Deliverable 8

Methodology and rules for design and rehabilitation of road pavement using new hot and cold recycled asphalt mixtures

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3. Compaction

4. Structural contribution
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   4.2 Mechanical analysis
A. Recommendations and improvements in the design, production and reliability analysis of rehabilitated asphalt pavements using cold recycled asphalt mixtures

1. MIXTURE DESIGN

1.1 Characterisation of the milled material

In order to be able to optimally develop and adapt the emulsions that are going to be used in cold recycling process, it is necessary to carry out the following tests:

- Grading of the milled material without having extracted the old binder. This will be the material directly used in the cold recycling process. It should be taken into account that excessively large sizes of the milling will negatively influence the final behaviour of the recycled mixture. Therefore, besides the grading of RA is a needed input for cold recycling, it can also be considered as a tool that can help to know the operation conditions of the milling machine and to adjust them, whenever possible. Also the specific surface of the milled material can be taken into account to better adapt the percentage of emulsion to be used.

- Characterisation of the old binder; considering mainly the binder content, its penetration and softening point (R&B).

The grading of the milled material once the binder extraction has been done, although this result can not be considered as an input for cold recycling process, is an useful information to always take into account.

1.2 Selection of the emulsion

The emulsion selection should be done by evaluating the emulsion behaviour together with the milled material and therefore, it is necessary to verify at the same time, the minimum percentage of added water needed as well as the percentage of emulsion required. Only in that way, it will be possible to evaluate the following:

- Aggregates coating test: a minimum of 90% of covered surfaces should be required (test procedure described in Deliverable 1).

- Active adhesivity: a minimum of 75% of covered surfaces should be required (test procedure described in Deliverable 1)

- Passive adhesivity: a minimum of 75% of covered surfaces should be required (test procedure described in Deliverable 1)

- Workability

Once, an estimation of the behaviour of the cold recycled mixture has been performed through the above mentioned tests, a further evaluation and optimisation of the cold mixture should be done in order to definitely establish the formula as well as the final behaviour of the mixture:

- Retained compressive strength test: minimum values of retained strength of 75% should be required.
• Indirect Tensile Test

1.3 Dosage of the mixture

The cold recycled mixtures design methodology is based on the indirect tensile test. First of all, it is determined the optimum moisture content of compaction of the milled material by means of Modified Proctor Test, which is a reference value for the compaction fluids (water plus emulsion). Starting from this value, the water and the emulsion contents are modified in order to obtain a proper coating and a high cohesion of the mixture. That way, it is determined the coating quality evolution and the indirect tensile strength evolution for different emulsion and water contents. The minimum number of specimen tested for each emulsion and water content, and for each testing condition is of 3 specimen

Specimen manufacture

Two procedures have been developed for the specimen manufacture, one, using a press for the manufacturing of the specimens by applying a static compaction, and the other, compacting with the gyratory machine.

Static compaction

The static compaction consists on manufacturing a cylindrical specimen of 101.6 mm of diameter and 5-6 cm of height, by pouring the material into a metallic mould of 101.6 mm of diameter. A compaction load is applied by a piston, with a deformation speed of 1.27 mm/min until the compaction load achieves 60 kN, which must be held up during 2 minutes.

Gyratory compaction

The gyratory compaction consists on applying 300 revolutions with a gyratory compactor. The pressure must be of 0.6 MPa and the angle of 1.25°. The specimens obtained, again with a 101.6 mm diameter and a 5-6 cm of height, have also similar densities and resistance to the cores extracted from the field.

The Swedish practise developed is to use 150 mm perforated molds, a pressure of MPa and an angle of 2°. The number of revolutions is limited to 35. The perforated moulds allow water to be released during the compaction process.

Curing process

Once the specimens are manufactured by using one of the methods explained above, they are removed from the moulds and they are brought about to an accelerated curing process, which takes place inside an oven at 60ºC during 3 days.

The Swedish practise is to cure in room temperature for one week and in a ventilated oven (40ºC) for one week.

Testing process

Dry test (conditioning of the specimen)

Once the specimens are cured, they are introduced in a chamber where temperature can be controlled. The specimens are inside the chamber at 5ºC during at least 4 hours in order that they reach the temperature homogeneously.

Testing after immersion (conditioning of the specimen)

In this case, the specimen will be introduced in water at 60ºC during 24 hours. Then, they will be air dried during 8-12 hours before placing them inside the temperature controlled chamber. As in the previous case they will rest in the chamber a minimum of 4 hours at 5ºC. Finally, they will be tested.
During the testing process, the load displacement speed (50.8 mm/min as Marshall speed test) must remain constant until the breaking of the laboratory sample. Both the load and the displacement are registered, and the indirect tensile strength or resistance is calculated by means of the following expression:

$$R_{TI} = \frac{(2 \cdot P)}{(h \cdot d)}$$

where,

$R_{TI}$, is the indirect tensile strength (in N.mm$^{-2}$, MPa),

$P$, is the breaking load (in N),

$h$, is the height of the specimen (in mm) and,

$d$, is the specimen diameter (in mm)

**Design criteria**

The emulsion content to be used will be the one which allows to achieve a minimum indirect tensile strength of 1.0 MPa. The test will be carried out at 5 ºC, determined on a specimen manufactured by static or gyratory compaction, after an accelerated curing process of 3 days in an oven at 60ºC. The minimum retained resistance (after water immersion during 1 day at 60ºC) is of 75%.
2. PRODUCTION

2.1 Enhanced milling drum and mixing chamber

The grading and mixing degree can be improved by changing the forward speed of the recycling machine, by changing the arrangement of the cutting tools on the milling drum and by changing the volume and exit area of the milling and mixing chamber on the recycling machine.

The improvements are:

- Extra „Paddles“ for improved mixing and transportation of the material being recycled
- Changed cutting tool arrangement
- Changing the internal shape of the milling and mixing chamber

The results are:

- approx. 60 % increase in advance speed
- improved grading
- improved material flow

2.2 Warming-up the material

A new heater system has been developed.

The new and old heater system of the Wirtgen HM 4500 was compared and tested.

The improvements are:

- new heater panels with combination of IR and fresh air heating

The results are:

- reduction in smoke emission
- 33 % saving in gas consumption
- improve binder coverage and compactability.
3. COMPACTION

The main recommendation one should consider when facing both cold recycling lay down and compaction of the mixture is to control the evolution of the mixture nuclear densities as long as the rollers pass properly over the mixture till the densities stabilize and get their maximum level.

The improvement is the new generation screed with vibration plates and tamper bar fitted on the Wirtgen 2200 CR.

The result are fewer roller passes after pre-compaction by the high compaction screed.

4. STRUCTURAL CONTRIBUTION

4.1 Deflection analysis

This chapter is going to be focused on cold recycling recommendations to evaluate the structural contribution due to the rehabilitation actions.

4.1.1. Structural evaluation of cold recycled tracks

The structural evaluation can be done by using NDT tests with a Falling Weight Deflectometer and by extracting road cores.

a) Tests and works carried out for road evaluation

Road Coring.

To obtain a representative number of road cores to know pavement layer thickness before and after the recycling actions. This information is being used as an input for back calculation methods.

Deflections measurements

To measure road deflections under 65 kN dynamic load with a FWD. Deflections have to be measured before and after the road rehabilitation. This data is going to be used for structural analysis.

As we are talking about cold recycling, tests after the recycling works must be done at least twice, after six and twelve months from the end of the rehabilitation works.

It is very important to know the moisture content of the granular layers, because it can cause variations on the measured deflections. To reach this goal, piezometers should be installed on road structure.

b) Road bearing capability evaluation

The structural evaluation has to be done through the central deflection and through back calculation methods.

b.1) Back calculation method

To estimate the dynamic modulus of pavement layers, deflections had to be analysed by using back calculations methods. As it consists on an iterative process, horizontal strains data measured by means of horizontal gauges installed underneath the recycled pavement layer, must be collected to perform forward calculations for mechanical parameters adjust purposes.
On the other hand, laboratory tests (Instant Resilient Modulus) had to be performed on road cores to compare laboratory and analytical results (Dynamic Modulus of Pavement Layer). An example can be seen in the figure below.

### b.2) Central deflection method

To check the variation of the total road structure strength, a central deflection analysis have to be done taking into account collected deflections before and after the road rehabilitation.

First of all, to compare both situations (the bearing capability before and after pavement recycling), the central deflection must be corrected because off the influence that moisture content has on granular layers.

A parameter that reflects local moisture variation has to be used. On the FWD, the farthest geophone measures displacements coming from the bottom part of the stressed area, caused by the dynamic load (coming from the subgrade). So if we compare in the same test point some subgrade displacements measured at different test date with several moisture conditions we can adjust them to the highest moisture content by calculating Chi parameter;
\[ Chi = \frac{d6(\text{wmax})}{d6(\text{wi})}, \text{ where } d6(\text{wmax}) \text{ is the farthest deflection with the highest moisture contents and } i \text{ is data collect date, measured at 1200 mm from the load point) } \]

And correcting the measured deflection;

Corrected deflection = \( \text{Chi* measured deflection} \)

With Chi we can corrected deflections measured at a dry day.

**4.1.2. Conclusions**

**Dynamic modulus**

We are expecting dynamic modulus of the cold recycling pavement layer to be about half of the dynamic modulus of conventional pavement layer. Cold material used to double its strength during the first year of live.

Dynamic modulus is not a long-term pavement behaviour parameter, so we cannot conclude about which is going to be its behaviour in the future. Because it is more flexible the cold pavement than conventional pavement, cold one could last more time due to its flexibility.

**Deflections**

Cold actions had diminished the total road structure deflection.

When we are comparing deflections before and after the rehabilitation works we have to correct the moisture effect on measured deflection.

**4.2 Mechanical analysis**

Numerical methods research partners propose a new methodology to analyse pavement’s behaviour under static and dynamic loads, based on the constitutive models developed.

- This methodology consists in a software code that calculates the material’s response under different loads, using as input the geometry of the multi-layered structure and mechanical parameters obtained from simple laboratory tests, like elastic Young modulus, Poisson ratio or yield stress for each material involved in the calculation process.

This constitutive values can be obtained from bibliographic references as well, for well known materials like granular layers, or applied loads like roller or pneumatic compactor.

- This constitutive parameters are used in the developed model based in the Finite Element Method, available for the end-users.

- The structural code offers as output the stress – strain distribution along de pavement structure, the deflections in the surface, the plastic strains in the pavement and the possibility of damage in the material, as well as the critical points in stresses or damage.
That leads us to a mechanical solution the user can study to take conclusions about the pavement’s behaviour. Once we have the simulation of the pavement’s behaviour the end-user can apply some quality control criteria to evaluate the response obtained, so as to change the material, its properties, or the geometry, layers’ thickness and so on.

According to these quality criteria the user can stop the design method if the quality parameters are acceptable, or repeat the design with the changes in the geometry or the material’s properties.

This methodology can be used as many times as necessary until an acceptable solution is reached.
Methodology and rules for asphalt pavements’ rehabilitation in road tracks

(CIMNE)

Geometry Definition

Material’s properties Definition

Calculation process
Finite Element Method
(Available for end-users)

Mechanical solution
Structural analysis
✓ Stress – Strain
✓ Displacements (Deflections)
✓ Plastic strains
✓ Damage

Redefinition

Quality control criteria

NO

YES

END of design process
B. Recommendations and improvements in the design, production and reliability analysis of rehabilitated asphalt pavements using hot recycled asphalt mixtures

1. MIXTURE DESIGN

1.1 Characterisation of the milled material

The characterization of the milling material is a crucial step to determine if the milling material is useful for hot bituminous mixes. The following characteristics are important:

- Detection of tar in RA. Severe limits are imposed in certain European countries, because of environmental and health reasons. In case tar is present, further use in hot bituminous mixes is excluded in these countries. Therefore, this is a first necessary check to be performed.
- Grading curve of the RA: this is an interesting information in order to prevent of having very large RA sizes. It can be considered also as a tool that can help to know the operation conditions of the milling machine and to adjust them, if possible.
- Grading curve of the RA once the binder extraction has been done: this is crucial for the later design of the mix. Also, the grading curve of the “clean” RA, is predominant for the type of mixes that can be produced with a given RA, especially in the case of use of high percentages of RA.
- Characteristics of the old binder present in the RA: content, penetration, Ring&Ball temperature and detection of modification by polymers

1.2 Selection of the new binder and new granular materials

The selection of the new binder should be based in the first place on the pen-rule of mixes of binders. For roads where high performance is required, special attention should go to the determination of the temperature susceptibility of the binder. For this purpose use is made of rheological measurements on the binders. The high temperature properties are determined by measurements by the dynamic shear rheometer at high temperature with determination of the parameters G*/sinδ or the zero shear viscosity are the most adequate parameters to be used as predictors for the rutting resistance of the binders. Together with the low temperature stiffness and the behaviour upon ageing, adequate binders have to be selected.

1.3 Dosage of the mixture

For the design of bituminous mixes with reclaimed asphalt the following mix design procedure can be followed. An analytical mix design is made by means of BRRC’s software Prado-Win. This phase requires that most of the characteristics about the reclaimed asphalt and the new materials gathered in steps 1 and 2 are introduced as input in the software. The analytical design makes it possible to get a good estimate of the design of the bituminous mix. It limits the number of trials to be made in the laboratory and hence is very time-saving and gains personnel. Fine tuning of the mix can subsequently be done as a result of simple laboratory tests, such as gyratory testing or Marshall testing, by which the void content in the mix can be determined. Gyratory compaction of the mix is further recommended to check the compactibility of the mix.
1.4 Performance testing

In case of heavy traffic roads, or when high performance is required, further performance testing is required on the mix prior to production and laying. Various performance characteristics can be checked, depending on the application and on the requirements that are found important for the road under construction:

- Resistance to rutting: use can be made of the European (pre)standard prEN12697-22, such as the large test device to determine the resistance to permanent deformation of the designed mix.
- Resistance to fatigue.
- Moisture sensitivity, stiffness and others.

As a general recommendation, the bituminous recycled mixture should be controlled by the same kind of tests required to the same type of bituminous mixture and fulfil, at least, the same requirements established for the bituminous mixture.

BTD and CTD tensile tests can be used to study the effect of the RAP content in the mixtures, the influence of using different types and percentages of binder, the grading of the mixture and the effect of the rest of the mixture components. For each variable, different specimens will be manufactured changing the value of the parameter considered. The curves obtained after the testing process will allow to select the mixture according to the design characteristics.

**BTD test specimen manufacture**

The specimens are manufactured and compacted in the Marshall compactor, using two especial bases which allow to pull of the mixture and to apply a tensile stress to it.

**Breaking of the specimen.**

The bases of the specimen are fastened to two especial jaws of the press. The deformation speed applied is 1 mm/min and the temperature is of 20°C.

During the test, the curve stress-strain is registered obtaining a similar curve to the one drawn in figure 1.

![Figure 1: BTD test, scheme and stress-strain curve.](image)
**CTD test specimen manufacture**

The specimen tested in CTD test is prismatic. Its dimensions are 5 cm x 5 cm x 15 cm, and it has and indent made with a saw in its central fibre in order to reduce this section and to force the rupture in this fibre.

*Breaking of the specimen.*

For the specimen testing, two metallic gripping devices are stuck to each base. They allow to subject the specimen to the press and to test it by applying a tensile load, Figure 2. A constant speed deformation of 0.1 mm/min is applied and the testing temperature is 20°C.

![Figure 2: Direct Tensile Test scheme.](image)

As for the BTD test, during the testing process the *stress-unitary strain* curve is registered by means of two extensometers placed in the area where the fracture is expected. They register a unitary deformation. This testing procedure allows a better control of the applied stresses and the deformations obtained, and it has been used, basically, in the study of the recycled mixtures.
Direct Tensile Resistance. BTD test  
S-12 Mixture

<table>
<thead>
<tr>
<th>Deformation (mm)</th>
<th>Direct Tensile Resistance (MPa)</th>
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<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
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<td>1.5</td>
<td>0.3</td>
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<tr>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
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</tbody>
</table>

- 100% de MBR
- 60% de MBR y 2% de B-150/200
- 40% de MBR y 2.8% de B-150/200
- 0% de MBR y 4.5% de B-60/70

Figure 3: BTD test of mixtures with different RAP contents.

In Figure 3, it can be observed that the mixtures manufactured with a high RAP percentage and a little new binder quantity have a fragile fracture, whereas, the higher the binder with renewing agents quantity is added and the lower the amount of RAP, the closer the performance to a conventional mixture.

2. PRODUCTION

2.1 New recycling process

To increase the quantity and the quality of the total recycling amount of asphalt plant is necessary to introduce milled material in the top layer mixes and to increase the recycling rate in some specific hot asphalt receipts; it is possible with the new process called “Combined cold & hot Recycling”.

The process consists in a preventive screening of milled material (reclaimed asphalt), with separation of fine and big grain (“sand” 0-5 mm and “gravel” 5-20 mm). Then these materials are inserted into the hot asphalt mix following two different ways: the “sand” is cold-added in small amount (up to 20%) into top layer mixes, the “gravel” is heated and added in bigger amount (up to 60%) into binder mixture.

The cold and hot inserts can be done also at the same time into binder mixtures (10% 0-5 mm, 45% 5-20 mm) utilizing a plant configuration as schemed below

The process requires some new machines and modifications in the asphalt plant layout.

1. RAP screen
   - It must have at least two nets with 8 mm and 25 mm openings.
   - A crusher has to work the material >20 mm.

2. Double feeding line
   - Two separate pre-feeders have to contain the 0-5 and the 5-20 selections.
- Meanwhile the hot feeding line goes through the heater, the cold one goes by a belt into a separate hopper over the RAP weigh machine.

3. Storage areas
- In addition to the milled material one, another storage areas have to be disposed for 0-5 and 5-20 mm selections.
- The 0-5 stock area will be better covered to avoid rain moisture.

2.2 Improvements in machine design
The design of the RAP drum dryer has been improved in the flame chamber with a new typology of shovels. They mix the milled material and make it flow without lift it during the rotation of the cylinder with reduction of material’s falling particles. The new drier increase the quality of the heated milled material, with less ageing of the bitumen and less polluting gases and vapors obtained by reduction of the flame exposition.

The screening system for the milled material has been studied and tested, considering a vibrating screen. To assure an efficient screening, without clogging and excessive flowing, meshes on the nets must be larger than the material to screen. To screen milled material with a granulometry of 5 mm, avoiding clogging, the meshes must be 7,5 mm (+50%) using “arpa” nets (made with a corrugated wire).

3. COMPACTION

The main recommendation one should consider when facing both hot recycling lay down and compaction of the mixture is to control the nuclear mixture evolution densities as long as the rollers pass properly over the mixture till the densities stabilize and get their maximum level.

Special attention should be given when dealing with High Modulus Mixtures. In this case the binder production temperatures must be over 180ºC. Otherwise, when producing hot recycled mixtures with high percentages of RA (30% or more) the final mixture temperature do not reach the 160-170ºC required range to success when laying down and compactioning the mixture.

4. STRUCTURAL CONTRIBUTION

4.1 Deflection analysis
This chapter is going to be focused on hot recycling recommendations to evaluate the structural contribution due to the rehabilitation actions.

4.1.1 Structural evaluation of hot recycled tracks
The structural evaluation can be done by using NDT tests with a Falling Weight Deflectometer and by extracting road cores.
a) Road Coring
To obtain a representative number of road cores to know pavement layer thickness before and after the recycling actions. This information is going to be used as an input for back calculation methods.

b) Deflections measurements
To measure road deflections under 65 Kn dynamic load with a FWD. Deflections had to be measured before and after the road rehabilitation. This data is going to be used for structural analysis.

Tests after the recycling works must be done at least twice, after six and twelve months from the end of the rehabilitation works.

Its very important to know the moisture conditions of the granular layers, because it can cause variations on the measured deflections. To reach this goal, piezometers should be installed on road structure.

4.1.2 Road bearing capability evaluation
The structural evaluation has to be done through the central deflection and through back calculation methods.

a) Back calculation method
To estimate the dynamic modulus of pavement layers, deflections had to be analysed by using back calculations methods. As it consists on an iterative process, horizontal strains data measured by means of horizontal gauges installed underneath the recycled pavement layer, must be collected to perform forward calculations for mechanical parameters adjust purposes.

On the other hand, laboratory tests (Instant Resilient Modulus) had to be performed on road cores to compare laboratory and analytical results (Dynamic Modulus of Pavement Layer).

b) Central deflection method
To check the variation of the total road structure strength, a central deflection analysis had to be done taking into account collected deflections before and after the road rehabilitation.

First of all, to compare both situations (the bearing capability before and after pavement recycling), the central deflection must be corrected because of the influence that moisture has on granular layers.
A parameter that reflects local moisture variation has to be used. On the FWD, the farthest geophone measures displacements coming from the bottom part of the stressed area, caused by the dynamic load (coming from the subgrade). So if we compare in the same test point some subgrade displacements measured at different test date with several moisture conditions we can adjust them to the highest moisture content by calculating Chi parameter;
\[ \text{Chi} = \frac{d6(\ w_{\text{max}})}{d6(\ w_i)} \], \text{where} \ d6(\ w_{\text{max}}) \ \text{is the farthest deflection with the highest moisture contents and} \ i \ \text{is data collect date, measured at} 1200 \text{ mm from the load point)}

And correcting the measured deflection;
Corrected deflection = \text{Chi} \times \text{measured deflection}

With Chi we can correct deflections measured at a dry day.

4.1.3 Conclusions

Dynamic modulus
We have to expect a dynamic modulus of the hot recycling pavement layer more or less equal to the dynamic modulus of conventional pavement layer.

Dynamic modulus is not a long-term pavement behaviour parameter, so we cannot conclude about which is going to be its behaviour in the future.

Deflections
Hot actions had diminished the total road structure deflection.

When we are comparing deflections before and after the rehabilitation works we have to correct the moisture effect on measured deflection.

4.2 Mechanical analysis

Numerical methods research partners propose a new methodology to analyse pavement’s behaviour under static and dynamic loads, based on the constitutive models developed.

- This methodology consists in a software code that calculates the material’s response under different loads, using as input the geometry of the multi-layered structure and mechanical parameters obtained from simple laboratory tests, like elastic Young modulus, Poisson ratio or yield stress for each material involved in the calculation process.

This constitutive values can be obtained from bibliographic references as well, for well known materials like granular layers, or applied loads like roller or pneumatic compactor.

- This constitutive parameters are used in the developed model based in the Finite Element Method, available for the end-users.

- The structural code offers as output the stress – strain distribution along the pavement structure, the deflections in the surface, the plastic strains in the pavement and the possibility of damage in the material, as well as the critical points in stresses or damage.

- That leads us to a mechanical solution the user can study to take conclusions about the pavement’s behaviour. Once we have the simulation of the pavement’s behaviour the end-user can apply some quality control criteria to evaluate the response obtained, so as to change the material, its properties, or the geometry, layers’ thickness and so on.
According to these quality criteria the user can stop the design method if the quality parameters are acceptable, or repeat the design with the changes in the geometry or the material’s properties.

This methodology can be used as many times as necessary until an acceptable solution is reached.

Methodology and rules for asphalt pavements' rehabilitation in road tracks

(CIMNE)