A STEP FORWARD IN THE RECYCLING FIELD. MIXED RECYCLING WITH EMULSION AND CEMENT

Juan José Potti (1)  
María Martínez (2)  
Javier Mancebo (2)

(1) PROBISA, Spain.  
(2) PROBISA, Spain.

Abstract

There exist different types of pavement recycling: by means of cold or hot techniques, with emulsion, with cement, mixed, in-place or in plant.

The subject of this paper is cold in-place recycling with emulsion and a small cement percentage, about 0.5% the aggregate’s weight. The addition of this small quantity offers the possibility to keep the flexible characteristics of a material which has been treated with bituminous binder; at the same time it is complementary with the characteristics of a hydraulic binder: the recycled mix becomes resistant much before, and it has higher water susceptibility, that is to say, conserved resistance can be assured at about 80%, much higher than the one required in article 20 “Reciclado en situ con emulsión de capas bituminosas” (In-place recycling with emulsion of bituminous wearing courses) of the Spanish specifications memorandum PG-4, Orden Circular 8/2001.

Likewise, comments are included as to small differences in the formulation of the mix, performance and setting-up of recycling with traditional emulsion.

1. MIXED RECYCLING. GENERAL

The different recycling techniques of pavement, whether they are “cold”, “hot”, “in-place” or “central” are used in a great number of countries forming just a small percentage of road rehabilitation techniques applied. However, today’s decrease in raw material and economic, environmental and legislative concern become more and more evident, and the Administration and Business Sectors have the obligation to anticipate more systematically the different existing techniques to reconstruct or recycle pavement.

One of these techniques consists in cold pavement recycling by means of a combination of bituminous emulsion and cement. These techniques have been widely developed in Canada, the Czech Republic or Japan; generally, they involve use of an important cement volume.

Using this technique as a point of departure, PROBISA has applied its large experience regarding cold techniques with bituminous emulsion: it has developed a type of mixed recycling (using emulsion and cement) with characteristics which vary from the already mentioned ones and which is adapted to Spanish characteristics, as far as compliance with current Regulations is concerned.
2. CURRENT REGULATIONS

- Orden Circular 8/2001 “Reciclado de firmes” (Pavement recycling) of the Spanish Ministry of Development, effective as from January 2002. Article 20 “In-place recycling with emulsion of bituminous wearing courses”, defines this type of recycling as follows:

“Homogeneous mix, conveniently spread and compacted, of the material resulting from milling of one or more courses of bituminous mix of an existing pavement with a thickness of between six and twelve centimetres, bituminous emulsion, water and, occasionally, additives. The complete execution process of this unit will be carried out at ambient temperature and at the same surface to be treated.

As far as implementation of this article is concerned, the material as defined above, will only be considered valid when 90% or more of the thickness of the courses which are to be recycled are mixes of hydrocarbonated binders.”

<table>
<thead>
<tr>
<th>Category of HGV traffic</th>
<th>Dry (Mpa)</th>
<th>After immersion (Mpa)</th>
<th>Conserved (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (only base courses)</td>
<td>3</td>
<td>2,5</td>
<td>75</td>
</tr>
<tr>
<td>and T2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3, T4 and hard shoulders</td>
<td>2,5</td>
<td>2</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 1. Minimum resistance values in immersion-compression (Spanish norm NLT-162)

- “Pavement dimensioning of the Andalusian Government”

Recycling type I: When 75% or more of the thickness of the courses to be recycled are mixes with hydrocarbonated binders

Recycling type II: When less than 75% of the thickness of the courses to be recycled are mixes with hydrocarbonated binders

<table>
<thead>
<tr>
<th>Category of HGV traffic</th>
<th>Dry (Mpa)</th>
<th>After immersion (Mpa)</th>
<th>Conserved (%)</th>
<th>Dry (Mpa)</th>
<th>After immersion (Mpa)</th>
<th>Conserved (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T0, T1 and T2</td>
<td>3</td>
<td>2,5</td>
<td>75</td>
<td>1,8</td>
<td>1,5</td>
<td>75</td>
</tr>
<tr>
<td>T3</td>
<td>2,5</td>
<td>2</td>
<td>60</td>
<td>1,2</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>T4</td>
<td>2</td>
<td>1,5</td>
<td>50</td>
<td>0,9</td>
<td>0,7</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 2 Minimum resistance values in immersion–compression (Spanish norm NLT-162)

- Dimensioning guide created by Probisa, “Guía para el dimensionamiento de firmes reciclados in situ en frío” (Guide for dimensioning of pavement which has undergone cold in-place recycling) (Del Val, 1998). It defines three classes of recycling with emulsion:
### Table 3

<table>
<thead>
<tr>
<th>Class (Recycling with emulsion)</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder contents</td>
<td>4-7%</td>
<td>3-5%</td>
<td>2-4%</td>
</tr>
<tr>
<td>Pavement to be treated</td>
<td>Bituminous materials (&lt;5cm) and granulated base course</td>
<td>Bituminous materials (&lt;10cm) and granulated base course</td>
<td>Bituminous materials</td>
</tr>
<tr>
<td>Thickness treated (cm)</td>
<td>8-15</td>
<td>8-15</td>
<td>5-15</td>
</tr>
<tr>
<td>Objective</td>
<td>Pavement stabilization and regularization</td>
<td>Regeneration of the mix</td>
<td></td>
</tr>
</tbody>
</table>

3. FORMULATION OF MIXED RECYCLING

Regarding formulation, Probisa applies a different point of view from the usually applied ones. It is based on:
- Use of harder binders
- Incorporation of a small amount of cement.

3.1. Initial cohesion.

Generally, the objective of pavement recycling is to restore its cohesion. Dry resistance of in-place material, before treatment, is small (see figure 1, point A). This has led to regeneration of a binder aged with an emulsion that has been formulated with bitumen enriched with rejuvenating binders. Besides, the base bitumen of this emulsion is normally soft bitumen with a high penetration level (about 250 dmm) and very susceptible to heat.

This caused interaction between the new bitumen and the aged one. In the end this should lead to bitumen with the adequate characteristics for correct functioning of the analogically recycled mix, finally obtained by hot central recycling.

Experience has shown that by applying these principles, short-term cohesion of the mix is generally bad, and short or medium-term mechanical efficiency is limited. In these conditions, use of an emulsion with harder base bitumen (with a penetration of about 80 dmm) allows increase both of cohesion of the mix and of the value of dry resistance (figure 1, point B).

However, incorporation of a new emulsion does not allow for a decrease of water susceptibility of the mix, and conserved resistance is normally below the values established by the Regulations. Incorporation of a small amount of cement (0.5% of the weight) allows for a decrease in the water contents of the mix, and by thus, a density increase. Dry resistance does not increase, but resistance after immersion notably does (figure 1, point C).
3.2. Medium and long-term behaviour. modulus.

Taking into account that for in-place recycling the manufacturing and extension process is carried out in one and the same operation, water contents of the mix forms one of the key aspects, not only as far as initial behaviour, the initial cohesion of the mix, is concerned, but also regarding final characteristics of the mix.

Water is an incompressible liquid, reason for which it is impossible, not even with the most energetic compaction elements, to move it. The final voids content of the mix not only depends on the mineral skeleton but also of the water contents of the mix. Finally, final mechanical characteristics of the mix depend on the voids content. This leads us to the conclusion that it is important to reduce the water contents as much as possible during the recycling process; it should be made compatible with the humidity conditions required for the milling process and the minimum humidity required for the coating process.

For these reasons, the already mentioned Orden Circular, 8/2001, limits the thickness of in-place recycling with emulsion to a minimum value of 6 cm and a maximum of 12 cm.

Probisa has analysed cores of its mixed recycling works in the Dourdan Laboratory of Eurovia (the Group’s Headquarters), by means of diametral compression tests at a temperature of 15°C according to frequencies 0.1-1-4 and 10 Hz; voids content of the different cores has been determined by gamma bench according to norm NFP 98-250-5.

Figure 1. Characteristics evolution of the recycled mix according to cement incorporation.
Figure 2. Evolution of the modulus values according to the voids content in the recycled mix.

As can be observed from the figure, a decrease of the voids content of two percent is reflected in an increase of 25% of the modulus.

This is another circumstance that favours incorporation of a small percentage of cement: medium-term verification (cores are normally extracted after 15 or 30 days after the recycling process) shows modulus values that are higher than those which have been accepted until now (2.500 Mpa at 20ºC according to the Andalusian norm).

By thus, the fact that cores can be extracted after a few weeks upon process commencement shows the positive effect of the incorporation of small amounts of cement as far as initial cohesion of the mix is concerned; besides, the obtained values of conserved resistance and modulus confirm the interest of this incorporation.

All these aspects are being studied in a European investigation project called Score (www.score-project.org).

Besides the type and percentage of emulsion and cement (according to the total mass of the dry recycling material) the following data have to be included into the working formula in order to obtain a correct formulation of this mix:

- Thickness of the in-place recycling with emulsion and cement.
- Grading of the milled material.
- Mass proportion, with respect to the total mass of the dry recycling material, of the water to be added.
- Optimum compaction humidity.
- Minimum density value to be obtained in the test stretch.

4. EXECUTION AND CONTROL OF THE WORKS

After formulation and the compulsory test track, the different operations which are necessary for the execution of cold in-place recycling with emulsion and cement can be resumed in the following way:
4.1. Milling.

Before this operation, if necessary, an adjustment of the transversal and longitudinal profiles of the pavement can be made.

The width of the milling drum is normally smaller than the width of the road that is to be treated; for this reason, works must be carried out by pass sequences paying special attention to the longitudinal joint.

Generally, we can consider that the overlay of the pass sequences corresponds to 1.5 or 2 times the thickness of the course to be treated; the minimum is 150 mm.

Milling between 1 m and 1.5 m of the already treated part treats the transverse joints. These joints must be placed at strategic points of the road to avoid that these “weak” points would degrade too rapidly. For this reason, placing the longitudinal joints in the passing zone of vehicle must be avoided; at the same time, the transverse joints must not coincide with intersections or any other point of vehicle halts.

The drum picks must be controlled regularly in order to obtain material with a grading curve corresponding to the one used for the working formula.

4.2. Grading correction.

If necessary, the grading curve of the milled material can be corrected by means of the incorporation of new aggregates, especially when one or more fractions are missing.

4.3. Cement incorporation.

Cement must be added in the form of powder, at very low quantities, about 0.5%, and without causing the already known problems related to the addition of powder exposed to the wind or dispersion to adjoining zones. This is the reason why a regulating device has been added to the recycling machine, designed by the Machine Department of Probisa, based upon the following criteria:

1. Compact unit, occupying as little space as possible within the recycling train, without hindering or interfering in the different working manoeuvres.
2. Possibility of fitting to the Wirtgen 2100 machine, and at the same time operating independently, so that, once dismantled, there remain no elements which could hinder other applications.
3. Easy and simple fitting to the machine for the assembly and disassembly manoeuvres to avoid any hinder and delay in the works.
4. To simplify design and construction, the driving force must proceed from machine type Wirtgen 2100.
5. Making dosing of the product controllable for adaptation to the necessities of the works.
6. Capacity to carry a palletised cement load of 2000 Kg, quantity corresponding to consume of a half-day’s work.
7. Dry cement extending, as near as possible to the recycling drum, thus avoiding any possibility of dispersion and environmental contamination because of the wind.
4.4. **Incorporation of the emulsion and the water.**

The emulsion and the water are added directly to the mixing unit of the machine; an efficient mix guarantees homogeneous distribution.

Let us bear in mind that too much water suits the coating process, although this means an increase in voids in the mix, and therefore, density decrease. For this reason regulation should be very precise.

4.5. **Spreading and compaction.**

Spreading is carried out by means of a ruler included in the recycling machine. Compaction is carried out with the help of the most powerful compacting machines allowing for a vigorous compaction of the mix. The compaction trains are variable and vary upon the objective proposed.

After this process, it is recommended to apply a sealing coat to protect the recycled material from rain or traffic; a rapid setting emulsion is applied, i.e. 250 to 350 gr/m² of residual binder, followed by spreading of an aggregate 4/6 or 2/4 in a measure of 2 to 3 l/m².

4.6. **Application of the reinforcement course.**

Spreading of the reinforcement course will be carried out after a minimum period of time so that mixture cohesion and water evaporation are sufficient. The water contents must be less than 1%, at least after 7 days upon recycling.

Works done during the OPTEL project have demonstrated that there exist minimum water contents that cannot be reduced after a large maturation process. However, bitumen fixation on the aggregates continues, and dry resistance of the recycled mix continues increasing. Therefore, cement incorporation allows obtaining a dryer mix leading to better short and long-term resistance.
5. CONCLUSIONS.

1. To improve initial cohesion of the mix and therefore reduce the traffic opening time, powdered cement is playing a triple role:
   - Abrupt pH modification of the aqueous phase causing the emulsion to break and facilitating initial cohesion intake
   - Adds a material with a high water absorption capacity, reducing therefore the final consistency of the mix. This leads to conserved resistances of 80%
   - Adds the additional characteristics of a hydraulic binder.
2. Analysis of cores extracted 15 or 30 days upon recycling execution may show modulus values which are higher than the ones accepted until now (2,500 Mpa at 20°C according to the Andalusian norm); this is due to the cement action reducing the water contents and, as a consequence, voids in the mix. A decrease in the voids content of two percent is reflected in an increase of 25% of the modulus.

6. SOME EXAMPLES OF MIXED RECYCLING WORKS CARRIED OUT BY PROBISA

Site: Aya (Guipúzcoa)

This project consisted in recycling of the wearing course at a thickness of 8 cm and, later on, reinforcement of the Gi-2631 roadway. It was carried out because of pavement deterioration due to structural exhaustion, as detected by visual inspection, presenting cracks, subsidence, and deformation of the longitudinal and transversal profile. Besides, in the section between mileage points 10+640 and 17+772 splits and crazing were detected. Afterwards, a slurry seal course was extended as road surface.

The Guipúzcoa Council carried out the work. Probisa assigned Mr. Iñaki Guezala as Work Superintendent, conducted by Mr. Alberto Zabala, Delegate of the Basque Country.
Site: N-120
This project consisted in rehabilitation of the N-120 roadway between mileage points 174+705 to 233+300 between the towns of Osorno and Sahagún, Palencia.
In this work, the project section consisted in milling and reposition at a different thickness, reinforcing later on the hot bituminous mix with 8 cm. The successful bidder proposed a modification of this project section, changing it into the current one, which consists in recycling with emulsion and 0,5% cement, varying thickness between 6 and 10 cm according to deflection characteristics of each road section. Afterwards, the surface was reinforced with 8 cm of bituminous hot mix, spread 15 days after the recycling process.
The work was carried out for a company named Corsán-Corviam. Regarding administrative aspects, the work depends on the Spanish Ministry of Development. The Work Superintendent, assigned by Probisa, was Mr. Adolfo Gallo, Head of the Burgos Cost centre.

Site: Navacerrada–Cotos
This project consisted in pavement recycling (according to the project) of the M-604 roadway between mileage points PK 41+790 and 48+500; the pavement showed clear signs of fatigue, like important alligator cracking.
Recycling was carried out with 3% emulsion and 0,5% cement, at a depth of 8 cm, and at a surface of 50,500 m². After applying this course and before opening the section to traffic, the recycling was sealed with emulsion type ECR-1 without covering aggregate.

Photo 1
The work was carried out for a company named Trabit; afterwards, Trabit extended a wearing course with hot bituminous mix. The Comunidad de Madrid is the owner of the project, and the Work Superintendent, assigned by Probisa, was Mr. Mariano Aguilar, Head of the Obras Group, Central Zone.
Site: Loeches–Nuevo Batzan.

For a company named Virton, Probisa carried out mixed recycling of a thickness of 7 cm at the M-219 road, part of the Comunidad de Madrid, between the towns of Loeches and Nuevo Batzan, of a stretch of 15 Km.

This is a modified project; the objective of the original project was rehabilitation of the M-219 roadway by means of milling and reposition of the sections that had suffered fatigue, and, later on, reinforcement.

Probisa was the designer of the finally accepted recycling solution.

6.- BIBLIOGRAPHY

(1) DEL VAL, M.A. Guía para el dimensionamiento de firmes reciclados in situ en frío, Probisa 1998.