

# Performance assessment of Cold Recycling in Place

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## 1. COLD IN-PLACE RECYCLING - BENEFITS AND LIMITATIONS OF USE

Every new industrial development must take on board the need to protect the environment, conserve natural resources and accommodate quality of life improvements. This also applies to the roadworks sector, in which more and more companies are making an effort to recover and re-use pavement materials. One of the most promising techniques that can be used to do this is indisputably cold in-situ recycling, which offers many economic and energy-related benefits.

Within EUROVIA, Spanish subsidiary PROBISA has been recycling bituminous surfacing in-situ with bitumen emulsion for ten years now, and the technique has been steadily gaining ground in France since 2005 under the name RECYCLOVIA. The process, carried out in a single pass by a single machine, consists in milling the materials making up the pavement to be repaired, adding bitumen emulsion (RECYCLOVIA E) or foamed bitumen (RECYCLOVIA M) to the scarified materials and then spreading and trimming this new mixture. The material is then compacted by conventional machines and surfaced, after a stabilisation period, with a new wearing course. RECYCLOVIA can be used to treat pavement thicknesses of up to 150 mm and offers a particularly advantageous alternative to conventional reinforcement and re-surfacing of pavements carrying low to medium traffic.



### 1. Conservation of resources

The most important benefit is the reduction in the consumption of virgin aggregates produced in quarries and/or gravel pits. The process also consumes less bitumen than new road construction using non-recycled materials.

### 2. Reduction in the amount of waste generated

The materials of the existing pavement are reused in their entirety, eliminating the need to landfill materials and to address all the economic and environmental issues associated with landfill operations.

### 3. Reduction in transport

In-situ recycling eliminates the need to transport milled materials to a landfill or to a coating plant and substantially reduces the need to transport new materials. This reduces not only the cost of transport (energy) but also all the adverse environmental effects of such transport (emissions) for road users and the surrounding community.

### 4. Energy savings

Energy savings are mainly related to the reduced need for transport, but energy is also saved in manufacturing since the in-situ technique is a cold process that does not require aggregate heating.

### 5. Reduction of emissions

As in every cold technique, emissions are reduced during laying. But the most important gains are due to the reduction in materials transport.

As a general rule, combined energy (materials manufacturing and transport) and materials (aggregates) savings of up to 20% can be achieved. The same is true for the reduction in gaseous emissions (CO<sub>2</sub> and SO<sub>2</sub> equivalents reduced by approximately 20%).

Despite these considerable advantages, cold recycling is still only used to a limited extent in road refurbishment in Europe.

In 2003, World Road Association (PIARC) Technical Committee C 7/8 on Road Pavements, headed by Jean-François Corté, issued a document on “Cold in-situ recycling with emulsion or foamed bitumen”. This document [1] was developed on the basis of work carried out by a committee of eight members and employees from a variety of countries (Estonia, Canada, Norway, the United States and Japan).

The document lists a series of practical drawbacks that may explain why the technique has so far failed to come into more widespread use worldwide. These drawbacks can be summed up in seven points:

1. quality of materials to be recycled;
2. quality of pavement to be recycled;
3. presence of materials that rule out milling;
4. existence of difficulties that rule out milling;
5. adverse weather conditions;
6. mechanical limitations;
7. limitations due to the protection layer (curing layer over the recycled material).

To better address these drawbacks and to foster more widespread use of the technique, the SCORE project was initiated in 2002, with PROBISA as coordinator.

## 2. THE SCORE PROJECT – MAIN ACHIEVEMENTS

The SCORE - Superior Cold REcycling – project was financed by the European Commission as part of the 5<sup>th</sup> Framework Programme for research and technological development (FP5). The project ran from June 2002 to June 2005 and involved eight partners: project coordinator PROBISA (Spain), NYNAS (United Kingdom), EUROVIA (France), SSZ (Czech Republic), Produktion (Sweden), Laboratoire Central des Ponts et Chaussées (LCPC – France), CEDEX (Spain) and Joseph Fourier University (France).

All aspects of recycling, from characterisation of milled materials to formulation of recycled mixes, were examined, culminating in the laying of a series of trial areas [2 – 11]. Some of the main results of this research are described below.

### 2.1 Milling conditions

The first project task was to quantify the effects of the basic parameters (speed of the machine, milling depth, rotational speed of the cutting drum, number of teeth, etc.) on the grading of the milled material [6].

One purpose of the milling process is to reduce the amount of particles of more than 25 mm. To this end, the preliminary pavement condition analysis must determine the status of layer bonding, so as to evaluate the potential efficiency of the scarification process. The LCPC (Laboratoire Central des Ponts et Chaussées) laboratory has arrived at this very interesting conclusion under Task Number 1. When there is partial de-bonding of the pavement courses to be recycled and above all when there is extensive cracking in the upper layer, one or more of the following measures can be taken:

- Preliminary milling of the pavement with a milling drum fitted with a large number of teeth,
- Reduced forward speed of the machine and/or increased speed of rotation of the drum (figure 1),
- Recycling of a sufficient thickness of pavement to include a substantial part of the stripped interface.

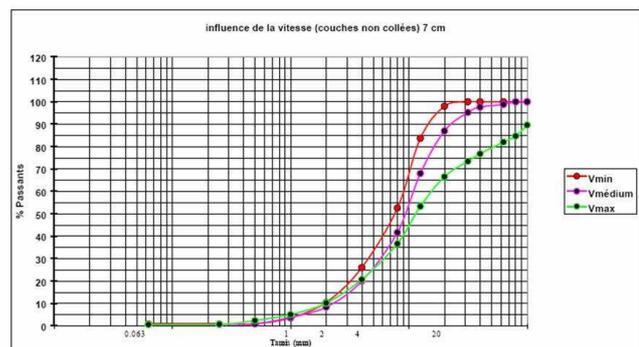
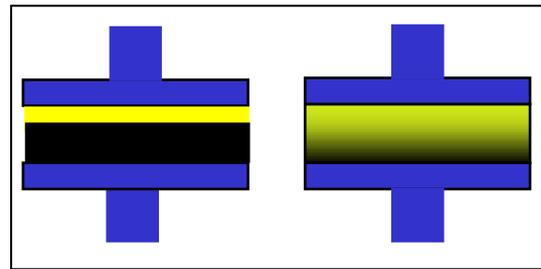


Figure 1: impact of milling speed

### 2.2 Regeneration of aged binder

Another part of the SCORE project was a scientific analysis of the possible interaction between the old binder and the added bitumen. To what extent can an aged binder be “rejuvenated” by means of a regenerating additive? How much time does this take?

This work has been carried out on the basis of rheological measurements to analyse kinetics of diffusion between the old and the new binder. (Figure 2). A layer of old binder and another layer of new binder are installed on the plates of a plate-plate type rheometer. The modulus of the system is then measured over time. The results can then be interpreted in terms of diffusion parameters. Diffusion kinetics values have also been measured directly on mixes so as to determine the degree to which the theoretical results match up with the actual measured results.



**Figure 2 :** study of diffusion with DSR

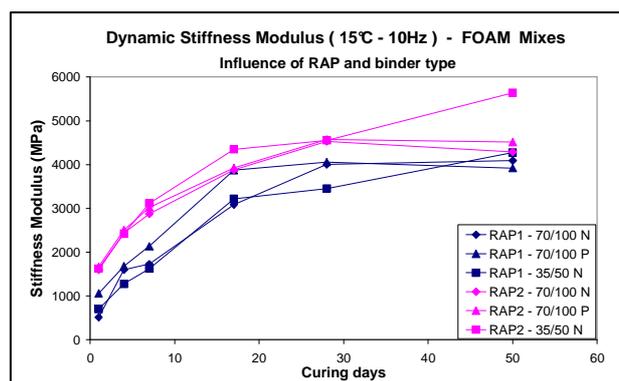
One of the tests carried out consisted in measuring the increase in the apparent modulus of a “sandwich” made up of a 0.1 mm layer of bitumen with a penetration value of 400 1/10 mm on top of a 0.2 mm layer of an artificially aged bitumen with a penetration value of 15 1/10 mm. The diffusion observed lasted for more than 30 hours at 80°C [2]. This and other experiments have demonstrated that at ambient temperature, the speed of diffusion of a soft bitumen in an aged bitumen is real but very slow. To ensure that the rigidity of a recycled asphalt mix is sufficient after laying, care must therefore be taken to ensure that the added bitumens are not too soft.

Studies have confirmed the possibility of regenerating a portion of the bitumen contained in milled materials by means of a regenerating oil (approximately 0.1 pph of dry milled materials), provided that a curing period of 7 days is complied with. This requirement rules out the technique for in-situ recycling and limits its use to situations in which the milled materials can be stored prior to re-use. Materials that have been regenerated in this way offer better compaction of the recycled asphalt mix when it is laid and a reduction in the demand for new bitumen. In addition to its lubricating effect, the injection of this regenerating oil into the milling drum also results in a reduction in drum teeth wear. In this technique, the use of a harder binder in formulating the emulsion, together with the addition of lime or cement (in amounts of less than 1 pph) made it possible to obtain mixes with better mechanical properties.

### 2.3 Mechanical performance of recycled mixtures

An important aspect of the performance of recycled materials is the mechanical strength one gets once the material is fully cured as well as the time it needs to reach that ultimate stage. SCORE has investigated this point on the basis of two RAP materials having approximately the same grading curve but differing significantly in binder content and consistency [5,11]. Whereas the binder in RAP1 (Spanish job site) was quite hard (average penetration value of only 6 mm/10 at 25°C) and low in content (4 to 4.2 pph), RAP2 (French job site) was less aged (average penetration of 21 mm/10 at 25°C) and higher in content (5.5 pph). In the laboratory, these materials have been treated with either foamed bitumen, a bituminous emulsion or a micro-emulsion (average particle size around 1 µm). The build-up of cohesive strength with time has been monitored on the basis of dynamic stiffness measurements.

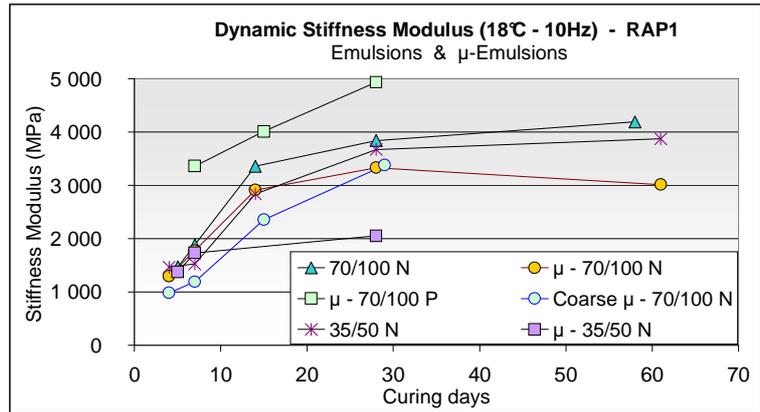
The main investigation has been conducted on gyratory compacted samples ( $\Phi = 150\text{mm}$  or  $160\text{mm}$ , height =  $115\text{mm}$  or  $160\text{mm}$ , depending on laboratory). The samples were compacted to a constant targeted void content of 15% and used as such (no further sawing nor cutting) for the mechanical testing. Assessment of stiffness over time was to be done via dynamic axial compression tests at 15 °C (3 repeats). The curing procedure consisted in two successive conditioning steps. During a first period of 7 days, which was to simulate the very early stage immediately after application, the samples were maintained at 18°C and 55% of relative humidity (RH). During the second period of curing the samples were kept at 35°C and 20% RH so as to accelerate the curing process (however without introducing possible artefacts due to excessive temperatures) and to get to the ultimate strength of the material. This procedure was to be continued till stabilisation. Figure 3 shows an example of results obtained with foamed bitumen.



**Figure 3 :** Stiffness evolution for foam treated RAP1

Under these conditions and for the tested materials, the stabilised stiffness modulus reached values around  $3000 \pm 1000$  MPa. This average value may increase by 15 to 30% depending on the type of RAP and by 10 to 20% for a decrease in void content of 5% (absolute value). The nature of the added binder (foam, emulsion) did only marginally impact these average values.

More differences are seen when switching over to  $\mu$ -emulsions, as shown in Figure 4 in the case of RAP1. With the 70/100 N and, more drastically, the 35/50 N bitumen, the stiffness curves obtained with the  $\mu$ -emulsions tend to stabilize quicker and at lower end values than those of the corresponding emulsion mixes. Significantly higher stiffness values and steeper slopes are however obtained for the 70/100 P (paraffinic) bitumen! With the coarser 70/100 N  $\mu$ -emulsion (which is also characterised by a higher amount of residual emulsifier), initial stiffness is lower but the slope of the curve is much steeper, which should lead to higher end values (Figure 4).

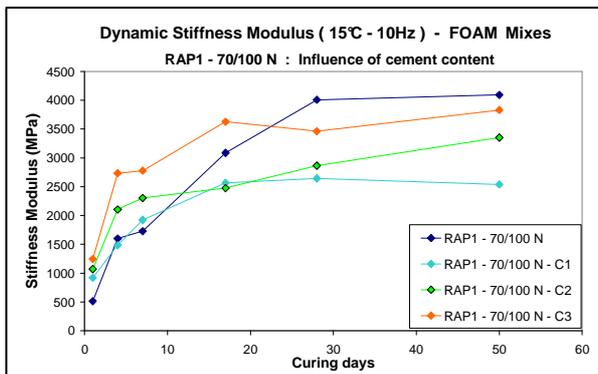


**Figure 4 :** Stiffness evolution for emulsion treated RAP1

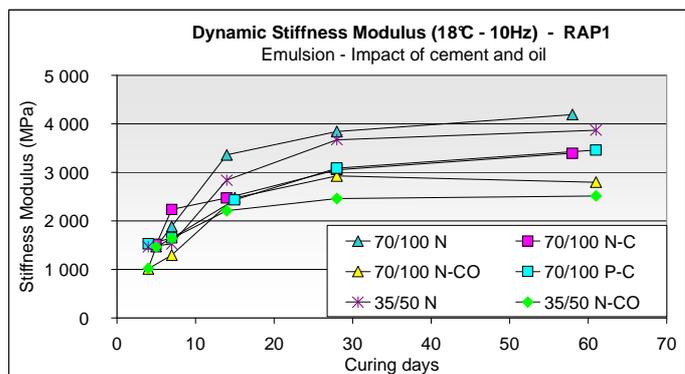
The available results being too limited to establish repeatability data, it is of course hazardous to draw any firm conclusion. It seems however that emulsion particle size distribution has indeed an influence on the build-up of strength, this parameter being certainly also coupled with the breaking behaviour and formulation of the emulsion (amount of emulsifier). More research is obviously needed to define an optimum !

Somewhat surprising results have however been obtained with RAP1 when adding increasing amounts of cement. Cement addition allows to significantly boost the build-up of strength in the early days (first conditioning period) but, after that, the curves level-off rather rapidly so that the end values may be lower than for the reference mix. Figure 5 illustrates this behaviour in the case of foam treated mixtures. Similar results have been obtained when adding 1 pph of cement (C), or adding 1 pph of cement + 0.1 pph of oil (CO) to emulsion treated material (Figure 6).

SCORE did not investigate this point further but it is contradictory to what is obtained in practice such as for instance on the test trials performed in the Czech Republic where the addition of significant amounts of cement allowed to reach high initial cohesion values. Beside possible complex interactions with the RAP material as such, it is suspected that the laboratory findings may rather be an artefact of the curing method itself. Indeed, the second curing step at 35°C and only 20% RH may “dry-out” the sample too quickly and thus stop the build-up of further hydraulic bonds.



**Figure 5 :** Foam treated RAP1. Impact of cement addition



**Figure 6 :** Emulsion treated RAP1. Impact of cement and oil addition

Beside stiffness, it is of course also important that the quite open recycled materials build up a sufficient resistance against water. This point has been addressed on the basis of diametrical stiffness and indirect tensile strength (ITS – prEN12697-23) (NAT equipment). Testing was done on gyratory compacted test samples (1.2 kg each,  $\Phi = 100\text{mm}$ ). Two series of, each time, 2x4 samples have been made. Unlike the previous procedure, curing has been immediately started at 35°C-20% RH ! The first series of samples has been cured for 7 days and the second until stable (28 days in this case). After each of these periods, half of the samples is kept in air at 18°C and half immersed in water at 18°C, again for 7 days. All samples are then tested for dynamic stiffness and indirect tensile strength at 15°C.

This work has been done on emulsion treated materials only. Added bitumen content was 2.5 pph on dry RAP instead of 2 pph. Test samples have been compacted to a constant number of 85 gyrations.

This study evidenced two major differences in behaviour between RAP2 and RAP1 materials (Figure 7). First, the general stiffness level for RAP2 mixes is significantly lower (approx. 60%) than with RAP1, despite the lower void content. These results are quite different from those obtained under axial compression on large samples. It may be explained by the fact that the impact of a softer residual binder and higher overall binder content is possibly emphasized when using smaller samples under diametrical loading conditions by comparison to what had been obtained on large samples under axial and purely compressive loading conditions.

Furthermore, retained stiffness and indirect tensile strength after water immersion are significantly better for RAP2 materials than for RAP1 materials, even after only 7 days of curing. This is to be ascribed to both the higher residual binder content and lower void content.

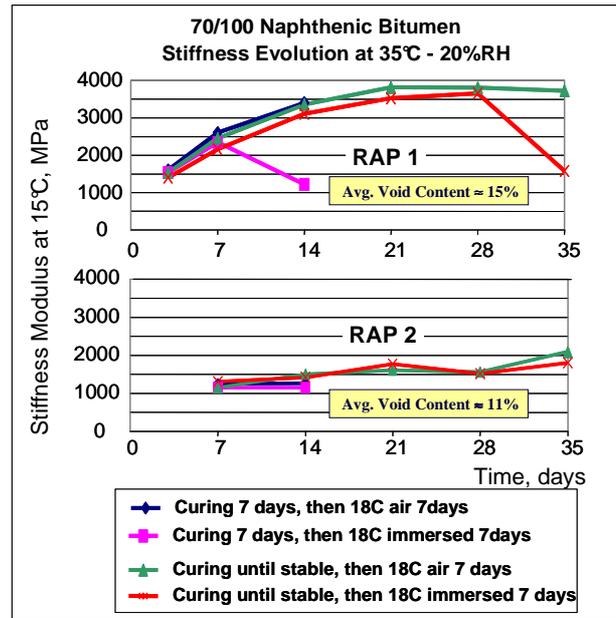


Figure 7 : Compared evolution of stiffness with RAP1 and RAP2 materials

The SCORE project has thus generated a lot of data on stiffness and its evolution with time. Characteristics of the RAP material and mix density confirmed to have a large impact on the final stiffness, whereas the impact of bitumen origin or binder type (emulsion vs foam) appeared as only marginal. Accelerated curing conditions may also not be equally applicable to any kind of material, as shown by the results obtained when adding higher amounts of cements.

### 3. DEVELOPMENT OF THE RECYCLOVIA PROCESS IN FRANCE

The SCORE project has been focused on the in-situ recycling of bituminous wearing courses. For many low to medium traffic roads, however, the bituminous cover is relatively thin and the rehabilitation of the road requires the underlying materials, which are either unbound granular materials or hydraulically bound layers, to be treated as well. This is namely the case encountered by EUROVIA in France and the development of the RECYCLOVIA process required thus to continue the research started within SCORE [14].

#### 3.1 In-situ recycling in France

In France, guidelines for cold in situ recycling have been established by the French Committee for Road Construction (CFTR) [12]. In the case of recycling with bituminous binders, these guidelines consider three types (classes) of treatment (Table 1), the bitumen being incorporated in the form of a bituminous emulsion. With regard to the mechanical performance to be obtained at formulation stage, the guidelines are mainly based on gyratory compaction (NF P 98-252) and DURIEZ (NF P 98 251-4) test criteria, i.e. compressive strength and resistance to water immersion. For pavement design consideration, average stiffness modulus values are recommended, depending on the class of treatment and the obtained DURIEZ compressive strength.

In-situ recycling with bituminous binders in France [2]				
Bit. layer Unbound or hydr. bound	Class I	Class II	Class III	
	10-15 cm	3 - 4 cm	4 - 8 cm <= 25%	5 - 12 cm
	5-12 cm			
<b>Objective</b>	Structural Reinforcement	Rehabilitation of the wearing course	Rejuvenating bitumen	
<b>Bitumen type</b>	Paving grade 70/100 or 160/220	Paving grade or rejuvenating bitumen	Rejuvenating bitumen	
<b>Added bitumen</b>	3 to 5%	1 to 3%	up to 2%	

Table 1: the 3 classes of recycling with bituminous binders

Although these guidelines constitute an excellent starting base, the development and optimisation of the technique still calls for a better understanding of how such recycled materials build-up their mechanical strength with time. This is especially true for Class I treatments (structural rehabilitation) in which the performance of unbound or hydraulically bound base layers is more subject to variability and more difficult to predict.

For such materials, there is also a need for establishing reference data in the case of in-situ recycling with foamed bitumen. This is indeed a very attractive technology as it is less sensitive to the chemical reactivity of materials than the emulsion technology.

These considerations have urged EUROVIA to continue the effort initiated within SCORE along two major routes, the assessment of mechanical properties of foam treated “mixed” RAP materials (Class I recycling jobs) and the comparison to the development of stiffness obtained in-situ.

### 3.2 Test sections

During the 2006 in-situ recycling campaign, extensive sampling of RAP material has been undertaken at five different job sites in France. All those recycling undertakings have been performed with a Wirtgen 2200 CR recycling machine.



The Wirtgen 2200 CR recycling machine



Sampling of RAP materials (Job site C)

The main characteristics of the performed recycling work and RAP materials are summarised in Table 2. Figure 6 shows the grading curve of the RAP materials.

Mechanical performance of laboratory prepared recycled materials has been assessed through two test procedures.

The evolution of stiffness of the recycled materials of these test sections was to be monitored via a periodic extraction of cores.

Job site	A	B	C	D	E
Type of recycling job (Class)	Class III	Class I	Class I	Class III	Class III
Date of works and sampling (2006)	27/06	02/07	21/08	04/09	24/10
Recycling depth and nature of materials	9 cm Asph. Concrete	~ 4 cm Surf. Dres.  ~ 11 cm Unbound Gran.	8 cm Asph. Concrete  8 cm Pouzz. Treated	7 cm Asph. Concrete	7 cm Asph. Concrete
Bitumen content in RAP (pph)	5	-	-	5,3	5
Penetration at 25°C (mm/10)	23	-	-	11	23
Softening Point (°C)	71	-	-	70	61
Added bitumen (grade)	160/220	70/100	70/100	160/220	70/100
Added bitumen (pph residual bitumen) Emulsion (60% bitumen) Foam	1,8	4	4,2	2	2,3
Added mineral additive (pph) Cement Hydrated lime	0,5	0,5	0,5	0,5	0,5

**Table 2:** Main characteristics of the recycling jobs considered for laboratory studies

### 3.3 Properties of laboratory recycled materials – DURIEZ test procedure (NF P 98-251-4)

The Duriez procedure, originally developed for hot mixes, is based on static compacted cylindrical samples on which one determines compressive strength after a curing procedure in air or under water, the ratio between these two values being taken as a measure for the resistance to water. Sample size differs depending on the maximum aggregate size of the mix. For cold (emulsion treated) materials, the French standard foresees, in addition to the usual static compaction load (120 kN for the large samples), a second compaction mode in which this load is reduced to one third (40 kN). It has indeed been recognized that, in the case of cold mixes, the high load leads to void contents which are unrealistically

low in comparison to what can be achieved in practice. Testing has been systematically performed according to these two DURIEZ procedures.

The results obtained with the DURIEZ procedure are gathered in Table 3 which also indicates the values prescribed by the French guidelines [2] for the heavy compaction mode.

Not surprisingly, sample density appeared as being very dependent on RAP characteristics and type of treatment. Emulsion treated Class III recycled materials (100% bituminous RAP) compact better than foam treated Class I recycled materials, most likely due to lower internal friction. Lowest void contents have been obtained with materials D and E, for which one may point at the shape of the grading curve (Figure 8) and the relatively high bitumen content (Table 2). The poorer compactibility of material A, which behaves similarly to the Class I materials, may possibly be explained by the particular shape of its grading curve (high amounts of passing at 2mm and 10mm).

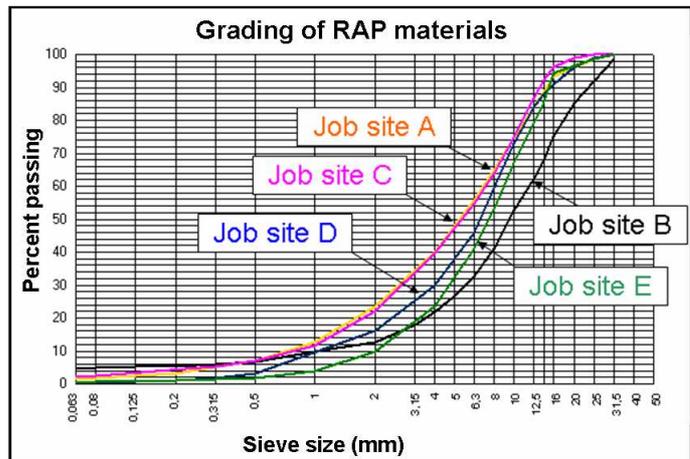


Figure 8 : Grading of the sampled RAP materials

Compressive strengths resulting from the 120 kN static compression exceed by far the specifications but do not seem to be correlated to void content (Class III materials). Specifications on resistance to water (ratio r/R) are met, even if sometimes borderline (Class I materials).

With the reduced compaction load, void contents are markedly increased whereas compressive strength values drop significantly. This is also true for the r/R ratio which seems also to be more affected in the case of Class I materials than for Class III materials (which is conform to intuition).

Material	CLASS III				CLASS I		
	A	D	E	Specs.	B	C	Specs.
	Compaction at 120 kN				Compaction at 120 kN		
Void content (%)	7,4	5,4	2,6	$\leq 14$	11,1	8,5	
Compressive Strength							
R (MPa)	7,02	6,15	6,72	$\geq 5$	4,22	6,15	$\geq 1,5$
r (MPa)	5,59	4,56	5,56		2,54	3,34	
r/R	0,8	0,74	0,83	$\geq 0,70$	0,6	0,54	$\geq 0,55$
	Compaction at 40 kN				Compaction at 40 kN		
Void content (%)	14,2	11,8	6,7		14,2	13	
Compressive Strength							
R (MPa)	3,83	3,34	4,37		2,71	3,86	
r (MPa)	2,72	2,27	3,37		1,06	1,8	
r/R	0,71	0,68	0,77		0,39	0,47	

Table 3 : DURIEZ test results

The main learning from these data is without doubt the strong impact of the compaction load. Knowing the void contents generally obtained in the field, (rather in a range from 10% to 15% than below 10%), they suggest indeed that for this type of materials, a reduced compaction load should be preferred.

### 3.4 Properties of laboratory recycled materials – Accelerated curing and stiffness

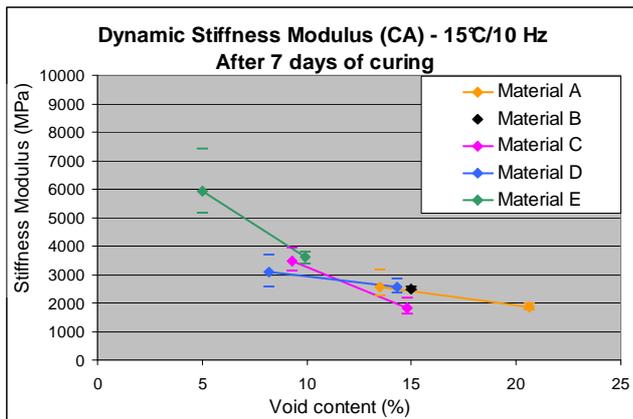
The two levels of density obtained with the Duriez compaction have also been used as a starting base for stiffness testing. For each mix, stiffness evolution with time has been monitored for two sets of samples, the average void content of each being targeted (in as far as possible) to approximately the same levels as those obtained with the two DURIEZ compaction modes. This was not only to associate stiffness to compressive strength but also to get an appraisal of the sensitivity of stiffness to degree of compaction.

All samples for stiffness testing have been compacted, one hour after manufacturing, with a gyratory compactor (PCG type II – NF P 98 252). Compaction has been stopped once the theoretical height, calculated from the actual mass of material and the targeted void content, was reached.

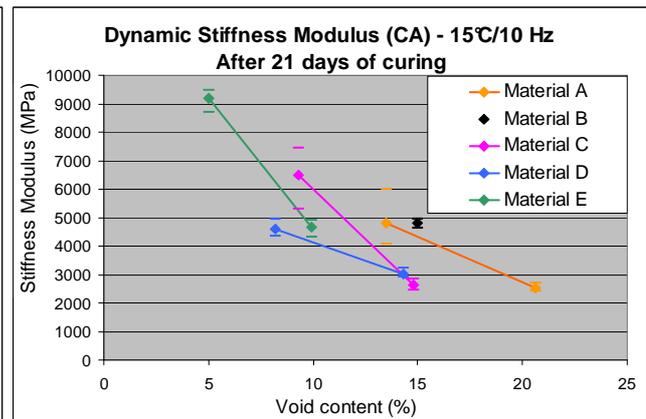
The so-compacted samples have then been subjected to a curing procedure derived from the SCORE project and other research [5,11,13]. Curing consisted in two successive conditioning steps. During a first period of 7 days, which was to simulate the very early stage immediately after application, the samples were maintained at 18°C and 55% of relative humidity (RH). During the second period the samples were stored for 14 days at 35°C and 20% RH so as to accelerate the curing process (however without introducing possible artefacts due to excessive temperatures) and to get close to the ultimate strength of the material. During the curing phase (in principle at days 3, 7, 10, 14 and 21), the samples were tested on compressive axial dynamic stiffness modulus (CA) at 15°C – 10 Hz, on a MTS electro-hydraulic test rig. This mode of loading on large samples ( $\Phi = 150$  mm,  $h \sim 115$  mm) has been chosen so as to avoid as much as possible any damage to the material (especially in the first days). Once cured, the sawing of these samples became possible and they have been cut to a height of 50mm and again tested for stiffness, this time in an indirect tensile mode. At this stage, it could be shown that :

- Stiffness modulus values measured at 15°C-10Hz under sinusoidal indirect tension conditions were comparable to those measured, at the same temperature and frequency, in an axial compression mode.
- These stiffness values were also comparable to the indirect tensile stiffness measured at 10°C with a pulse time of 124 ms.

In Figures 9 and 10, stiffness values are plotted against void content for 7 and 21 days of curing. After the first period of seven days (ambient conditions) the different materials are not strongly differentiated and the dependency upon void content is not very strong although materials C and E already seem to follow a different trend. At the end of the second curing period, differences are more marked. The steeper evolution of stiffness with density is confirmed for materials C and E. Whereas the highest stiffness levels (at similar void contents) are observed for A and B, material D appears as the weakest. Differences in RAP grading, type of treatment, residual and added bitumen characteristics ... are however too numerous to allow any sound correlation of these findings to mix composition.



**Figure 9:** Stiffness in relation to void content - Comparison after 7 days of curing



**Figure 10 :** Stiffness in relation to void content - Comparison after 21 days of curing

### 3.5 Evolution of stiffness in-situ

In principle, it has been planned to take core samples from the reference job sites after 6 months and 1 year, then at 1 year intervals. Yet, in practice, both core taking and their subsequent testing often suffer some unexpected delays, due to constraints on the road itself, availability of the coring team and scheduling of laboratory tasks. This, together with the late carrying out of some jobs (e.g. job site D and E) explains that, at the time of writing of the paper, only a limited number of results from these job sites were available. Since 2005, cores have however been taken and tested for dynamic stiffness from other job sites as well. A selection of Class I and Class III job sites, similar (in as much as possible) to the reference sites has thus been made and the available stiffness results included in our set of data.

#### 3.5.1 Analysis of cores taken from Class III job sites

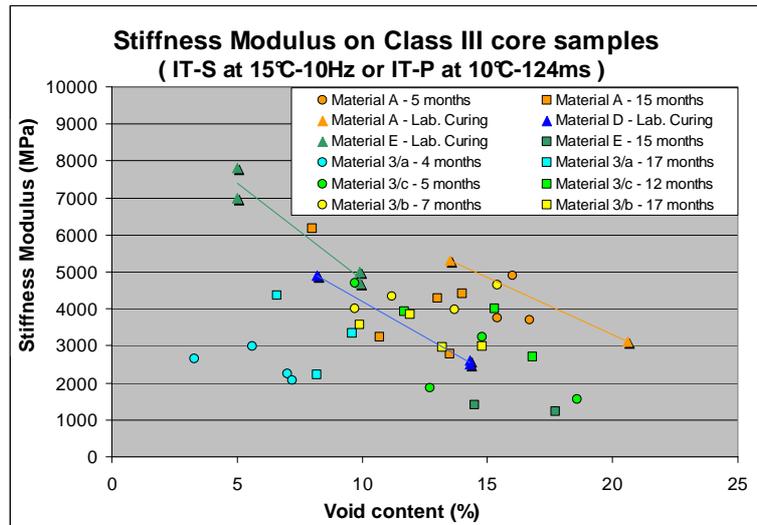
With the exception of job site E, all Class III recycling works have been emulsion treated with a soft 160/220 bitumen grade and the addition of 0,5 pph cement. Characteristics and amount of the residual bitumen as well as the amount of added bitumen are in general reasonably close with however one noticeable exception in the case of job site 3/a. In this case, actual binder content of the RAP material proved to be significantly higher than estimated from the preliminary

investigations, leading to much higher overall binder content in the final mix than projected. In Figure 11, these stiffness values measured on field cores are compared to those obtained on laboratory cured materials A, D and E.

Material A is the only one for which a direct comparison to laboratory cured samples is possible. After 5 months, results on the field cores appear as being already quite close to those obtained in the laboratory.

After 5 or 7 months, materials 3/b and 3/c have also reached stiffness levels which are in the domain delimited by those measured on laboratory cured materials A and D. One may further observe that for material 3/c, the evolution between 5 and 12 months seems to be limited.

Material 3/a is more disappointing. Despite relatively low void contents, its stiffness after 4 months is quite low. There is however an evolution with time, the stiffness values getting closer to the general trend after 17 months. This particular behaviour has certainly to be ascribed to the significantly higher overall binder content of this mix.

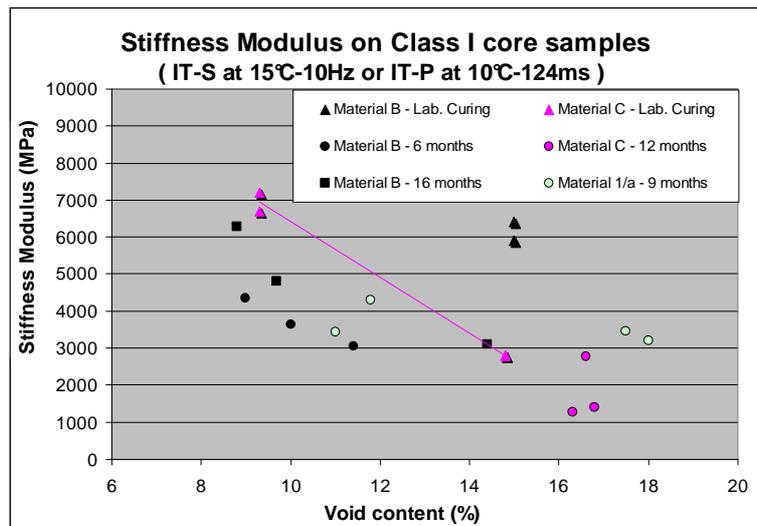


**Figure 11 :** Stiffness of field cores as compared to laboratory cured Class III materials

### 3.5.2 Analysis of cores taken from Class I job sites

The three considered Class I job sites have all been foam recycled with a 70/100 grade bitumen and the addition of 0,5 pph hydrated lime. Considering the composition of the treated material, material 1/a should rather be compared to material C, both including 50% of hydraulically bound materials whereas material B is significantly different, both with regard to the amount (up to 75%) and nature (unbound gravel) of the “white” material and the nature (successive surface dressings) of the “black” material.

Results were available after 6 months for material B, 9 months for material 1/a and 12 months for material C. In Figure 12, these stiffness values are compared to those obtained on laboratory cured materials B and C.



**Figure 12:** Stiffness of field cores as compared to laboratory cured Class I materials

Due to the poor level of density measured on the extracted field cores, the stiffness measured on material C after 12 months is quite low but follows the trend evidenced on the laboratory cured samples. This seems also to be the case for material 1/a (most comparable to C) after 9 months.

For material B, however, stiffness after 6 months is only about half of the potential maximum value expected from the laboratory studies. Possible main reason is the larger heterogeneity of this kind of material (75% of “white” materials) and hence the bigger gap between controlled laboratory conditions and the field.

### 3.5.3 Conclusions

The strongest outcome of our investigations is certainly that they constantly evidenced the major incidence of density on the mechanical properties (compressive strength as well as stiffness) of recycled materials.

It is also to be underlined that the stiffness measured on field cores seems to be less strongly correlated to void content than what has been observed on the laboratory made samples. This has certainly to be related to the greater heterogeneity encountered in the field which impacts both the measured stiffness and the calculated void content (which assumed the same theoretical composition for all samples). More attention will have to be given to this aspect in future investigations.

The still limited number of available data on both laboratory cured and comparable field cores does not yet allow to make any firm conclusion as to the validity of the accelerated laboratory curing procedure applied in this study. For the types of recycled materials studied here, we may however dare following statements.

- The accelerated procedure leads to fairly stabilized stiffness values for at least Class III materials. Curing tends to be slower for Class I materials, for which the procedure might have to be extended somewhat. For both types of materials, the increase of stiffness with curing time tends to be faster for the more heavily compacted test samples.
- It is not yet possible to conclude whether the end stiffness values obtained in the laboratory will be reached or exceeded in practice. At first sight, they seem to give a reasonable estimate of what one is likely to get. The reliability of this estimate is probably closely linked to the potential heterogeneity of the material. In other words, it will more reliable for Class III materials than for Class I materials, especially for those with a large proportion of “white” materials.
- The time period after which the ultimate stiffness will be reached in practice may also strongly depend on the type of material and be shortest for Class III materials.

It is hoped that the continued monitoring of these job sites will allow us to shed some more light on these questions.

## 4. FUTURE PROSPECTS FOR RECYCLOVIA

### 4.1 A tool for life-cycle analysis

The main advantages of cold in-situ recycling are of course its economical and environmental benefits. When answering a tender, those aspects should be evaluated at the same level as the purely technical aspects. There is definitely a growing awareness of environmental issues, this is why EUROVIA has designed and developed a tool called GAÏA. It is a software package to determine the environmental impact of the job site, it compares the use of conventional techniques with the use of Eurovia’s environmental solutions.



### 4.2 How to extend the use of in-situ recycling

Although it has numerous and obvious economic and environmental advantages, in-situ recycling also suffers from some limitations :

- Equipment is expensive
- Thorough preliminary investigations are necessary, especially when traffic volume become of some importance
- The technique is not well adapted for work in urban areas
- A given equipment may not always be the best suited for a given job site and thus not allow optimum performance (e.g. width of road vs. width of the machine, milling depth capacity, ...).

The future development of cold in-situ recycling will thus be conditioned by the possibility to ensure an optimum cost-effectiveness of equipment. In other words, the possibility to treat longer stretches of roads and to also remediate structural shortcomings under higher traffic volumes.

#### **4.2.1 *Mastering material properties***

This first requires a better mastering of material properties. SCORE and the on-going work at EUROVIA show that our knowledge of the behaviour of cold recycled materials, be it with an emulsion or with foamed bitumen, has made considerable progress. In particular, we also have a much better idea on what a material formulation methodology and the corresponding laboratory test methods should be. Our present thinking is as follows :

The method would be based on diametrical stiffness and indirect tensile strength testing, those methods having the advantage of being run on relatively small size samples ( $\Phi = 100$  to  $150\text{mm}$ ), thus reducing the amount of needed RAP material. They are also applicable to core samples from job sites. Additional work remains however to be done to fine tune test conditions for this type of materials and to ensure the level of reliability required for a mix design methodology. As suggested above, samples would be compacted at a fixed compacting energy, preferably according to a procedure allowing samples to be tested “as such”, without further coring or cutting. This energy should be defined for each equipment so as to obtain, on a “standard” type of mix, a void content close to what is frequently obtained on site (e.g. 15%). The actual curing and evaluation procedure would be a mix of the two procedures described above and be run in two steps. The first step would evaluate the speed of initial stiffening under ambient (e.g.  $18^{\circ}\text{C} - 55\% \text{RH}$ ) conditions. The objective of the second step would rather be to get to the ultimate mechanical performance via an accelerated curing procedure (e.g.  $35^{\circ}\text{C} - 20\% \text{RH}$ ) until stabilisation. In both steps, stiffness (as a non destructive test) would be monitored over time. At the end of each step, failure strength and water sensitivity would be assessed via a retained stiffness and retained indirect tensile strength test procedure. The duration of each step may have to be adjusted depending on the actual composition of the material, i.e. step 1 may have to be extended for cement rich mixes.

If the material is to address structural issues, one has also to evaluate its resistance to fatigue, i.e. its fatigue life. Due to the need for an adequate curing time and the specific nature of such materials, conventional fatigue tests as used for hot mixes are difficult to run. Their interpretation and use in pavement design methods also requires some adjustments. EUROVIA has started to look into these issues.

Better mix formulation and pavement design tools will then in-turn facilitate the search and development for better performing materials. One of those could be micro-emulsion based mixes, for which SCORE could not draw definite conclusions but which do certainly deserve further investigations.

#### **4.2.2 *Improved laying and compacting***

It has to be acknowledged that the density levels obtained for in-situ recycled materials are rather on the low side (usually between 10 and 15% for Class III materials and even more for Class I materials). This is due to both the high internal friction of this kind of materials and, in many cases, to the relatively low bearing capacity of the underlying structure. As already stated, this means on one hand that formulation studies or material characteristics (such as stiffness) to be used in design calculations have to be made or determined on samples compacted to realistic (likely to be obtained in practice) densities.

On the other hand, and more importantly, this means also that significant progress is to be expected from improved compaction on site. The choice of adequate and sufficient compacting equipment and compaction schemes is a first step. The possibilities of advanced equipment, such as the variation of amplitude during compaction (“Asphalt Manager”), are yet to be explored. Finally, compaction aids, such as the addition of small quantities of oil, are further tracks for getting higher densities.

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