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Technical guide

Pavement roadmixing and recycling of bituminous pavement materials

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RÉPUBLIQUE FRANÇAISE

ministère
de l'Équipement
des Transports
de l'Aménagement
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de la Mer

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Pavement roadmixing and recycling of bituminous pavement materials

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Main actions of the CFTR:

- laying down documents expressing the state of the art;
- drawing up technical advices on fitness for the use of processes, products and equipments, as well as qualification documents for equipments;
- issuing approvals for road laboratories;
- carrying out procedures of certification and conformity with standards.

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Foreword

All major road construction companies favor so-called "noble" materials, i.e. those developed, controlled and laid to obtain the best possible use.

Pavements age from ever-increasing traffic and climatic stress, resulting in courses with properties no longer compatible with their intended functions at the end of their lifetime.

The trend is basically towards re-using existing materials in a lesser function to maintain and upgrade pavements.

The Highways Department has opted for this solution under the policy of coordinated strengthening, by considering the pavement at the end of its life as the foundation for a new structure requiring the addition of "new" materials as base and surface layers.

Environmental constraints for non-renewable resource-based economies and mandatory recycling (law of 13 July 1992) impose recycling of natural deposits in the pavements and restrict the amount of so-called "new" materials used to maintain them.

At the end of their lifetime, existing materials in the pavements must be re-used with minimum addition of "new" materials.

The purpose of this document is to list the various existing practices for the re-use of pavement materials from surfacings and road foundations based on where they will be used in the future. It is therefore a response to the need to construct and maintain pavements out of a concern for sustainable economy in compliance with increasingly demanding environmental constraints.

Four techniques will be examined:

- *in situ* cold roadmixing;
- plant cold roadmixing;
- *in situ* hot-mix recycling;
- plant hot-mix recycling.

The first two involve road foundation materials (materials processed with or without a cementitious binder) and surfacing materials.

The second two involve asphalt materials for surfacings and base layers.

Each technique is presented with its advantages, scope and use limitations.

Common points stand out:

- *these techniques are not new;* they are known and are either totally controlled or can be controlled. Some of them are covered by technical guides or standards and are widely used in neighboring European countries;
- *these techniques involve the same approach*:
  - identification of the material for re-use;
  - definition of the area(s) of use based on experimental results.

The greater the planned recycling in terms of end product quality and re-use rate, the more detailed the studies will be.

- *these techniques undergo constant development, given*:
  - environmental constraints;
  - mandatory recycling by law;
  - technical advances in the materials, the result being efficiency and unquestionable product quality;
  - recyclable products for roads are estimated to weigh some 20 million metric tons per year, which represents 10% of the aggregates used for roads.

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In situ cold roadmixing of old pavements

Introduction

The aim of this chapter is to present a synopsis of *in situ* cold roadmixing techniques for old pavements using a bituminous or cementitious binder or a composite binder (mix of bitumen emulsion or foam with cementitious binder).

The technical guide "*In situ* cold roadmixing of old pavements", comprising a common work book and a technical work book specific to each of the three binders, provides greater detail and information.

Definition

In situ cold roadmixing of old pavements is a road structure maintenance and rehabilitation technique carried out entirely on site from the natural deposits in the old pavement. Once the old pavement has been broken up and any correcting aggregates and water added, the method consists of cold processing the materials with a binder in a mobile machine working at the heading.

Scope

This technique applies a new road foundation or binder course using materials already found in the pavement.

Use limitations

The limitations of this technique lie in the maximum dimension of the natural deposits. It is considered that the D should be less than 80 mm for the unprocessed graded aggregates, which excludes cement concrete or cobbled roads (unless eliminated or crushed in advance).

Roadmixing classification

Based on the processed thickness of the old pavement, the results are as follows:

• structural strengthening (for example, strengthening of the intrinsic mechanical characteristics of the old pavement which are no longer suitable for the changes in traffic);

• improved surfacing characteristics (for example, elimination of reflective cracking, surfacing rebonding, improved adhesion and evenness characteristics, etc.).

Under these conditions:

• roadmixing with a cementitious binder can restructure a pavement foundation to a depth of 20 to 30 cm;

• roadmixing with bitumen emulsion can be structural when it is laid 10 to 15 cm thick or a means of improving surfacing characteristics when laid between 5 and 12 cm thick;

• roadmixing with a composite binder is used to obtain a rigidity between the two previous techniques. The thickness range covers both techniques.

Depending on the stated objective, the nature of the roadmixing and the thickness being processed, distinction is made between five categories in Table 1 below.

Table 1: roadmixing classification

Roadmixing category	Objective	Material being reprocessed	Thickness	Binder dose rate
CATEGORY I	Bituminous binder			
	Structural strengthening	Old foundation + dressings	10 to 15 cm	3 to 5% (residual binder)
CATEGORY II	Rehabilitation of surface courses	≥ 3/4 black	5 to 12 cm	1 to 3% (residual binder)
CATEGORY III		100% black	5 to 12 cm	up to 2% (residual binder)
CATEGORY IV	Cementitious binder			
	Structural strengthening	All or part of old pavement	20 to 30 cm	3 to 6 %
CATEGORY V	Composite binder[1]			
	Structural strengthening or rehabilitation of surface courses	Old foundation or surfacings	10 to 30 cm	3 to 7 %

[1] *Composite binder: mix of bitumen emulsion or foam and cementitious binder*

Pavement structures

Roadmixing categories I, IV and V are intended to resolve a structural problem with the old pavement. A conventional production sequence (Figure 1) involves roadmixing materials over all or part of the old pavement, possibly adding aggregate, and recovering the new structure with new surfacing.

Roadmixing categories II, III or V are normally chosen to resolve a surfacing problem. A conventional sequence is *in situ* roadmixing of all or part of the old pavement surface (Figure 2), possibly adding aggregate, and recovering the roadmix structure with a new surface course.

Studies

The pavement is studied in advance to determine the technical and economic feasibility of the roadmixing solution.

The studies aim to assess the characteristics of materials being processed in order to propose roadmixing of type and dimension suitable for the site in question.

The roadmixing guide distinguishes between two study levels depending on the traffic:

• traffic ≤ T3: work defined without in-depth diagnostic study;

• traffic > T3: work with in-depth diagnostic study and definition of work solutions.

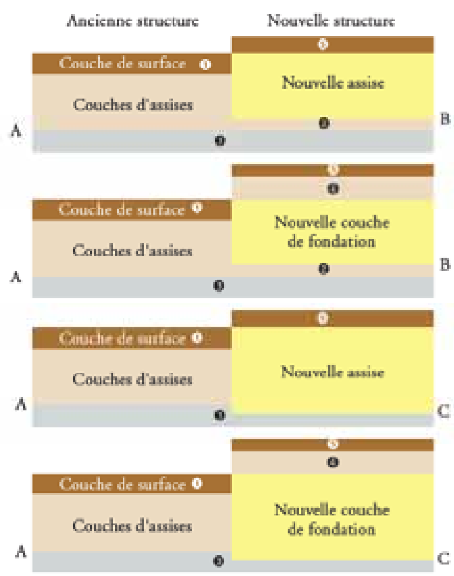

Figure 1 : exemple d'un retraitement classique pour résoudre un défaut structurel

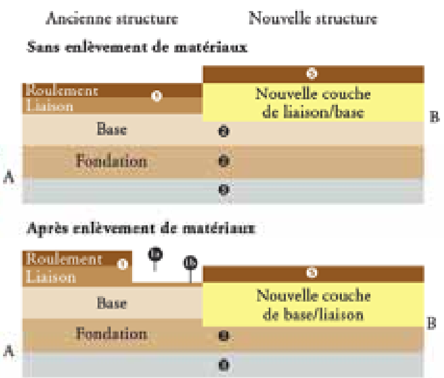

Figure 2 : exemple d'un retraitement classique pour résoudre un problème de surface

Couche(s) de surface bitumineuse(s).
Partie de l'ancienne structure enlevée.
Partie de(s) couche(s) de surface conservée(s).
Partie de l'ancienne assise conservée.
Sol support (couche de forme ou partie supérieure de terrassement).
Nouvelle couche de base. / *Nouvelle(s) couche(s) de surface.* } *Matériaux rapportés*
Nouvelle couche obtenue par retraitement en place
A : Ancienne plate-forme.
B : Interface ancienne et nouvelle assise.
C : Nouvelle plate-forme.

Figure 1	Figure 1
exemple d'un retraitement classique pour résoudre un défaut structurel	sample conventional roadmixing to resolve a structural defect
Ancienne structure	Old structure
Nouvelle structure	New structure
Couche de surface	Surfacing
Couches d'assises	Road foundations
Nouvelle couche de fondation	New foundation course
Nouvelle assise	New road foundation
Figure 2	Figure 2
exemple d'un retraitement classique pour résoudre un problème de surface	sample conventional roadmixing to resolve a surface problem
Sans enlèvement de matériaux	Without removing materials
Roulement	Surface

Liaison	Binder course
Base	Base
Fondation	Foundation
Après enlèvement de matériaux	After removing material
Nouvelle couche de base/liaison	New binder/base course
Couche(s) de surface bitumineuse(s)	Asphalt surfacing(s)
Partie de l'ancienne structure enlevée	Part of old structure removed
Partie de(s) couche(s) de surface conservée(s)	Part of surfacing(s) retained
Partie de l'ancienne assise conservée	Part of old foundation removed
Sol support (couche de forme ou partie supérieure de terrassement)	Subgrade (capping layer or upper earthworks section)
Nouvelle couche de base	New base layer
Nouvelle(s) couche(s) de surface	New surfacing(s)
Matériaux rapportés	Brought-in materials
Nouvelle couche obtenue par retraitement en place	New course from *in situ* roadmixing
Ancienne plate-forme	Old platform
Interface ancienne et nouvelle assise	Old interface and new foundation
Nouvelle plate-forme	New platform

In any event, a minimum pavement survey is essential. The success of the project will depend on the quality of this survey. It must include:

• investigating the pavement history;

• test boring the geometry of the natural deposits to be processed (cross section);

• sampling materials to be processed for identification;

• estimating the subgrade bearing capacity;

• assessing the preparatory work (drainage) and site restrictions (purges, regulating, buried networks, curb boxes, etc.).

Roadmixing and equipment quality levels

If technical feasibility is confirmed by the natural deposit survey and a laboratory study, the roadmixing solution can be adopted.

Roadmixing quality level R1 or R2 is defined by the construction manager based on several criteria:

1. the function of the new foundation and the traffic class
   R1 for base layers with traffic > T3
   R2 for all-traffic road foundations or base layers with traffic ≤ T3,

2. the quality of the natural deposit in the old pavement,

3. the performances of equipment being used to obtain the desired quality level (fragmentation/mixing equipment, spreading equipment, compacting equipment).

Spreading and roadmixing equipment

In sections 1 to 3 of the technical guide, the performances of the spreading and roadmixing equipment are graded 1 to 3 (3 being the highest mark) against the following criteria:

• the criteria adopted are for the fragmentation and mixing equipment:

H - mix Homogenization quality (material + binder);

T - control of Thickness of the pavement roadmixing;

P - the available Power to break up the old pavement;

I - the means of Injecting water into the mixing system;

B - accuracy of Binder dose rate when this is incorporated during mixing;

• the criteria adopted for the spreading materials:

L - Longitudinal spreading homogeneity;

T - Transverse spreading homogeneity;

V - the possibility of Varying the spreading width.

Tables in each technical work book indicate the minimum grades to obtain roadmixing quality R1 or R2.

Compacting equipment

Reference will be made to the indications given in the guide to *in situ* cold roadmixing of old pavements.

For roadmixing with a cementitious or composite binder, quality R1 requires compacting quality q_1 (the highest densification level) for base layers with traffic > T3 and q_2 for base layers with traffic ≤ T3. Quality R2 permitted for base layers with traffic ≤ T3 thus requires compacting quality q_1.

For all-traffic road foundations, quality R2 is acceptable. It requires a minimum compacting quality of q_2.

For cold roadmixing with bituminous binders, the target is an average void percentage of less than or equal to 20%.

Inspections

The quality of an *in situ* cold roadmixing site depends widely on the performance of materials used and inspections are justified to monitor this. Similarly, all the technical guides list the fundamental, specific inspections of materials, implementation, compacting, etc.

- inspections are spread out in line with the phasing of the work: before, during and after the work;
- the size of a construction site dictates the number of inspections;
- for sites over 50,000 m^2, a suitability test is necessary to check the control of the roadmixing quality.

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Plant cold roadmixing

Introduction

This chapter presents a synopsis of plant cold-mix techniques for materials from pavement demolition and/or deconstruction, with or without the addition of cementitious, pozzolanic or bituminous binders, or of correcting materials. Adding bitumen emulsion or foam binders is also a possibility.

Origin of the natural deposits

There is a tremendous variation in quality of the materials present depending on the classification of constituents and traffic classes (standards NF 98-113, 116 to 119, 120, 122 to 124 and 128).

Materials are sorted on the site during *deconstruction* into their various types: hydrocarbon, cementitious, pozzolanic or natural. They can be milled materials, crusts, plates or powdery materials.

In situ demolition, with no sorting, produces a mix of cementitious, pozzolanic, hydrocarbon and natural materials. They can be crusts, plates or powdery materials.

Original products must not contain either asbestos or carbon chemistry or other polluting products.

Equipment used

There are two main types of equipment used to demolish or deconstruct existing pavements:
- "milling tools" which produce an immediately-usable material;
- shovels and rock-breakers, which produce crusts and plates; these have to go through a crushing and sieving process to obtain a usable material.

The material crushing and sieving process can vary in sophistication and thus produce materials of variable particle size and quality:
- primary crushing without sieving: graded aggregates 0/63;
- primary crushing with sieving and recycling: graded aggregates 0/31.5 , 0/20 and 0/14;
- primary crushing, sieving, secondary crushing and sieving: aggregates 0/6 and 6/20 and graded aggregates 0/31.5, 0/20 and 0/14.

Table 1

Graded aggregate category	GR2	GR3	GR4
Grading	0/D, D ≤ 31.5	0/D, D ≤ 20	0/D, D ≤ 20
Hardness	LA ≤ 45 MDE ≤ 45 LA+MDE ≤ 80 i.e. E	LA ≤ 40 MDE ≤ 35 LA+MDE ≤ 65 i.e. E+	LA ≤ 35 MDE ≤ 30 LA+MDE ≤ 55 i.e. D
Cleanliness	ES ≥ 50 or MB(1) ≤ 2.5 i.e. b	ES ≥ 50 or MB ≤ 2.5 i.e. b	ES ≥ 50 or MB ≤ 2.5 i.e. b

Characteristics of materials for plant recycling

Materials produced by milling, crushing and sieving are by nature very varied:
- homogeneity: each category is identified by bituminous or cementitious or pozzolanic or natural materials. The main difficulty is in identifying the various origins;
- heterogeneity: product sorting has not been possible and is therefore a mix of bituminous, cementitious, pozzolanic and natural materials. This adds to the difficulty in identifying the various origins.

Aggregates from several origins can be accepted subject to preliminary conclusive studies and tests on all specifications in standards.

Non-reconstituted graded aggregates processed with cementitious binders

These materials must comply with standard NF EN 13-043, with a sulfate content defined in standard P 18-581 (Table 1):
- average value = 0.6
- specified upper value = 0.7
- maximum value = 0.8

Reconstituted graded aggregates processed with cementitious binders

Sands must have cleanliness b and sulfate content as defined in Table 1.

Chippings must be type E, E+ or D.

Manufacturing plant

The manufacturing plant will be level 1 or 2.

Use of manufactured products

1/ For non-reconstituted graded aggregates processed with cementitious binders (Table 2).

2/ For reconstituted graded aggregates processed with cementitious binders (Table 3).

Preliminary studies

In chronological order, these studies include:
- identification of recycled aggregates prior to plant processing
- development of finished product formulation.

Table 2

Graded aggregate category	Foundation	Base	Other
GR2	≤ T3+	≤ T4	
GR3	≤ T2+ T1+ (1)	≤ T4 T3+ (1)	Compliance with mandatory grading envelope for GNT type A under standard NF P 98-129
GR4	≤ T1+	≤ T3+ T2+ (1)	

Table 3

	Foundation	Base
Chippings E	≤ T2+	≤ T4
Chippings E+	≤ T1+ T0 (1)	≤ T2+ T1+ (1)
Chippings D	All traffic	≤ T1+

(1) *This use can only be envisaged for experimental sites*

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In situ hot-mix recycling

Technological advances in *in situ* roadmixing of asphalt use a degraded layer to the greatest advantage after heating by making it re-usable without removing or adding material or by additions, with total or partial removal of material, to achieve the desired material once laid.

These techniques, known as *hot remixing, hot reforming* or *repaving*, are grouped under the single term of hot remixing or *in situ* hot recycling. This includes all bituminous asphalt recycling on the site by heating, pavement scarification, mixing with or without additions (aggregates with or without pre-coating, binders, additives, etc.) and re-laying the mix.

In operation, this technique may give off vapors and fumes and requires particular attention and warning signs to avoid any risk of accidents.

Principles and equipment

The process for *in situ* roadmixing of asphalt, be it slipped from its substrate, cracked or rutted, is as follows:

• *raise* and maintain *the temperature of the bituminous pavement* prior to breaking its cohesion using a set of pre-heaters fitted with large areas of radiating panels. The minimum heating surface is 175 m² to 200 m², which must be increased to 250 and even 300 m² depending on the thickness to be treated and weather conditions.

The heating unit advances at between 2 and 6 m/min and must be adjusted to the prevailing conditions to maintain a temperature of 80°C at the interface with the upper substrate;

• *break the cohesion of the asphalt and, depending on the material*, to windrow it in the machine axis or hold it in place;

• *mix* the old asphalt with the necessary correcting agents and additions;

• *spread out to the desired profile* the mix obtained using a screed or paver;

• *compact* using conventional equipment suitable for the processed thickness.

The equipment used on the French market is basically distinguished by its mixing system.

Scope

This technique is used to restore surface courses. It applies to clearly-dimensioned pavements in the following fields:

• *rebond a thick surface course to its substrate.* If the course is too thick, it is first milled so as to roadmix the thickness compatible with the machine's recycling capability, to reinstate the interface and upper part of the asphalt substrate (1 to 2 cm);

• *obliterate cracking caused* by ageing of the binder in the surface courses of road and airport pavements, by regenerating the binder characteristics;

• *restore the transverse evenness of a pavement* rutted by creep, by incorporating into the mix, as appropriate;
- pre-coated chippings;
- bitumen to offset the burning and drop in binder content due to the addition of chippings;
- other additives to be defined during the formulation study;

• *recycle* thin asphalt or porous asphalt *surface courses*, with the addition of polymer binder to reinstate the characteristics of the original asphalt;

• *obtain* an anti-cracking course *by adding a bituminous mortar* rich in sand and polymer binder and possibly fibers and hot homogenization over 2 cm with the existing asphalt. This applies to semi-rigid pavements to be covered with a new, very thin asphalt surface course.

The technological limitations of the process relate to:
- the heating unit capacity;
- operation time;
- thickness of the course to be processed;
- pavement geometry (curve radii too tight);
- meteorological conditions (rain, cold, strong winds);
- the types of material found in the asphalt; the application of this technique may be inadvisable if the bitumen has aged too much.

Studies

Whatever the problem, a preliminary site survey is necessary. For the success of this survey, the compounder has a duty to compile information on the material to be processed (formulae, material characteristics and inspections), to break down the homogeneous composition zones and highlight unusual points.

The materials on the site *are characterized* from samples taken by core sampling or by plates cut from the asphalt, in the lane axis if rutting is involved.

Based on the characteristics of the sampled materials, *the processing study* determines the roadmixing parameters:
- depth;
- type and proportion of additions.

The aim of the *formulation testing* is to characterize the product after recycling by checking that the specifications have been met correctly based on a few tests.

It is not always necessary to process the entire pavement if rutting is involved, simply a single direction or the slow lane, for example.

If the problem is cracking, it is possible, indeed necessary, to apply a new surface course over and above the asphalt processing.

Laying conditions and inspections

Daily performances vary between 5,000 to 10,000 m², the unit advances at between 2 and 6 m/min, depending on the thickness processed (not recommended beyond 7 cm) and any water present in the course being processed (interface).

Useful widths can be from 2.50 to 4 m, when the company has adjustable pre-heaters, cohesion breakers and extensible paver screeds.

Operating inspections focus on checking:
- the roadmixing thickness;
- the interface temperatures (higher than 80°C) and the recycled asphalt behind the cohesion breaker;
- aggregate, binder and addition dose rates;
- forward speed;
- the finished product must be checked for compliance in the composition, bonding to the substrate (core samples) and compaction efficiency (% voids);
- the surface characteristics: longitudinal evenness and macrotexture must be checked as for all surface courses.

Expected performances

The surfaces processed over the last fifteen or so years can be used for a first assessment of this technique, which is fairly highly rated among the range of techniques made available to managers by the companies.

This technique is normally applied to obliterate or correct surface defects: slippage, cracking and creep. Although the result of the formulation study is a material with specifications complying with the objectives, this technique has a few sensitive points:

• *in terms of heat*: the mix temperatures rarely exceed 130°C and also rarely higher than 100°C between 6 and 7 cm. It is therefore unrealistic to roadmix thicknesses of more than 7 cm, particularly if two courses have to be rebonded.

To obtain the recommended temperatures (130°C for the mix), it is preferable to increase the number of pre-heaters rather than reduce the speed of the machine, to avoid burning and overaging;

• *in terms of homogeneity*, regardless of the mixing method, samples taken behind the pavers reveal:
- dispersions of binder contents higher than noted on new asphalts normally linked to the heterogeneity of the asphalt being recycled and operating conditions;
- no significant changes in grading apart from the higher percentage of fines than the original asphalt.

Course rebonding is normally effective. It can however by altered by the presence of water at the interface, the meteorological conditions during the work, poor assessment of the interface and sometimes insufficient heating capacity;

The surface characteristics measured when a hot-recycled asphalt is not covered, show that:
- the macrotextures taken from the recycled medium coarse asphalt are the same as for a new asphalt of the same type, but with higher dispersions,
- the longitudinal evenness complies overall with the specifications.

A key point in this technique is the study phase, used to define additions required and indirectly to improve control of the dose rate variations of the various constituents.

Hot remixing more than any other technique requires well-trained laying teams and suitable inspections: grading, binder content, bitumen characteristics, void percentages and surface characteristics.

Particular attention must be paid to start-up areas, potential sources of segregation and risk of stripping.

Future of the technique

In situ hot remixing is one way of saving on raw materials - aggregate and bitumen. By re-using "*in situ*" the entire thickness of the course being renewed, it contributes indirectly to environmental preservation. The economic conditions and technical progress made over the last ten years show that this type of technique is potentially of interest to road managers, inasmuch as the constant improvement of materials should produce the homogeneity sought.

Although its niche use is recycling thick, medium coarse asphalt courses (6 to 7 cm), company experiments are being finalized to widen its scope (thin and porous asphalt recycling) and are the subject of innovation charters.

Hot remixing is part of an overall road network maintenance strategy of the GLAT type (major regional development links) or motorways under concession; it can increase the service life of surface courses (this may be doubled) at an advantageous cost and preserve the environment.

It can only be envisaged to process large surface areas (normally more than 50,000 m²), given the daily performances which can reach 8 to 10,000 m²/day for 4 m width under favorable meteorological conditions.

Economically, a surface course showing serious disorders and requiring substantial maintenance or repair (overlay or milling and replacement) can, after hot remixing, can be deferred for several years, for a cost equivalent to very thin asphalt surfacing, depending on the areas to be processed.

Motorway companies are most appreciative of its operating flexibility (construction sites operated at night with installation and rapid removal of material) and the technique is currently used in the main to correct rutted slow lanes.

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Plant hot-mix recycling

Origin and state of asphalt for recycling

The plant hot-mix recycling of asphalt discussed in this document only involves aggregate mixes bound with bitumen. They come from *in situ* dismantling of old pavements, total or partial dismantling (trenches and purges) or from discarded asphalt manufacture. This involves surface, binder, base and foundation courses. These materials are defined under the term of asphalt aggregates in standard NF P 98-149. Experimental standard XP P 98-135 deals with characterizing asphalt aggregates for plant hot-mix recycling.

The dismantling methods normally used are:

- milling, which produces a fragmented material with an apparent D lower than or equal to 31.5 mm;
- percussion drill, mechanical shovel and loader, which produce blocks of a few kilos to a hundred kilos and an area of up to one square meter.

Bituminous materials for recycling are classified into three major categories according to their origin (their homogeneity) and their storage:

- mixes with a single origin;
- mixes with miscellaneous origins stored individually;
- mixes with miscellaneous origins.

Single-origin bituminous mixes come typically from major construction sites and are obtained by milling. They have a certain homogeneity and their original composition is often known. Under suitable milling conditions, these properly-identified asphalt aggregates are directly ready to use immediately after milling, or after a very short storage period if they have to be stored.

The bituminous mixes of miscellaneous origins, stored individually, often come from medium-sized construction sites. They have a certain homogeneity but their original composition is not always known. They are procured most of the time as milled materials, otherwise they have to be crushed and sieved.

Bituminous mixes of miscellaneous origins come from small manufacture reject sites and are procured as milled material or as blocks. Restricted quantities are stockpiled without differentiation. They must be fragmented by crushing and sieving before use, to reduce them to asphalt aggregates with a maximum dimension of 31.5 mm. These asphalt aggregates have a very heterogeneous make-up. This currently represents the bulk of bituminous materials for recycling seen in the coating plant areas.

Conditioning

After milling and (or) crushing and sieving, the asphalt aggregates must comply with experimental asphalt aggregate standard XP P 98-135. The apparent asphalt aggregate dimension (in any event ≤ 31.5 mm) depends on the material being broken up correctly as it passes through the plant.

The milling operation (forward speed amongst other things) can condition the "D" and the fines content of the milled material. The dimension of the aggregate portion of the asphalt aggregates must be compatible with the particle size of the final mix.

Storing and re-use take place with a view to encouraging homogeneity of asphalt aggregates, which is essential to ensure a representative study, regular manufacture and constant performance.

Use of asphalt aggregates in the formulation of hot bituminous materials

Standards published in 1999 and subsequently allow the use of a certain percentage of aggregates as show in Table 1.

Article 5.4 of these various standards indicates that, in the absence of any other indications written into the contract, the business may include the percentage of aggregates as show in Table 1.

However, whatever type of bituminous mix is used in the asphalt aggregates, this must comply with the corresponding product standard. This implies that the mechanical performances and constituents (including the asphalt aggregates) comply with the indications of the standard. It may therefore be necessary to characterize the asphalt aggregates according to the percentage used.

Some product standards, which have not been revised recently (for example, standard 98-136 on asphalt concrete for flexible pavements), give no information on whether or not aggregates may be used. By extension, the flexible asphalts can accept the same rates as for the medium coarse asphalt and with the same uses.

Standards 98-134 on porous asphalts and 98-137 on very thin asphalts indicate in this same Article 5.4 that the use of aggregates is not covered in the current standard. This means that traditionally aggregates have not been incorporated into these formulae. On the other hand, for a specific contract (recycling old porous asphalt, for example), these aggregates may be re-used, but in this case the desired technical specifications must be written into the contract.

Standard XP P 98-135 "characterization of asphalt aggregates for plant hot-mix recycling" states how these materials are characterized and indicates the conditions for use in its informative appendix. This characterization is based on the binder content and on the binder and aggregate characteristics.

In general terms, the clearer the aggregate identification, the more it can be incorporated in the asphalt. Table 2 below summarizes and illustrates the various possibilities based on the knowledge of the asphalt aggregates.

Refer to the indications in the standard for the intermediate recycling rates.

Equipment suitability for aggregate recycling

Material technology plays a major role in the final quality of the asphalt and any atmospheric pollution. A constant-weight feeder with a low storage capacity silo proportions the asphalt aggregates and ensures the correct product flow (almost vertical walls, wide extraction conveyor and anti-clogging coating). The automatic manufacturing plant control must take into account the specific features of the asphalt aggregates (old binder content and, depending on where these asphalt aggregates are introduced, dephasing to natural aggregates).

Recycling suitability of bituminous mixing plants relates mainly to the type of heat exchange that governs the manufacturing process. Based on the material type and the principle of introducing asphalt aggregates, possible recycling rates are summarized in Table 3.

The limiting factors indicated take the asphalt aggregates to be totally homogenous.

To summarize

• if the asphalt aggregates are not characterized or if the characterization results in non-specified parameters, recycling is not permitted for a surface course. It can be permitted with a rate of 10% in a binder or foundation course.

• to be able to recycle asphalt aggregates in a surface course, these aggregates have to come from a surface course or have a binder content of 5.5%, or the asphalt aggregate characteristics must be in line with the surface course usage.

• 40% recycling can be envisaged in a surface, binder or foundation course if the various characterization parameters comply with the values in Table 2.

Table 1

Standard number	Product	Permitted asphalt aggregate percentage
NF P 98-130	Medium coarse asphalt	10% in surface course and 20% in binder course
NF P 98-131	Aeronautical asphalt	10% in surface course and 20% in binder course
NF P 98-141	High-modulus asphalt	10% in surface course and 20% in binder course
NF P 98-138	Bitumen-bound graded aggregate	40%
NF P 98-140	High-modulus bituminous mixture	40%
NF P 98-132	Thin asphalt type C	10% in surface course

Table 2

<table>
<tr><th rowspan="4">Use in pavement</th><th colspan="3">Type of course</th><th colspan="6">Re-use rate</th></tr>
<tr><td colspan="3">Surface course</td><td>0</td><td>0</td><td colspan="2">10% under condition(1)</td><td>30%</td><td>40%</td></tr>
<tr><td colspan="3">Surface course</td><td rowspan="2">10%</td><td rowspan="2">20%</td><td colspan="2" rowspan="2">30%</td><td colspan="2" rowspan="2">40%</td></tr>
<tr><td colspan="3">Foundation course</td></tr>
<tr><td rowspan="10">Information on aggregate components</td><td rowspan="5">Bituminous binder</td><td>Binder content</td><td>Range</td><td>Not specified</td><td colspan="2">≤ 2%</td><td colspan="3">≤ 1%</td></tr>
<tr><td rowspan="4">Residual characteristics (penetrability or binder softening point (TBA))</td><td>Penetrability 1/10 mm</td><td colspan="2" rowspan="4">Not specified</td><td>≥ 5</td><td colspan="3">≥ 5</td></tr>
<tr><td>Penetrability range</td><td>-</td><td colspan="3">≤ 15</td></tr>
<tr><td>TBA °C</td><td>≤77</td><td colspan="3">≤77</td></tr>
<tr><td>TBA range</td><td>-</td><td colspan="3">≤8</td></tr>
<tr><td rowspan="5">Aggregates</td><td rowspan="3">Grading</td><td>Passing fraction slackened</td><td colspan="2" rowspan="3">Not specified</td><td colspan="2">80 to 99≤ 15</td><td colspan="2">85 to 99≤ 10</td></tr>
<tr><td>Range of passing fraction 2 mm</td><td colspan="2">≤ 20</td><td colspan="2">≤ 15</td></tr>
<tr><td>Range of passing fraction at 0.08mm</td><td colspan="2">≤ 6</td><td colspan="2">≤ 4</td></tr>
<tr><td rowspan="2">Intrinsic characteristics</td><td>Category</td><td colspan="3" rowspan="2">Not specified</td><td colspan="3">B</td></tr>
<tr><td>Angularity</td><td colspan="3">RC2</td></tr>
</table>

(1) If average binder content exceeds 5.5%, the asphalt is considered to be an asphalt concrete with the choice of aggregates based on minimum criteria close to those sought for the recycled material.

Table 3

Plant type	Reintroduction of asphalt aggregates	Heat transfer	Max. recommended rates	Limiting factors
Discontinuous	Hot-mix boot pan	Conduction	15%	Water vapor evacuation and clogging
Discontinuous	Dryer recycler	Conduction	25%	Hot-mix pan clogging
Discontinuous	Specific dryer for asphalt aggregates	Convection + conduction	50%	Environment
Unidirectional flow dryer drum mixer (TSE)	Mid drum section	Convection + conduction	30%	Sleeve filter clogging
Counter flow TSE	Except gaseous flow	Conduction	50%	Aggregate overheating, drum temperature, gas temperature

Organization of preliminary studies

Asphalt mixture compliance (including those manufactured with asphalt aggregates) with product standards is nowadays mandatory outside experimental sites.

Preliminary studies, upstream of the site, are used to characterize the proposed asphalt mixture and to provide the manufacturing plant with the composition to be followed based on the recycling rate.

Apart from the physical aspect, the recycling rate is dictated by the following elements:

• re-use of all or part of the available asphalt aggregates;

• characteristics of these asphalt aggregates;

• destination of the recycled mixture.

Whatever the context, these preliminary studies always include, in chronological order:

• component identification;

• formula development;

• formulation testing.

Two cases must however be considered which dictate the content of the previous points.

General case

Component identification

• quantification of asphalt aggregate stocks;

• characterization of natural aggregates (NF EN 13-043);

• characterization of asphalt aggregates (XP P 98-135):
 - grading prior to stripping of binder;
 - composition after stripping of binder:
   - grading (particle size homogeneity);
   - binder content (average value and range);
 - intrinsic characteristics and angularity of recycled aggregates;
 - old binder: minimum penetrability, maximum binder softening point and range.

Formula development

- determining the various constituent percentages:
  - conventional weighting percentages for the formulation study;
  - weighting percentages as instructions for the mixing plant;
- choice of added binder (classic or regenerated);
- characterization of added binder;
- choice of recycling rates.

Formulation testing

The aim of formulation testing is to establish for the composition determined during the development stage that the characteristics of the manufactured mixture comply with the product standard for the level required and the chosen category.

Special case when it is impossible to characterize asphalt aggregates

When the stock of asphalt aggregates is made up of very heterogeneous bituminous materials (nature and quantity of recycled aggregates and bitumens), representative sampling cannot be used to characterize these asphalt aggregates and their variation levels, nor to develop them from variants taking the variations into account. This results in the availability of asphalt aggregates with characteristics marked as NS (not specified) in the draft standard XP P 98-135. In this case, the recycling rate limitation minimizes the impact of the asphalt aggregate heterogeneity and the formulation method is adapted as follows:

Component identification

• characterization of natural aggregates (NF EN 13-043);

• statement of average characteristics of asphalt aggregates:
- grading;
- binder content;
- true aggregate density.

The asphalt aggregate characteristics considered are stated values acting as specified values. They are taken from previous data (traceability of old construction sites, average representative values of local supplies) and are not the result of random analyses of temporary stocks.

Formula development

The recycling rates are fixed at 10% for the binder courses and 15% for the foundation courses.

In the specific context of limiting the recycling rate to 10%, surface courses that are theoretically subject to understanding explicitly the minimum characteristics of the recycled aggregates can be envisaged if one of the following conditions is met:

• the asphalt aggregates come from a surface course;

• documentary proof that the asphalt aggregates are at least category C is produced;

• the average binder content after conditioning and homogenization of the asphalt aggregates is higher than 5.5%.

The mixture compounder is free to choose the means of obtaining the performances stipulated by the customer. It is proposed to move towards the approach, depending on circumstances, of:

• starting with an existing, verified formulation with natural aggregates. This should not be at specification limits. This formula will thus serve as a basis and can be modified to incorporate asphalt aggregates;

• starting with an existing, verified formulation, using asphalt aggregates;

• in all cases, the recycling mixture formula is developed based on values obtained by standardized tests on natural aggregates and stated values for the asphalt aggregates.

Formulation testing

Experiments show that for a stock of asphalt aggregates from miscellaneous origins conditioned in advance (crushing-sieving) and for the recycling rates quoted to develop the formula, the risk of a lack of representativeness of an asphalt aggregate sample does not alter the mechanical properties of the recycling mixtures in low recycling rates.
Checks on manufacture incorporating asphalt aggregates confirm, for the recycling rate in question, that the recycling mixture does in fact have the characteristics provided for in the product standard corresponding to the level required and the chosen category. Note that "surface course" product standards include a requirement on the macrotexture which applies naturally to the mixture manufactured with asphalt aggregates.

Terminology

Asphalt aggregates (NF P 98-149)	Granular material from milling or demolition of bituminous asphalt, an input in the composition of recycling mixtures.
Recycling mixture (NF P 98-149)	Hot- or cold-mix asphalt totally or partially including recycled materials (asphalt aggregates from milling - milled materials - or from the demolition of existing asphalt), whether manufactured *in situ* or in a plant.
Recycled aggregates (NF EN 13-043)	All particles between 0 and 125 mm. The aggregates are called recycled when they come from structural demolition or are re-used.
Natural aggregates (NF EN 13-043)	All particles between 0 and 125 mm. The aggregates are called natural when they come from loose or solid rock and undergo mechanical processing only.
Mix composition (NF P 98-149)	Weighting proportion of components in a mix (grading fraction, binder, any additives) with indication of their type and origin.
Formula or nominal or target or theoretical formula (of a mix) (NF P 98-149)	Description of an identified mix which has undergone formulation testing. The formula includes the component weight composition and origin, a grading curve and the results of formulation testing on a representative sample.
Recycling rate (NF P 98-149)	Proportional weight of the recycled asphalt aggregates in the recycled mixture.
Grading (NF P 98-149)	Dimensional distribution of particles in an aggregate or asphalt aggregate.

Grading curve (NF P 98-149)	Graphical representation of the grading.
Bitumen (NF P 98-149)	Highly-viscous or almost solid material, virtually non-volatile, adhesive and water-resistant, produced from crude oil or found in natural bitumen, which is totally soluble in toluene, or almost.
Hydrocarbon binder (NF P 98-149)	Generic term describing an adhesive material containing bitumen, tar or both.
Binder content (NF P 98-149)	Ratio between the weight of hydrocarbon binder and the weight of dry aggregates, expressed as exterior percentage.
Exterior percentage (NF P 98-149)	Percentage of binder as a ratio of the dry aggregate weight or adhesion agent as a ratio of the binder weight.
Formula development (NF P 98-149)	Procedure whereby the composition of a formula is adjusted with minimum testing so that it complies with the requirements of formulation testing and any other requirements.
Formulation testing (NF P 98-149)	Pre-defined sequence of laboratory tests on a given composition mix used to determine characteristics meeting defined requirements.
Formulation checking (NF P 98-149)	Testing made up of one test or a series of tests run on a formula with components of the same origin as the formula being checked, characterized in particular by a grading curve and binder content.

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The purpose of this document is to list the various existing practices for the re-use of pavement materials from surfacings and foundation courses based on where it is intended to use them in the future. It is therefore a response to the need to construct and maintain pavements under a concern for sustainable economy in compliance with increasingly insistent environmental constraints.

Four techniques will be examined:

- *in situ* cold roadmixing,
- plant cold roadmixing,
- *in situ* hot-mix recycling,
- plant hot-mix recycling.

The first two involve road foundation materials (materials processed with or without a cementitious binder) and surfacing materials.

The second two involve asphalt materials for surfacings and base layers.

Each technique is presented with its advantages, scope and use limitations.

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