In situ cold retreatment of wearing courses - Example of works reducing emissions of greenhouse gas and the use of virgin aggregates

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ABSTRACT

Maintenance of surface courses is a daily problem for road managers and it has become even more complicated considering the increasing demand for the preservation of natural resources and environmentally friendly techniques. This context has been the driver for the development and implementation of a cold in-place retread technique using either bituminous emulsions or foamed bitumen. The process targets the rehabilitation of the surfacing of flexible or semi-flexible pavements, up to about 150mm thick. All the functions needed to complete the process are dealt with by a single and powerful specific equipment (cold recycling machine). The technique is thus a clever alternative to usual techniques of rehabilitation/reinforcement by planning and laying of new materials. Its main advantages are economic and ecological, in particular with regard to the saving of virgin aggregate resources and the reduction of the emissions related to hot mix manufacturing and transportation. The paper presents an overview of the research activities which have supported this development and discusses the outcome of the monitoring of several job sites. The magnitude of the environmental benefits which are achievable with the process are illustrated by two case histories.

1. COLD IN-PLACE RECYCLING – THE PROCESS

The cold in-place retread process used by EUROVIA (RECYCLOVIA®) is based on a specific and powerful machine (Wirtgen 2200 CR) which allows the process to be conducted in a single pass.

The different functions ensured by the machine are:

- The milling of the existing pavement.
- The proportioning and injection of the binder which may be a bituminous emulsion or foamed bitumen. In the later case, the foamed bitumen is produced directly on the machine (simultaneous injection, via special nozzles, of hot bitumen and water).
- The proportioning and spreading of possible mineral additives (cement/lime).
- The injection of water for adjusting the water content of the final mix.
- The homogenization and mixing of the treated material,
- The spraying and trimming of the treated material using a paver screed.

Figure 1 – The Wirtgen 2200 CR recycling machine

The machine can manage a working width of up to 2.20 m and its four independently driven caterpillars allow it to easily cope with difficult road geometries. The binder (bituminous emulsion or hot bitumen for the production of foamed bitumen) is supplied by tank trucks which may place themselves in front or aside the machine and which are connected to the mixing unit by a flexible hose. The necessary water is stored in a dedicated tank installed on the machine itself.

Progression on-site is quite fast, as the daily output may easily reach 3500 m²/day. Since the full recycling train is rather compact, the inconvenience caused to road users is limited.

2. IN-PLACE RECYCLING – BENEFITS AND LIMITATIONS

Cold in-place recycling offers substantial economic and environmental advantages.

2.1. Conservation of resources.

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

2.2. Reduction in the amount of waste generated.

The materials of the existing pavement are reused in their entirety, eliminating the need to landfill materials as well as the associated economic and environmental issues.

2.3. Reduction in transport.

In-situ recycling eliminates the need to transport milled materials to 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.

2.4. 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.

2.5. Reduction of emissions.

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

2.6. Less inconvenience.

Less transport and a very compact laying train do also significantly reduce the hindrance caused to road users and the neighbourhood of the job site.

Despite these considerable advantages, cold in-place recycling is still only used to a limited extent in road refurbishment in Europe. To explain this situation, one may for instance refer to the document [1] issued in 2003 by the Technical Committee C 7/8 on Road Pavements of the World Road Association (PIARC). This report has listed a number of practical constraints of which the quality of the material to be recycled, the need for adequate weather conditions and the mechanical properties to be achieved by the final material appear as being the most stringent ones.

Being conscious of these hurdles, the EUROVIA group has devoted important resources to a better understanding of cold in-place recycled materials. A major effort has first been done through the animation of the European SCORE project. Since then, this effort is being pursued on a more continuous basis by the monitoring of a number of identified paving projects.

3. SCIENTIFIC BACKGROUND – THE SCORE PROJECT

The SCORE - Superior Cold REcycling – project was financed by the European Commission as part of the 5th 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 [2-4]. SCORE has however been restricted to the recycling of bituminous materials. As an example, two particular aspects of this research are briefly exposed hereafter.

3.1. Milling conditions

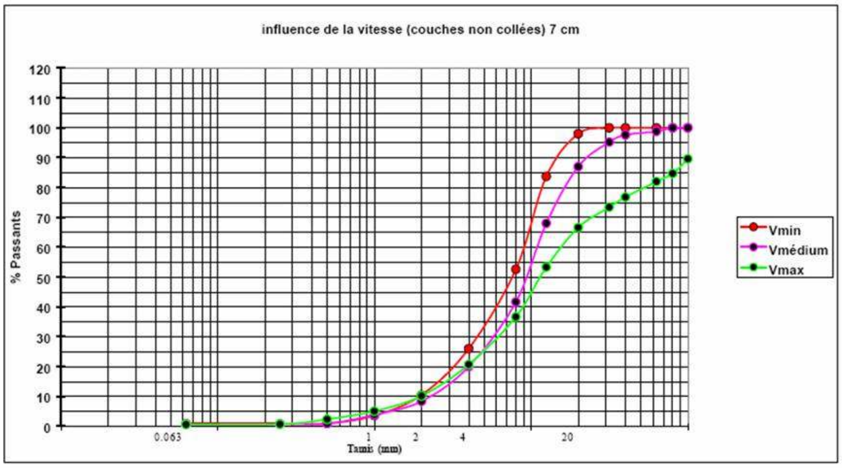


Figure 2 – Impact of translation speed. Depth of milling : 70mm. Non-bonded layers [3]

The grading of the milled material has a major impact on the final result of in-place recycling works. Maximum size of the milled material should be as small as possible so as to make compaction easier and enhance the mechanical properties of the recycled layer. The final grading depends of course on the nature and stage of degradation of the old paving materials but SCORE has shown that results can be significantly improved by choosing appropriate operating parameters. A large number of grinding teeth (to be renewed as often as necessary) and high rotation speed of the milling drum are of course favourable. Practically, it is the lowering of the translation speed (Figure 2) which will offer the most convenient lever for adjusting to most of the encountered pavement conditions. In extreme cases (highly cracked and de-bonded upper layer), it may be necessary to perform a preliminary milling of the upper layer.

3.2. Mechanical performance of recycled material

An important aspect of the performance of cold 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. To investigate this point, SCORE has tried out different accelerated laboratory curing procedures, the evolution of mechanical properties with time being monitored via stiffness modulus testing [4]. Both bituminous emulsion and foamed bitumen have been used. Since cold in-place recycled materials do in general not reach the same density as conventional hot mixes, it is important to define laboratory compaction procedures

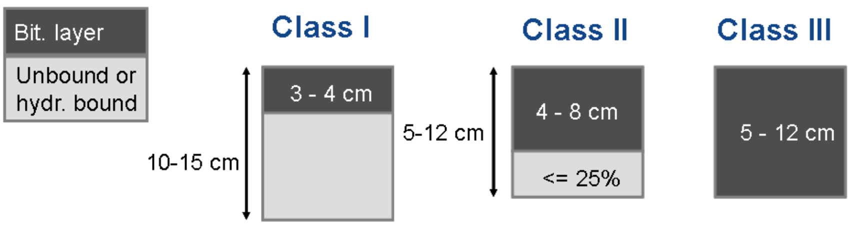
leading to void contents similar to those achievable on site (around 15%). Gyratory compaction proved to be quite convenient in that respect.
Initial characteristics of the RAP material and mix density confirmed to have a dominant impact on the final stiffness, whereas the impact of bitumen origin or binder type (emulsion vs foam) appeared as only marginal. But accelerated curing conditions may also not be equally applicable to any kind of material. When adding higher amounts of cement, for example, a too fast curing process may stop the built-up of stiffness due to a premature “drying-out” of the sample. Sample size may also have a significant impact on the speed of cohesion built-up. Curing procedure, sample size and material formulation are thus interacting and curing procedures may have to be adapted in relation to selected test procedures (sample size) and materials to be tested. It is however one of the curing procedures proposed by SCORE (see § 5.1.2.) which has been followed for the job site monitoring work reported hereafter.

4. COLD IN-PLACE RECYCLING IN FRANCE

In France, guidelines for cold in situ recycling have been established by the French Committee for Road Construction (CFTR) [5]. 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. Depending on the class of treatment and the obtained DURIEZ compressive strength, average stiffness modulus values are recommended for pavement design considerations.

Table 1 – The three cases considered in France for the
in-place recycling with bituminous emulsions [5]

Cold in-place recycling with bituminous binders in France



	Class I	Class II	Class III
Objective	Structural Reinforcement	Rehabilitation of the wearing course	
Bitumen type	Paving grade 70/100 or 160/220	Paving grade or rejuvenating bitumen	Rejuvenating bitumen
Added bitumen	**3 to 5%**	**1 to 3%**	**up to 2%**

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 (not studied within SCORE) in which the performance of unbound or hydraulically bound base layers is more subject to variability and more difficult to predict.
These considerations have urged EUROVIA to continue the effort initiated within SCORE [6].

5. MONITORING OF JOB SITES

Since 2005, cores are being taken at different time intervals on a number of RECYCLOVIA® job sites in France. In general, Class I and II recycling jobs are performed with foamed bitumen (70/100 penetration grade). In the presence of unbound or hydraulically bound materials, foam technology is indeed particularly attractive as it is less sensitive to chemical reactivity of materials than emulsion technology. In the case of Class III recycling jobs, the new binder (usually a 160/220 penetration grade bitumen) is generally added in the form of a bituminous emulsion. The evolution with time of the recycled materials is monitored by measuring the stiffness modulus of the extracted cores.

In addition, during the 2006 in-situ recycling campaign, an extensive sampling of five different RAP materials has been undertaken. Objective was to reproduce the recycled material in the laboratory, to assess its mechanical properties after curing and to compare those to the values obtained in-situ. Three materials were Class III materials treated with an emulsion of 160/220 penetration grade bitumen (materials A and D) or with a foamed 70/100 penetration grade bitumen (material E). Two materials were Class I materials treated with a foamed 70/100 penetration grade bitumen (materials B and C).

5.1. Properties of laboratory recycled materials

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

5.1.1 DURIEZ test procedure (NF P 98-251-4)

The Duriez procedure, originally developed for hot mixes, measures the axial compressive strength of statically compacted cylindrical samples after curing in air or under water. Sample size depends 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 (120kN for the large samples), a second compaction mode in which this load is reduced to one third (40kN). The results obtained with those two compaction modes are gathered in Table 2 which also indicates the values prescribed by the French guidelines [5] for the heavy compaction mode.
Not surprisingly, sample density appeared as being very dependent on RAP characteristics and type of treatment. Compressive strengths resulting from the 120kN 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. The r/R ratio is slightly decreased and seems also to be more affected in the case of Class I materials than for Class III materials (which is conform to intuition).

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% if not 20% than below 10%), they suggest indeed that for this type of materials, a reduced compaction load should be preferred.

Table 2 - DURIEZ test results

	CLASS III				CLASS I		
Material	A	D	E	Specs.	B	C	Specs.
	Compaction at 120 kN				Compaction at 120 kN		
Void content (%)	**7,4**	**5,4**	**2,6**	**<= 14**	**11,1**	**8,5**	
Compressive Strength							
R (MPa)	7,02	6,15	6,72	>= 5	4,22	6,15	>= 1,5
r (MPa)	5,59	4,56	5,56		2,54	3,34	
r/R	**0,8**	**0,74**	**0,83**	**>=0,70**	**0,6**	**0,54**	**>=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**	

5.1.2 Accelerated curing and stiffness

All samples (Φ = 150mm, h ~ 115mm) for stiffness testing have been compacted with a gyratory compactor (PCG type II – NF P 98 252). Two levels of compaction have been aimed at, so as to get as close as possible to the values obtained with the two DURIEZ compaction modes.

The so-compacted samples have then been subjected to the curing procedure derived from the SCORE project and other research [4,7]. 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 where 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 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, under either a sinusoidal loading (IT-S) or impulse loading (IT-P). 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 124ms.

The final stiffness values obtained after 21 days of curing are to be seen in Figures 3 and 4. Stiffness levels differ from one material to the other. The possible reasons (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. Major finding is the strong dependency of stiffness upon compacity.

5.2. Evolution of stiffness in-situ

5.2.1. Analysis of cores taken from Class III job sites

Although quite scattered, the stiffness moduli measured on field cores show the same dependency on density as those measured on the laboratory made samples. Void contents are frequently higher than 15%, which results in stiffness moduli below 3000MPa or even lower than 2000MPa. Values between 3000MPa and 4000MPa are more easily obtained for void contents below 15%.
Material A is the only one for which a direct comparison (similar density) 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. Generally, maximum stiffness on site seems to be reached in the first year.
Material 3/a is a special case since actual binder content of both the RAP material and final mix proved to be significantly higher than estimated from the preliminary investigations. This would explain both the low (but probably underestimated) void contents and the low stiffness values (which increase however after 17 months).

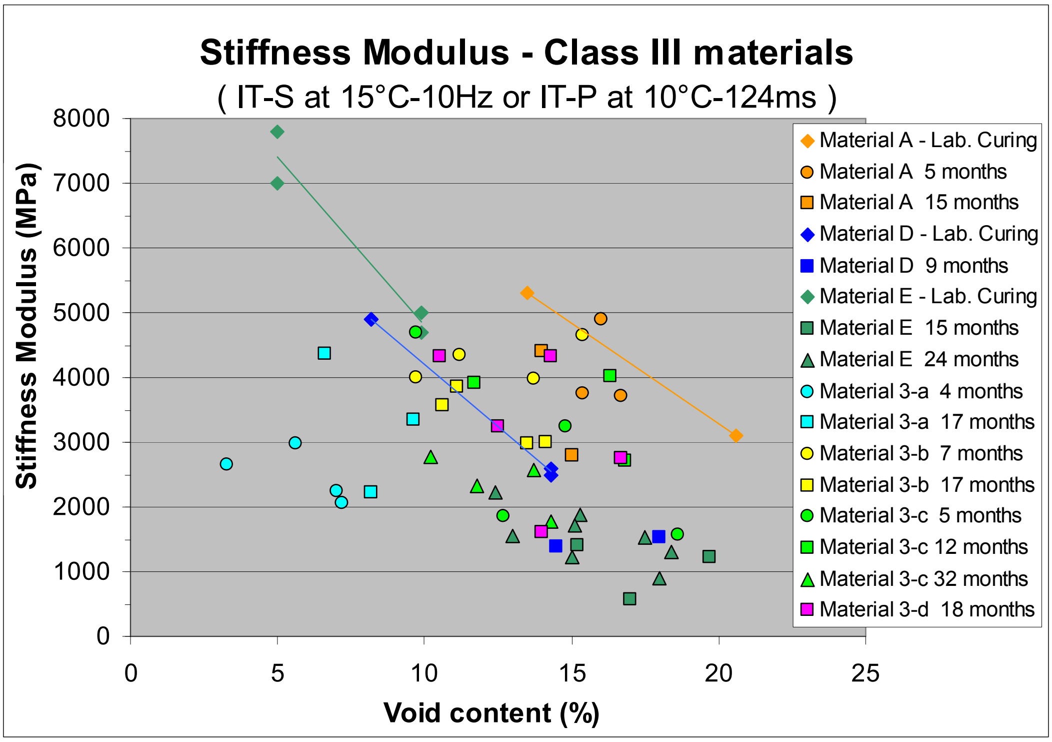


Figure 3 – Stiffness values - Class III materials

5.2.2. Analysis of cores taken from Class I & II job sites

Again, we see a strong relationship between stiffness and void content. Void contents below 15% and close to 10% seem however to be more easily obtained than in the case of Class III materials. This is likely to be due to the grading curve of the RAP material which, especially when it includes unbound materials, shows higher contents in fines and sand, which could make this material easier to compact than Class III materials. The resulting stiffness moduli are then more constantly in a range between 3000MPa and 5000MPa than in the case of Class III 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. For material B, however, stiffness follows a different path from what is suggested by the laboratory cured samples. 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.

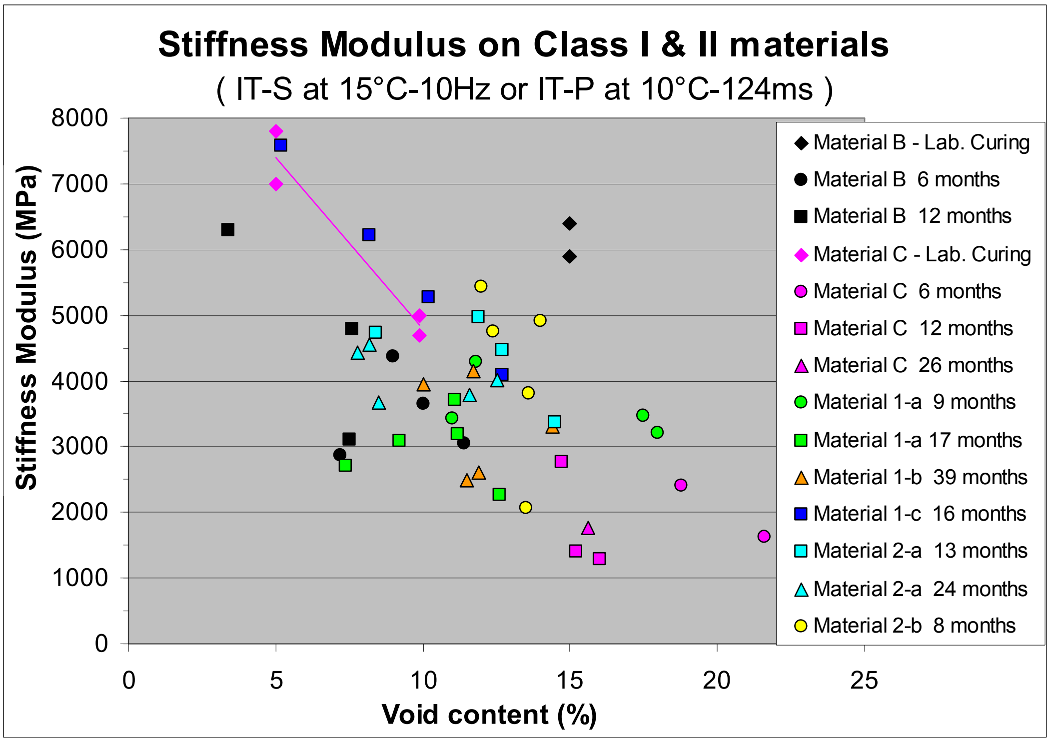


Figure 4 – Stiffness values - Class I & II materials

5.3. Monitoring of job sites - some 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 therefore recommended that formulation studies for cold recycled materials are made on samples compacted to realistic (likely to be obtained in practice) densities. Reducing the compaction load in the case of static compaction (DURIEZ procedure) or adjusting the number of gyrations in the case of gyratory compacted samples are possible ways to achieve this goal.
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.
In most cases (especially for the materials with a high void content), the stiffness obtained in-situ seems to level-out relatively quickly (between 6 and 18 months). For Class III materials this level is fairly well in-line with the stiffness versus void content correlation obtained on laboratory samples cured according to the procedure described in § 5.1.2.
The situation is less clear in the case of foam recycled Class I & II materials for which more field and lab data are obviously needed.

6. BEST PRACTICE – FIELD OF USE

A more thorough analysis of the particular conditions of each job site has further allowed us to evidence a number of factors affecting both the obtained densities and stiffness values. Those which impact most the final density are the intrinsic characteristics of the milled material (grading, content and hardness of the residual binder) but also the bearing capacity of the underlying structure and insufficient compaction. Adequate curing conditions are also essential. Cold in-place recycling should preferably be done in spring and early summer, adequate drainage of the pavement structure should be ensured and the recycled layer covered with a surface course of appropriate thickness. Shortcomings on one or several of these recommendations were involved in the case of materials A, D and C and are likely to explain the relatively poor in-situ behaviour of these materials.
Along with the above exposed "laboratory data", the job site monitoring activities have thus allowed EUROVIA to better understand the limits of applicability of the cold in-place recycling technique as performed with the Wirtgen 2200 CR machine. Those are summarized hereafter.

6.1. Good practice recommendations

The aggregate grading curve of in-place recycled materials, for which we consider as a base case that there is no virgin material added (except for some cement or hydrated lime), is essentially driven by the milling conditions and the state of degradation of the existing pavement layer. We have seen in § 3.1 that adequate operating parameters can have a significant impact on mainly the larger aggregate sizes and thus enhance compaction and evenness of the recycled layer. Milled materials are indeed generally characterized by a relatively "open-graded" aggregate gradation (low sand fraction) which makes their compaction intrinsically difficult. This is especially true for Class III treatments for which void contents typically range from 15% to 20%. Under well controlled and favourable conditions (in particular on a rigid sub-structure) values in-between 10% and 15% are however possible. This range may be more easily obtained for Class I and Class II materials which incorporate a certain amount of untreated granular materials. In this case, the grading is often more favourable for compaction, provided however that this advantage is not thwarted by the adverse effect of material roughness.

In-place recycling also imposes the retreated material to be compacted as a single lift. Together with the above considerations on the specific grading curve of milled materials, this constraint explains that, more importantly than the intrinsic possibilities of the recycling machine, it are the possibilities of the compacting equipment and the bearing capacity of the underlying structure which condition the limiting depth for the RECYCLOVIA® process. Although the machine allows milling depths up to 180mm, our experience confirms the recommendations already given in the SETRA Guidance document [5], i.e. of a maximum depth of 120mm for Class II and III works and of 150mm for Class I works.

As for any cold mixed material, adequate curing conditions are essential for a successful cold in-place recycling job. This means that works in late autumn are to be proscribed, especially under the least favourable climatic and environmental conditions (rainy climate, mountain areas). First stage curing is accelerated by delaying the application of the final wearing course by 2 to 3 weeks (weather conditions need however to be favourable). The application of a chip seal, which protects the freshly retreated layer against early ravelling and further water ingress allows however the immediate opening to traffic. But favourable weather conditions are not the only key factor for a quick and large increase in cohesion. It is also essential to ensure a proper drainage of the whole pavement structure. The hereto necessary additional works (clearing of ditches) should never be forgotten!

As stated earlier, compaction of the retreated material occurs on a single lift. The thicker the lift, the more difficult it will be to guarantee a high standard of longitudinal and transverse profile. Correction of evenness as well as the need to protect a material having a relatively high void content and low stiffness in its early stage make it compulsory to apply an overlay of which the thickness depends also very much on the expected traffic.

It is further to be emphasized that the in-situ recycling process as described here is entirely dependent on the state of the existing road structure and the intrinsic quality of its constituent materials. It is then essential to get an early and good understanding of these givens so as to correctly evaluate both the feasibility and the cost-effectiveness of the considered project. This calls for preliminary investigations (visual assessment, deflection measurements, borings …) so as to determine the pavement composition, its structural condition (bearing capacity, layer bonding) and the origin of the observed distresses. It is also important to determine the variability of these parameters over the length of the job site since too large fluctuations may compromise the applicability of the technique.

Extracted cores and samples of road materials are to be as representative as possible of the different identified "homogeneous" sections of the job site since they are the basis for the necessary laboratory formulation studies. This is where adequate laboratory procedure (such as specific laboratory sample manufacturing and accelerated curing procedure), as well as the experience gained by the pavement engineer, are of prime importance.

In the case of Class I and Class II works, in which variable amounts of untreated or hydraulically bound materials are encountered, we found it preferable to use foamed bitumen. It is then not necessary to cope with the problem of mastering the breaking behaviour of a bituminous emulsion in relation to the fluctuating reactivity of the "white" materials. In many cases, it is also advised to use the foam in conjunction with some lime (0.5 to 1%) to improve the stripping resistance of the final material. Bituminous emulsions are preferably (but not exclusively) used in the case of Class III materials which show a much lower reactivity. The addition of cement allows boosting early cohesion and may be more particularly advised in cases where expected curing conditions are poor.

6.2. Field of use

As it is shown in § 5.2, the stiffness values likely to be reached by cold in-place recycled materials when observing the rules of "good practice" discussed in § 6.1 range from about 3500MPa to 4500MPa (15°C-10Hz). These relatively modest values imply that the intrinsic reinforcing power of a cold in-place recycled layer is limited. In the case of a clear structural weakness of the existing pavement and/or heavy traffic loads, a relatively thick overlay of new materials will be necessary. It is however to be mentioned at this stage that so far the technique has been used with only a limited amount of mineral additives such as cement or lime (max. of 1%). Much higher stiffness values are certainly achievable with higher amounts of cement or lime but have not been tried so far considering the higher costs and the risks of shrinkage cracking.

In other words, it is the thickness of the bituminous cover imposed by the structural condition of the existing pavement and the expected traffic intensity which will determine the cost-efficiency and acceptability of the cold in-place recycling technique. Cold in-place recycling is more particularly well suited for the remediation of surface course disorders such as surface ageing, stripping and ravelling, de-bonding of layers, … on pavement structures which are still structurally sound such as thick bituminous pavements or semi-rigid pavements. In such cases, the depth of milling will generally be limited to just under the interface of the worn-out surface course (typically 50mm to 80mm) and the thickness of the new overlay will be imposed by specifications on final evenness and traffic intensity rather than by structural design considerations. In cases where the pavement requires deeper milling and when the structural condition is no longer sufficient with regard to the expected traffic (e.g. in the case of flexible roads), the thickness of the new overlay will be more directly imposed by structural design considerations. In all cases, a correct appraisal of the structural condition of the existing pavement appears obviously as essential for the adequate design and success of a cold in-place recycling operation.

7. ENVIRONMENTAL IMPACT

7.1. A dedicated tool

As stated earlier the environmental benefits are one of the main drivers for cold in-place recycling and, when answering a tender, those aspects should be evaluated at the same level as the purely technical aspects. This is why EUROVIA has designed and developed a specific software package called $GAÏA_{BE}$. It allows to evaluate and compare the environmental impact of different pavement maintenance solutions for a given job site. This means that all the input data to be entered, such as supply distances, type of transportation, type of mixing and laying equipment, … are those which specifically apply to the considered job site. The environmental impact parameters and the methodology retained by the software are in conformity with those defined in the NF P 01-010 and NF EN 14040 standards on Life Cycle Analysis. In particular, they include the depletion of natural resources, energy consumption and the emission of greenhouse gases. The software does also consider a number of additional indicators which are more specific to the road industry such as the consumption of virgin aggregates, direct consumption of fuel or the amount of local transport.

To illustrate and quantify the environmental benefits one may expect from cold in-place recycling, two example $GAÏA_{BE}$ calculations are presented hereafter. Six environmental indicators have been retained.

Depletion of natural resources (ADP – Abiotic Depletion Potential)
Sum of natural resources taken from the environment (e.g. aggregates, bitumen, …). Each item is weighed by a factor which accounts for its lower or greater occurrence in nature. The end result is expressed as an equivalent mass of Antimony (kg S_b equ.)

Consumption of virgin aggregates
This specific indicator quantifies the amount of natural aggregates (excluding reclaimed or artificial materials) which are required for the paving job.

Energy consumption
Energy consumed for the manufacturing of materials, their transportation to the job site and the execution of the paving works. It includes the direct consumption (activities of the road building company) as well as the indirect consumptions (upstream and downstream activities). The retained indicator (expressed in MegaJoules – MJ) is the total energy consumed, i.e. a weighed sum of renewable and non-renewable energy resources.

Direct consumption of fuel
Energy consumption directly related to the paving operations, i.e. fuel or gas used for the manufacturing of paving mixes, transportation to and from the job site, recycling and laying operations. This indicator is expressed as an equivalent volume of fuel (l fuel equ.).

Emission of greenhouse gases
The greenhouse effect is the main phenomenon pointed at for being responsible for climatic changes. It is related to the increase in the atmospheric concentration of gases known as “greenhouse gases”. The “greenhouse gases” indicator is calculated as the sum of the emitted amounts of these gases weighed by a factor which reflects their specific incidence on the greenhouse effect. For instance, 1 kg of methane (CH_4) has the same impact as 21 kg of carbon dioxide (CO_2). The indicator for the emission of greenhouse gases is thus expressed in kg CO_2 equ.

Local road transport
This indicator accounts for the nuisance caused by the transport of materials from and to the jobsite. It is expressed as the mass of transported material multiplied by the transport distance (ton.km).

7.2. Environmental impact – Case history N° 1.

The first case history corresponds to a typical “Class III” (see § 4) in-place recycling operation in which a worn-out bituminous surface (ravelling, poor bonding to base layer) is to be renewed. The overall structure is still sound and does not need to be reinforced. The conventional repair would consist in milling-off the surface course over a depth of 70mm and replacing it with 50mm of semi-coarse asphalt concrete topped by 25mm of a very thin surface course mix. The alternative consists in the in-place treatment of the old bituminous wearing course with a bituminous emulsion and a low amount of cement, still over a depth of 70mm, followed by the application of a 40mm overlay of thin asphalt concrete. These givens and the resulting values for the six above defined environmental indicators are summarized in Table 3.

Table 3 – Environmental impact – Case of a Class III in-place recycling project

Project description	Depth / Thickness (cm)	Quantity (tons)	Transportation distance (km)	ton.km
Base case				
Milling of existing structure / Withdrawal of RAP	7	5 900	40	236 000
Application of new bituminous concrete	5	4 200	40	168 000
New surface course mix	2.5	2 100	40	84 000
				488 000
In-situ recycling with emulsion (Class III)	7	-	-	
Supply of water	-	170	10	1 700
Supply of emulsion	-	165	150	24 750
Supply of cement	-	29	200	5 800
New surface course mix	4	3 300	40	132 000
				164 250
Environmental indicators	***Base case***	***In-situ recycling***		
Depletion of natural resources ADP (kg Sb equ.)	10 543	7 508	**-29%**	(1)
Energy consumption (MJ)	5 405 974	3 614 278	**-33%**	(1)
Emission of greenhouse gases (kg CO2 equ.)	336 830	236 435	**-30%**	(1)
Consumption of virgin aggregates (tons)	5 961	3 167	**-47%**	(2)
Direct fuel consumption (l fuel equ.)	92 506	49 055	**-47%**	(2)
Local road transport (ton.km)	488 000	164 250	**-66%**	(2)

(1) Indicator calculated according to the rules set by NF P 01-010 standard of Dec. 2004
(2) GAÏA$_{BE}$ specific indicator

7.3. Environmental impact – Case history N° 2.

The second case history corresponds to the case of a degraded surfacing (50mm of bituminous materials) laid on top of a hydraulically bound granular base. The conventional repair would consist in milling-off the surface course over a depth of 60mm and replacing it with 60mm of semi-coarse asphalt concrete topped by 40mm of a thin surface course mix. The in-place recycling alternative is performed over a depth of 70mm, the milled material being treated with foamed bitumen and the addition of hydrated lime. The so-treated material is covered with 50mm of asphalt concrete so as to maintain the overall structural capacity of the road. The depth of the treatment and the proportion of non-bituminous material (~30%) in the treated layer classify this job as close to a "Class II" recycling operation (see § 4). These givens and the resulting values for the six above defined environmental indicators are summarized in Table 4.

Table 4 – Environmental impact – Case of a Class III in-place recycling project

Project description	Depth / Thickness (cm)	Quantity (tons)	Transportation distance (km)	ton.km
Base case				
Milling of existing structure / Withdrawal of RAP	6	1 100	20	22 000
Application of new bituminous concrete	6	1 100 (10% RAP)	20	22 000
New surface course mix	4	750	20	15 000
				59 000
In-situ recycling with emulsion (Class III)	7	-	-	
Supply of water	-	60	10	600
Supply of bitumen	-	40	200	8 000
Supply of hydrated lime	-	7	200	1 400
New surface course mix	5	920 (10% RAP)	20	18 400
				28 400
Environmental indicators	***Base case***	***In-situ recycling***		
Depletion of natural resources ADP (kg Sb equ.)	2 453	2 108	**-14%**	(1)
Energy consumption (MJ)	1 430 149	960 509	**-33%**	(1)
Emission of greenhouse gases (kg CO2 equ.)	77 987	59 774	**-23%**	(1)
Consumption of virgin aggregates (tons)	1 647	797	**-52%**	(2)
Direct fuel consumption (l fuel equ.)	23 572	12 600	**-47%**	(2)
Local road transport (ton.km)	59 000	28 400	**-52%**	(2)

(1) Indicator calculated according to the rules set by NF P 01-010 standard of Dec. 2004
(2) GAÏA$_{BE}$ specific indicator

8. CONCLUSIONS

Cold in-place recycling offers undoubtedly considerable environmental benefits. As shown by the two presented case histories, emission of greenhouse gases and energy consumption are reduced by at least 20% to 30% whereas the gain in the consumption of virgin aggregates can easily reach as much as 50%. Although they may vary depending on the location of the job site and the distances to the various supply points, the transportation needs, and hence the associated costs and environmental nuisance, are very substantially decreased.

Thanks to dedicated research and continuous monitoring activities, it has been possible to better understand the actual performance one may expect from cold in-place recycled materials. The main factors influencing this behaviour have also been identified, leading to practical guidelines for a better efficiency. Appropriate milling conditions, proper drainage of the structure and good curing conditions are the main keys for a successful job whereas further improvements may be expected from better compaction equipment and compacting schemes. We have also gained a better insight on the significance of our usual laboratory tools. Several tracks for improving test methods and in particular for assessing the curing behaviour of cold recycled materials have been identified. They will allow to further optimize the formulation of these materials.

The essential preliminary step to any potential cold in-place recycling operation is however the auscultation of the existing pavement so as to clearly identify the causes for the observed distresses. A too advanced structural deficiency, which would request a significant thickness of overlay on top of the recycled layer, may indeed compromise both the technical and economical feasibility of the project.

All these advances and the observation of the inherent limits of the process should certainly allow cold in-place recycling to fully conquer the market of rehabilitation works for which it is suited.

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