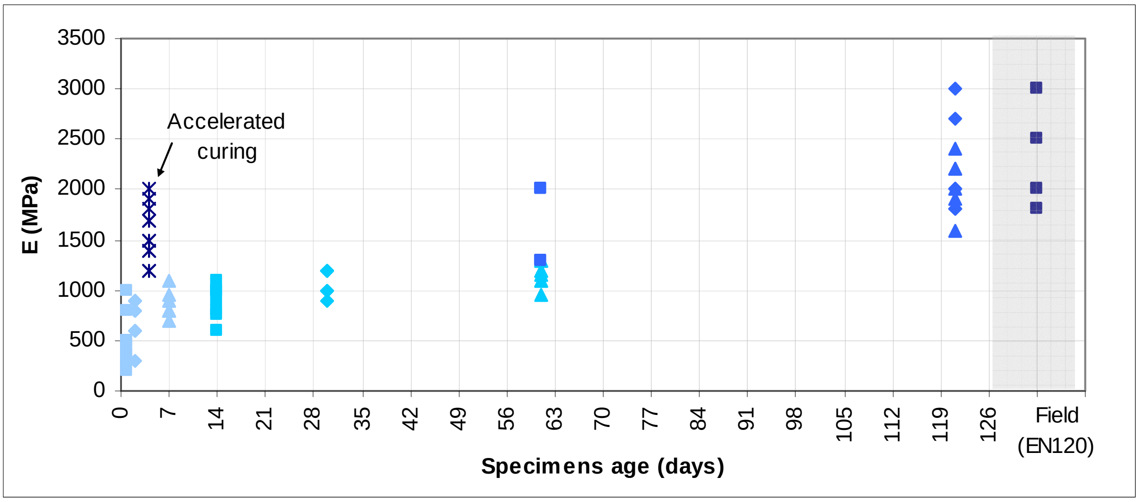

Figure 4: Stiffness modulus (E) of laboratory prepared specimens and field specimens.

The results presented in Figure 4 show that the stiffness modulus of specimens increases as the curing process develops from early curing specimens (1 to 2 days) until 4 months cured specimens. The specimens cured in the oven did not reach these values, which may indicate that cold mixtures submitted to that type of curing process (3 days at 60ºC), which is the one used in the mix design method, do not represent the mixtures "final properties".

Figure 5 presents the variation of the stiffness modulus with temperature, for asphalt cold mix specimens submitted to similar curing conditions, for recycled cold mix field specimens as well as for asphalt hot mixtures specimens.

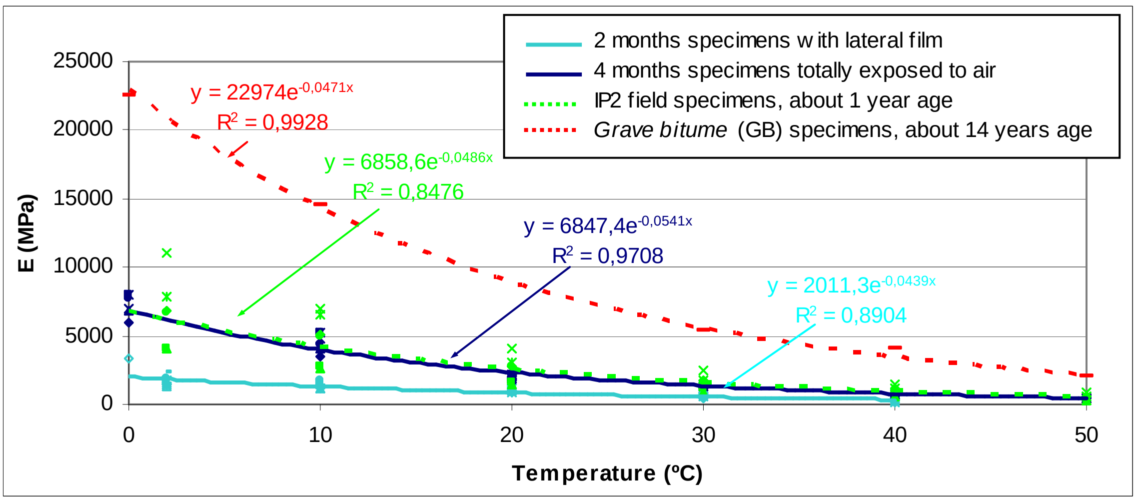

Figure 5: Variation of the asphalt cold mix specimens'stifness modulus (E) with the temperature.

The results presented in Figure 5 show that there is a considerable influence of the temperature on the modulus of all the mixtures tested, which can be represented by an exponential relationship. The behaviour of the 2 months old asphalt cold mix specimens cured in the laboratory with lateral film is still far from the one observed for 4 months old laboratory specimens or recycled cold mix field specimens.

4.3.3 Resistance to fatigue

The tests to assess fatigue resistance of cold mixtures were performed at controlled stress at a temperature of 20ºC. The stress levels applied to the specimens varied within a range of 50 to 350 kPa. The fatigue life for a certain level of stress was defined as the number of load pulses leading to a reduction of 50% in the initial indirect tensile stiffness modulus.

Figure 6 shows the fatigue curves obtained for cold mix specimens, both laboratory prepared ones, which were submitted to different curing conditions, and field specimens. This Figure also presents the fatigue curve obtained for asphalt hot mix specimens.

From the results obtained in fatigue tests, it was concluded that, the fatigue properties of the mix were similar for all specimens tested at relatively early ages (up to 2 months). For these mixtures, the slope of the fatigue life is lower than the one obtained for the hot mixture.

When the curing process of the cold mixtures is completed, their fatigue behaviour is very similar to the one obtained for the hot mixture (Grave-bitume).

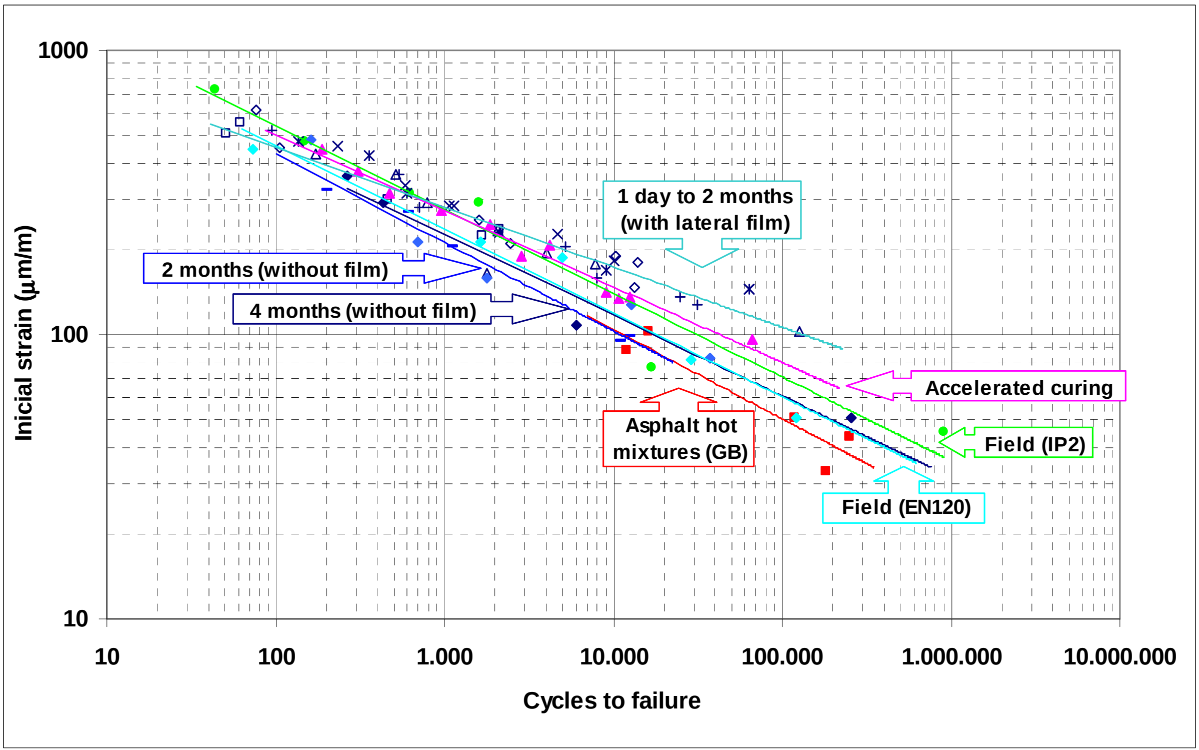

Figure 6: Fatigue life of asphalt cold mix specimens and hot mix specimens.

4.4 Resistance to permanent deformation

Repeated loading uniaxial tests were performed in accordance with the British Standard BS DD 226:1996, in the conditions indicated below. These tests were complemented with wheel-tracking tests:

- Test temperature: 50ºC;

- Conditioning period: 10 min. at a constant stress of 10 kPa;
- Repeated axial load
  - Load cycle: "square wave", 1 s of 100 kPa loading stress and 1 s of rest period
  - Test duration: 3600 cycles (2h)

Figure 7 presents the average permanent deformation of each group of specimens tested with the same characteristics in the NAT equipment. In this case, the tests were carried out on different ages asphalt cold mixtures (ACM) laboratory prepared specimens (LS) as well as on field specimens (FS) of different types of mixtures (RCM – recycled cold mixtures; AHM – asphalt hot mixtures).

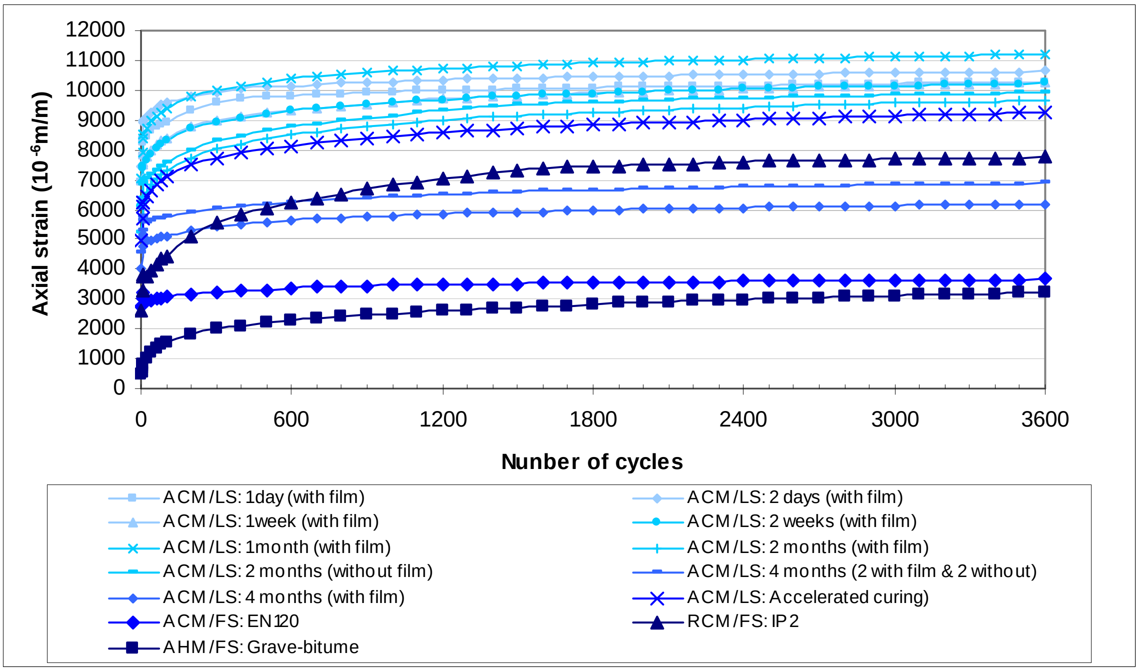

Figure 7: Permanent deformation of specimens repeated load axial tested.

From the results obtained in the repeated loading uniaxial tests and in the wheel-tracking tests, the following conclusions were drawn:

- Asphalt cold mixtures, mainly the early cured ones, have a relatively high deformation in the primary phase, when compared to hot mixtures. The fact that cold mixtures are still curing when the test begins will allow for the mineral particles to "move", resulting in these higher deformations.
- When the primary phase is concluded, the deformation rate of asphalt cold mixtures specimens decreases considerably, resulting in a secondary phase with a reduced deformation rate.
- Recycled cold mixtures seem to have a behaviour somewhat between the "new" asphalt cold mixtures and the hot mixtures.

Taking into account that these cold mixtures are used in the road base and therefore, they will have one or more layers placed on top of them, any deformation that had already occurred (primary phase) will be corrected when the upper layers are applied. Therefore, as the asphalt cold mixtures permanent deformation rate in the secondary phase is much reduced, it can be concluded that after construction works have finished (all layers placed), these materials will have a satisfactory permanent deformation performance.

5 FINAL REMARKS AND FUTURE WORK

Although asphalt hot mixtures are more commonly used in pavement rehabilitation works, asphalt cold mixtures present important benefits, namely in terms of environment and energy savings, and they can provide an interesting alternative, specially for the rehabilitation of low volume roads. The use of this type of material can be done either through the placement of a new overlay on the existing pavement, or through *in situ* recycling of the existing pavement layers, with significant environmental and economic benefits.

The work performed concerns mainly the mechanical characterization of asphalt cold mixtures during the curing process, and also after curing. It provides results (stiffness modulus, fatigue resistance and permanent deformation), which are essential inputs for the development of analytical design methods for road pavements incorporating this type of materials.

It also proposes some practical methods for in situ evaluation of the curing condition and for laboratory test specimens preparation and conditioning.

To complete this work, it is recommended that performance related specifications are developed in order to allow for the use of this type of unconventional solutions.

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