LABORATORY METHODOLOGY FOR TESTS ON ASPHALT MIX CONTAINING RECLAIMED ASPHALT PAVEMENT (RAP)

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ABSTRACT

In France and throughout Europe, a strong-willed drive to promote sustainable development has led public and private sector decision-makers to step up their use of reclaimed asphalt pavement, notably in asphalt mixes, for the design, construction and maintenance of roads, streets and urban infrastructures.

In light of the above, European regulations and standards were drawn up. Companies which design, manufacture and apply asphalt mix with RAP use existing standards, in particular those which cover the laboratory production of asphalt mixes (NF EN 12697-35: "Laboratories mixing – test methods for hot mix asphalts). This document provides a detailed description of experimental conditions, but remains imprecise, enough to actually impact the mechanical characteristics measured on the mix.

. An example of assessment of the method on results is presented in this article, along with a proposal including a simple, accurate operating mode that leaves no leeway for imprecision.

Keywords: RAP, mixing process, mechanical characteristics

1. INTRODUCTION

There is nothing new about adding recycled asphalt pavement (RAP) to asphaltic mixtures. The first trials date back to more than 40 years ago. Contractors are able to manufacture and lay mix designs that contain RAP without any difficulty. In spite of this, France is not at the forefront in this area when we compare the average percentages of recycling in France to those achieved internationally, not only in the USA but also in countries nearer to us such as Belgium. Efforts are therefore continuing to develop different applications of recycling, including in warm mixes, in order to make greater use of this environmentally-friendly solution which saves resources (of both aggregate and hydrocarbon binders). In France, after the Grenelle Environment Summit and the major decisions made by the road construction industry to pursue this approach, there has been a significant increase in the number of mix designs which include RAP. These studies are also the outcome of recent investment that has been made in industrial equipment with a view to developing the practice. In addition, it is apparent that, from the laboratory mix design stage, a number of clarifications and descriptions of good practice ought to be incorporated into the current version of the standard EN 12697-35+A1 [1]. This is the topic covered by this paper. It will clarify some points concerning the laboratory manufacturing method, after a review of the regulatory and normative context and a rapid survey of recent developments in industrial equipment and the techniques which are now available for recycling asphalt pavements.

2. LITTERATURE REVIEW

2.1 Existing practises

There have already been several detailed analyses of possible disparities in the laboratory manufacturing procedure for mixtures containing RAP. In this connection, the interested reader can refer to the work conducted in the framework of the European Re-road project which describes practices in a number of European countries, both with regard to the available industrial equipment and laboratory design methodologies [2]. This survey has been supplemented by a study that set out to define a laboratory manufacturing methodology for mixes containing RAP, which proves that the standard required some clarification [3]. For example, the order in which the constituents should be added is not described precisely in the standard, and only a maximum mixing time is given, which may vary according to the type of equipment used, the only obligation being to achieve a homogeneous mix with good coating. This last point is among those dealt with in the Re-road programme and we shall study its effect by comparing the results obtained when the mixing times were doubled, but the same manufacturing procedure was applied. This work is still in progress and it is not yet possible to reach a conclusion on these issues.

We can also mention a recent study which investigated the effect of the prior conditioning of the RAP on gyratory shear compactor workability in the case of a high modulus asphalt containing 50% of RAP [4]. A variety of conditions were tested, such as heating both the RAP and the aggregate to 180°C, or using cold RAP with aggregate conditioned at 180°C and overheated for 15 minutes at 380°C before mixing. The effect of the total mixing time (between 2 and 5 minutes) was also investigated, as was the behaviour in the gyratory shear compactor of a mixture produced in a mixing plant with a blend which was identical but made with stripped aggregate obtained from RAP and the extracted binder, mixed with virgin aggregate and added binder. Increasing the mixing time seems to have an effect, as does the prior overheating of the virgin aggregate which improves the quality of the coating of the RAP with the binder before the addition of the virgin asphalt. However, the differences between the manufacturing conditions as measured with the gyratory shear compactor remained quite small, of the order of 1%.

The need to define precisely the conditions to be applied has also been clearly identified in the USA, with the publication of recommendations for Superpave mix design of mixtures containing RAP [5]. In the case of small quantities of RAP, between 1 and 2 kg, conditioning at 110°C for a maximum of 2 hours is recommended as longer heating at a higher temperature could modify the characteristics of the RAP. The virgin aggregate must be heated at a temperature that is 10°C higher than the mixing temperature.

It is therefore not possible to avoid a first stage in which the experimental conditions for laboratory studies are defined before considering difficult issues such as the contribution made by the binder in the RAP to performance.

2.2 Regulatory framework

The political will to recycle asphalt pavements has resulted in the publication of several regulatory texts that specify conditions for hot recycling in a mixing plant that eliminate technical risk. Originally, what was involved was the application of the 1992 law setting out the rules for landfill disposal. This was followed by two circulars which dealt with the planning of the management of waste from the construction and civil engineering industry [6] and the management of waste from the national road network [7]. At the same time, IFSTTAR (formerly LCPC) and USIRF (*Union syndicale des industries routières françaises*) had shown that the use of RAP with an apparent particle size distribution of 0/10 mm that had been crushed and screened beforehand in a proportion of 10% in semi-coarse asphaltic concrete and 15% in roadbase asphalt had no significant impact on the measured performance during the laboratory mix design study up to level 3 [8,9].

As a result of rising environmental pressure, a new series of proactive measures that aimed to increase the use of recycling were introduced by the competent ministry and the profession (the FNTP and the USIRF) as stated in a declaration of intent signed in 2009 [10]. This aims to increase recycling rates in order to reduce consumption of natural resources and transport fuel. The goals have remained the same since the outset, but the development of new production methods such as warm mixes and the significant improvement in production equipment, with regard to controlling the introduction of RAP, provides new possibilities for recycling. We should also not forget that knowledge that has been acquired in the sphere of recycling has helped to reduce psychological resistance to the use of RAP, as the aim in this area has always been to propose mixes with chemical characteristics that are equivalent to those of the formulae made exclusively with “virgin” aggregate.

2.3 Normative context

The laboratory procedure for manufacturing mixes containing RAP is laid down in the standard EN 12697-35+A1 of September 2007. RAP is also considered in the following standards: EN 13108-8 [11] which specifies the requirements regarding the description of RAP and the standard EN 12697-42 [12] which describes the visual method for determining the proportion of coarse extraneous aggregate in RAP.

3. INDUSTRIAL EQUIPMENT

There are now a very large number of ways of incorporating RAP in mixtures. It can be added at the base of the hot conveyor, to the drum with a launching belt or directly into the mixer via a recycling ring. Some models can even achieve a recycling rate of 50% using a recycling ring.

Other recent models of batch mixing plants include a dedicated tube for heating the RAP, and this can also be fitted to continuous plants. Double jacket mixing plants have also evolved and now seem to be moving towards a separation of functions, with the heating the RAP performed by a double jacket, while coating and mixing are performed at the tube outlet. In the case of high recycling rates (>30 to 40%) plants which are able to heat the RAP before it is mixed with the virgin aggregate are mainly used, with a target temperature of approximately 110 -130°C. Figure 1 shows mixing plants used within the Colas Group which feature these latest innovations and provide the firm with even more effective equipment to foster the development of recycling.


a)


b)


c)


d)


e)

Figure 1: Examples of recent mixing plants capable of high recycling rates

a) Batch mixing plant with dedicated tube for heating RAP
b) Continuous (Double Rap)
c) RMS 300 continuous mixing plant
d) RF 400 retroflux mobile asphalt plant
e) Contimix 300 continuous mixing plant with dedicated tube for conditioning RAP

We therefore have good knowledge of the initial state of the RAP, and the temperature of the mixture at the end of mixing. How they change in the event of overheating in the hot conveyor is more uncertain. In the case of the most effective equipment, for example those which possess a dedicated tube for conditioning the RAP, their temperature is perfectly controlled. This large number of possibilities cannot be simulated by a single laboratory procedure.

4. A DETAILED ANALYSIS OF THE STANDARD EN 12697-35

Specifying the reference temperature for manufacturing the mix (§ 6.1.1)
When this is calculated, it is necessary to take account of the characteristics of the added binder and the binder extracted from the RAP.

This first point already elicits some remarks. The characteristics of the binder in the RAP are known from the characterization procedures that justified its use. Those of the added binder are also known. It is therefore quite possible to calculate the reference temperature to be obtained during mixing. However, it is more difficult to forecast the conditioning to be applied to the materials to reach that goal. The temperature of the RAP varies depending on the selected procedure (conditioning at 110°C or at the reference temperature) and may differ from the recommended temperature, particularly if the RAP is moist and conditioned in a thick layer. This may seem unimportant in the case of small batches for which we can assume that the temperature of the RAP achieves a good level of uniformity. However, the issue is less trivial in the case of large test specimens such as plates with a dimension of 600x400 x120mm from which trapezoidal specimens are cut for the complex modulus test and the fatigue test according respectively to the standards EN 12697-26 and 24. In this case, the amount of RAP to be handled may reach 30 to 40 kg. However, recycling is used the most for this type of mixture intended for sub-base and roadbase layers which are characterized using a fundamental approach.

Another difficulty relates to the alternative mentioned in the standard for selecting the temperature to which the RAP should be heated (§ 6.3.) It may be prepared at the recommended temperature if it is heated industrially at the mixing plant or alternatively conditioned at just 110°C for 2.5 +/- 0.5 hours. However, as we have mentioned in connection with industrial equipment, RAP is never heated to temperatures in excess of 110-130°C, even if the mixing plants have a dedicated tube for it.

The standard therefore leaves quite a large degree of freedom. It is also reasonable to think that RAP can, or should, be conditioned at a certain temperature without preliminary drying. At least this is what the note that accompanies paragraph 6.3.2 can lead them to believe: “The hopper must be shaken regularly in order to prevent any rise in pressure inside it”. The possibility of using undried RAP makes it significantly more complicated to determine the target temperature for the materials. It is not certain that RAP which is moist at the outset and conditioned at temperature for only 2.5 hours, will be dry at the time of manufacture. However, if at the time of mixing there is a release of steam when residual water is driven off, there is an increased risk of the operator sustaining burns.
In addition, there is nothing disturbing about the idea that RAP can be dried, as experience shows that hot, or even warm mixes that contain RAP have very low water contents when they leave the mixing plant, always below 0.5%. This has been observed numerous times during the manufacture of varied mix designs containing high percentages of RAP (up to 30%), in mixing plants in which RAP is introduced and heated in a variety of ways.
In the case of the use of RAP that has been heated to 110°C (§6.3.3), the standard also leaves a certain degree of freedom, as it states that it is possible to heat the virgin aggregate to a higher temperature than normal. This point is quite vague, as it is not explained what is meant by “a large amount of recycled mixture”, or above what level the approach should be applied. No details are given about the degree of overheating either.

To remove any doubt about the impact of any additional ageing of RAP during its conditioning prior to manufacture, it is advisable to prepare only the quantities that are necessary for the mass of mixture to be produced and to discard any surpluses once manufacture is complete.

These issues will remain on the agenda so long as we do not have sufficient experience to assess their impact on laboratory performance. In order to advance debate on this topic, we shall present some results from studies below and illustrate some possible impacts on the characteristics of mixes.

Apart from the central issue of the target temperature for RAP, and how appropriate this temperature is for the industrial equipment, we must not ignore the strong constraints associated with the cost of mix design studies. In some geographical areas where there is a high density of mixing plants, such as in the Paris region for example, a large number of mix designs are shared for a number of mixing plants which do not necessarily use the same production equipment. It becomes unrealistic to have one study for each mixing plant. It becomes even less realistic when we desire to have a mix design study that is updated for each stockpile of RAP, particularly when fundamental studies which include the determination of modulus and fatigue characteristics are involved. It is therefore important as of now to consider ways of demonstrating how the binder in the RAP contributes to performance and validating blends that contain a moderate proportion (whose level is to be decided) of RAP on the basis of the compliance of the measured mechanical characteristics of mixes with high recycling rates (for example, greater than 30%). For example, for a given aggregate used for roadbase asphalt and high modulus asphalt with RAP contents of 15, 20, 25 and 30 %, it is necessary to conduct more than 8 full studies for a single batch of RAP. Even with substantial resources, this type of study becomes utopian within the time taken for the stockpile of RAP to be consumed. A more realistic validation approach based on a high proportion of RAP for mix designs with less RAP is necessary and would be closer to the historical approach and therefore justify the abandonment of mix design studies for mixes with low recycling rates [8,9]. This vital point will not be dealt with here, but it will determine the future of mix design laboratories which will not be able to cope with an increase in the need for studies as a result of greater use of recycling.

5. EXPERIMENTAL RESULTS

To give an example, we shall present below the results of a level 2 study supplemented by diametral compression modulus measurements on an asphaltic concrete base course made with 35/50 pen asphalt (0/14 roadbase asphalt with 40% of class 3 RAP). It would of course be possible to argue that this type of mix is not necessarily the most sensitive to the rutting test. Nevertheless, this type of product has a fairly open texture and a low binder content and gives a good idea of the impact on water resistance. In addition, in order to maximize the impact on measured performance, the study was conducted with a high percentage of RAP and the conditions under which the RAP was prepared were also “extreme”, outside those specified in the standard EN 12697-35 +A1.

Three different conditioning regimes were adopted for the RAP:

- Drying to 60°C followed by heating at 160°C, virgin aggregate heated to 160°C
- Drying to 60°C conditioning of RAP at 110°C for 2 hours and virgin aggregate heated to 190°C
- RAP added at ambient temperature with a water content of 4.5% and virgin aggregate heated to 230°C

It should be noted that the water content of the RAP adopted here is not particularly high. It corresponds to that of a batch of RAP stored without any particular precautions and used after a major rainfall event. It is normally preferable to use much drier RAP, which in the best case has been stored under cover on an appropriately drained and shaped surface that helps stormwater to drain away. The aim was obviously to avoid loosing the benefits of RAP as a result of the need to pointlessly heat the water it contains.

The batches were manufactured with a Rayneri mixer with a heated bowl. The total mixing time was 4 minutes, conducted in the following stages:

- mixing of the virgin aggregate (this mix design contained no added filler) for 1 minute$
- introduction of RAP and mixing for 1 minute
- introduction of new binder and mixing for 2 minutes

Three level 2 mix design studies were conducted for the 3 manufacturing protocols, as were diametral compression modulus measurements. All the results are given table 1.

Table 1:Summary of the performance measured for the 3 types of conditioning applied to RAP

	0/14 roadbase asphalt (35/50 pen) + 40% RAP 160°C	0/14 roadbase asphalt (35/50 pen) + 40% RAP 110°C	0/14 roadbase asphalt (35/50 pen) + 40% moist RAP	Categories of 0/14 roadbase asphalt to EN 13108-1
Mix design number	**1**	**2**	**3**	
Conditioning of RAP	160°C	110°C → 2H	20°C 4.5 % eau	-
Gyratory shear compaction test Percentage of voids after 100 gyrations	4.3	5.1	4.3	V_{max10}
Duriez test Percentage of hydrostatic voids Water resistance (r/R)	4.2 88	3.6 86	4.7 76	$ITSR_{70}$
Rutting test Average percentage of voids in plates Rut depth as a percentage of thickness after 30 000 cycles at 60°C	7.4 1.1	7.0 3.1	6.8 2.4	Vi = 7% et Vs = 10% P_{10}
modulus measured on UTM Average percentage of voids in specimens Modulus at 15°C – 124ms in MPa	8.3 16200	8.9 13540	8.6 12690	Vi = 7% et Vs = 10%

The curves showing the changing density measured during the gyratory shear compactor test have been plotted on Figure 2.

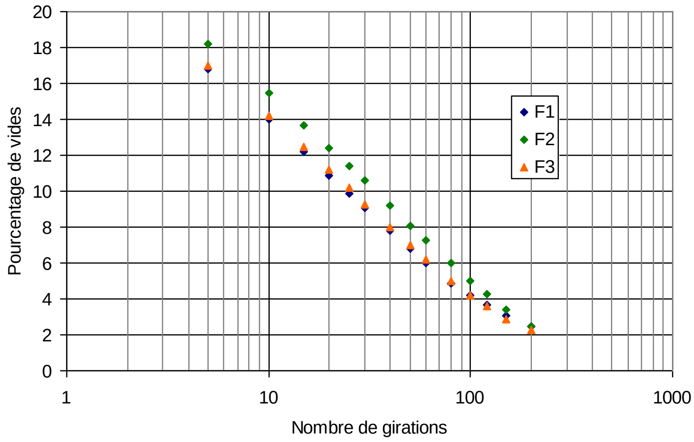

Figure 2: Gyratory shear compactor result with the three manufacturing protocols

The differences observed in the results from the gyratory shear compactor test are relatively small, a voids content difference of less than 0.8 % between mix design 2 and mix design 3. This is below the test's reproducibility limit. There is practically no difference between mixes 1 and 3, as has already been noted elsewhere [4]. Two characteristics seem to be particularly affected by the manufacturing procedure: the water resistance and the modulus. The evaporation of water may temporarily disturb the coating phase and doubtless alters the quality of the aggregate-asphalt and/or RAP-asphalt bonding. In all three cases, rutting resistance is excellent. However, this observation cannot be considered to apply to all cases as roadbase asphalt normally has good rutting resistance. Last, there was a significant difference in the measured modulus values. These were almost the same for mixtures 2 and 3, and significantly lower than those for mix design 1 manufactured with RAP heated to 160°C. There are a number of possible explanations for this: better mobilization of the binder in RAP because of its higher temperature, which also improves performance but may also cause additional ageing to the binder in the RAP.

6. PROPOSED PROTOCOL FOR MANUFACTURING ASPHALT MIXES CONTAINING RAP IN THE LABORATORY

It is apparent that the clarification of the manufacturing protocol to be applied given in the standard EN 12697-35+A1 is insufficient. First of all, it would appear to be necessary to complete Table 1 of the standard in question which provides the reference temperatures on the basis of the class of road asphalt including the hard road asphalts that are specified in the standard NF EN 13924 [13]. When RAP is used, it would be possible to calculate the temperature to which the virgin aggregate should be heated, on the basis of the above reference temperature and the RAP content. When the RAP is used, the temperature to which the virgin aggregate should be heated could be calculated from the reference temperature mentioned above and the proportion of RAP. We propose to apply the formula developed by Baroux [14] for this calculation, which gives the following table.

Table 2: Estimation of the temperature to which virgin aggregate should be heated on the basis of the proportion of RAP and the target temperature for the mix

Target temperature for the mix	Proportion of RAP (%)			
	10	**20**	**30**	**40**
120	120	125	125	130
130	130	135	140	145
140	145	150	155	160
150	155	160	165	180
160	165	175	180	190
170	175	185	195	210
180	190	200	210	230

It can be seen that this table considers the case of warm mixes.
For the calculation, the RAP is deemed to be dry and conditioned at 110°C as specified in the standard. We have already seen that the desire to have a reproducible method which is straightforward and safely applicable by staff militates in favour of the use of dry RAP. In order to limit the possible change in the binder contained in RAP during drying, we recommend that drying should be conducted at a moderate temperature of the order of 60°C ± 10°C, to constant mass, after the RAP has been declumped and spread out to a maximum thickness of 5 cm on a tray, which guarantees uniform heating.
Last, conditioning at 110°C for 2.5 hours ±0.5 hours as recommended in the standard is appropriate with RAP in a thin layer (approximately 5cm) in order to guarantee the most uniform possible temperature.
In addition, the mixing time of the dry aggregate (including RAP if it is used) should be approximately 30 s.
Last, it is essential for RAP to be used only once. The amounts that are required to manufacture the specimens for the planned mix design tests (gyratory shear compactor test, rutting plates) must only be temperature-conditioned once and any surpluses must be discarded, in order to avoid the use of RAP which has been subjected to successive heating cycles that cause additional ageing. It is therefore necessary to estimate the amount of RAP that is required for the study.

7. CONCLUSION

The analyses conducted in this article with regard to the application of the standard NF EN 12697-35 which deals with the mixing in the laboratory of a hot hydrocarbon mix has led us to propose that this standard be revised in order to simplify it, making practices more uniform and reduce the risk of errors in the procedure with a view to improving the reproducibility of mix design tests. This stage is necessary to obtain a basis on which additional studies can be conducted to add to our knowledge on the performance of mixtures that contain RAP and attempt to optimize their composition and thereby improve the quality of these products even further.

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