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REDUCING EMISSIONS AND CONSUMPTION OF VIRGIN AGGREGATES THROUGH COLD IN-PLACE RECYCLING

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ABSTRACT

The increasing demand for the preservation of natural resources and environmentally friendly techniques is a strong incentive for the development and implementation of cold in-place recycling techniques. The paper presents a process in which all the functions needed to complete the recycling work are dealt with by a single and powerful equipment (cold recycling machine. It allows recycling to be done with either a bituminous emulsion or with foamed bitumen. The laboratory and in-situ performance of such recycled materials has already been presented at the 2008 E&E Congress. This paper presents additional laboratory and field data. This accumulated experience has allowed to better identify the main factors influencing material properties, leading to practical guidelines for best practice and better efficiency. A major part of the paper is however devoted to the environmental benefits which are achievable with this technology. This is done on the basis of several case histories by calculating a number of specific indicators, of which the most important ones are the emission of greenhouse gases, energy consumption, depletion of natural resources, consumption of virgin aggregates and amount of road transport.

Keywords: Emissions, Economics, Environment, In-situ Recycling, Stiffness

1. INTRODUCTION

Cold in-place recycling offers substantial economic and environmental advantages. A reduced consumption of virgin aggregates and bitumen, a nearly complete elimination of any waste to go into landfills, a significant reduction of transport activities and the associated costs, reduced emissions and nuisance to road users as well as energy savings are obvious incentives for the development of these techniques. To get the full benefits of these potential advantages, it is however necessary to fully master the technique and to clearly identify its true domain of application. Premature failures are indeed the worst enemy of any new process, whatever its potential long term sustainability. This has urged EUROVIA to devote important resources to the formulation and assessment of the product, as well as to the monitoring of its performance in-situ. These studies have already been addressed in a previous communication [1]. Additional results are reported here together with the practical lessons learned from these laboratory and on-site investigations. Once these lessons are fully understood and applied, one may be confident about gaining all the expected environmental and economic advantages. Two practical examples show that those are indeed considerable.

2. COLD IN-PLACE RECYCLING

2.1 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 in-place 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.

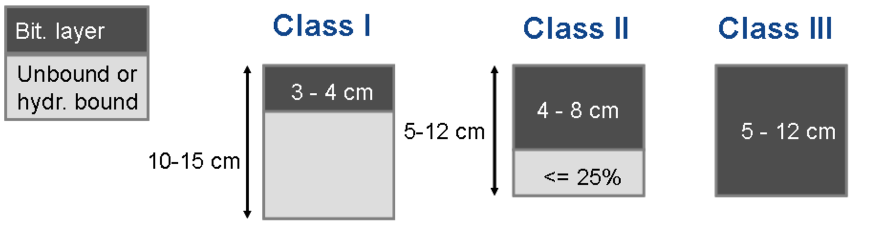
Figure 2 – Recycling work in progress

2.2 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) [2]. 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.

Table 1 – The three cases considered in France for the in-place recycling with bituminous emulsions [2]

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 required a better understanding of how such recycled materials build-up their mechanical strength with time. This is especially true for Class I treatments in which the performance of unbound or hydraulically bound base layers is more subject to variability and more difficult to predict.

3. MONITORING OF JOB SITES

Since 2005, cores are being taken at different time intervals on a number of in-situ recycling jobs 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.
An extensive sampling of five different RAP materials has further been undertaken during the 2006 in-situ recycling campaign. 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). The mechanical performance of these laboratory prepared recycled materials (compressive strength and evolution of stiffness following an accelerated curing procedure), as well as a first set of field data, have been extensively reported in a previous communication [1]. They are briefly reminded hereafter.

3.1 Properties of laboratory recycled materials

3.1.1 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). Our results constantly showed a very strong impact of compaction load. Whereas for the standard procedure, the obtained void contents are generally lower than 10%, they are markedly higher when the compaction load is reduced. Knowing the void contents generally obtained in the field, (rather in a range from 10% to 15% if not 20%), they suggest that for this type of material, a reduced compaction load should be preferred.

3.1.2 Accelerated curing and stiffness testing

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 samples have then been subjected to a curing procedure derived from the SCORE and other projects [3, 4]. Curing consisted in two successive conditioning steps. To simulate the very early stage immediately after application, the samples were first maintained for 7 days at 18°C and 55% of relative humidity (RH). This phase was followed by 14 days of storage at 35°C and 20% RH so as to get close to the ultimate strength of the material. At regular intervals during the curing process, samples were tested for dynamic modulus in an axial sinusoidal compressive mode at 15°C-10Hz. At the end of curing, additional tests performed in a diametrical compressive mode under either sinusoidal loading (IT-S) at 15°C-10Hz or impulse loading (IT-P) at 10°C-124ms gave similar results, comparable to those obtained under axial loading conditions. These results, which may of course not be extrapolated to different kinds of materials (in particular materials exhibiting higher density and stiffness levels), did however validate the possibility to compare stiffness values measured on field cores in a diametrical compressive mode (IT-S at 15°C-10Hz or IT-P at 10°C-124ms) to the values measured on the laboratory cured samples.

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.

3.2 Evolution of stiffness in-situ

The data already reported in 2008 [1] have been completed with a number of additional data. For the sake of readability, only a selection (yet representative of the full data set) of these results is represented in Figure 3 and 4.

3.2.1. Analysis of cores taken from Class III job sites

Although quite scattered, the stiffness moduli measured on field cores show the same strong dependency on density as those measured on the laboratory made samples. Void contents are frequently higher than 15%, which often 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%.

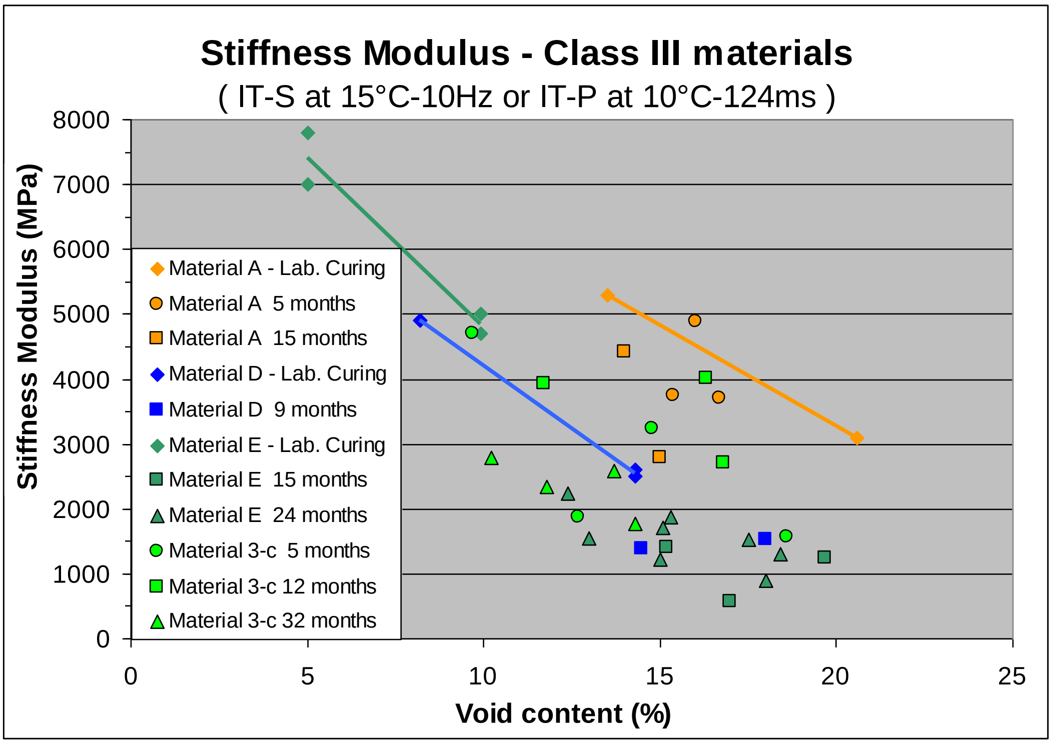


Figure 3 – Stiffness values - Class III materials

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

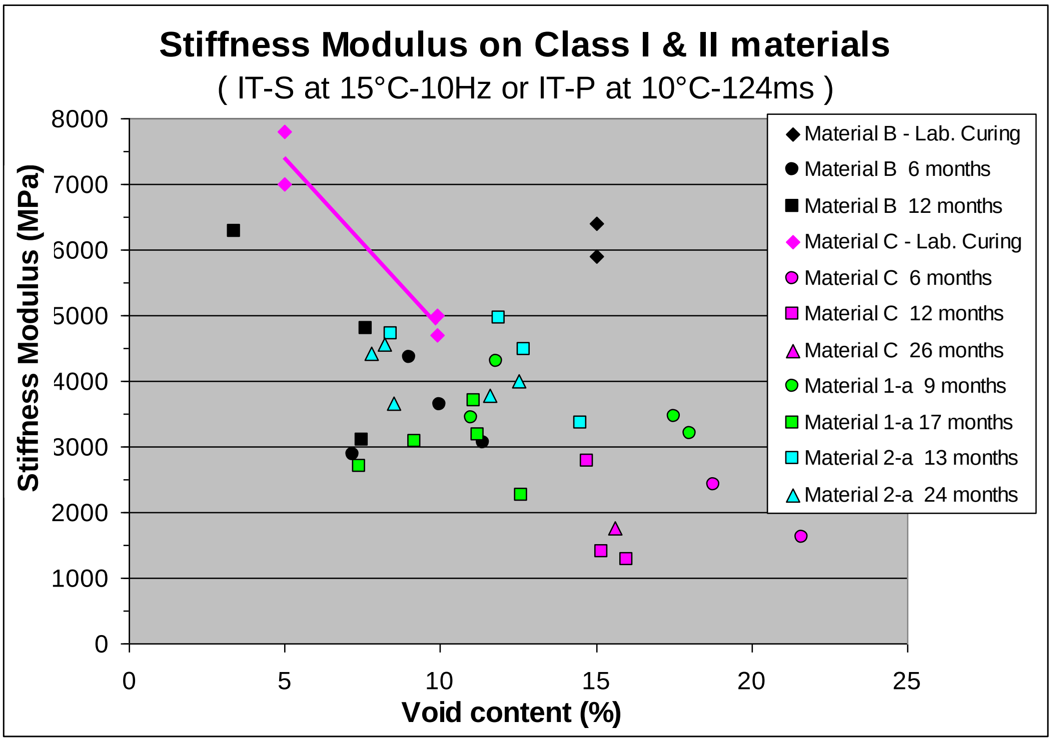


Figure 4 – Stiffness values - Class I & II materials

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 fact that the grading curve of the RAP material, especially when it includes unbound materials, shows more fine and sand materials and is thus 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.

3.3 Some conclusions – accelerated curing

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 offer possible ways to achieve this goal.

Considering the limited number of available results and the variability of the void contents measured on field cores extracted at different points in time, it is not possible to clearly identify the occurrence of a maximum for in-situ stiffness. In most cases, it seems however that maximum stiffness is reached within the first year.

Since the void levels obtained in-situ often proved to be higher than those achieved via laboratory compaction, it is also hard to conclude on whether the maximum stiffness on-site is comparable to the stiffness obtained after laboratory curing. In the case of Class III materials, one may however observe that the stiffness values measured in-situ are consistent with the “stiffness versus void content” line obtained on the laboratory cured samples. The situation is less clear in the case of foam recycled Class I & II materials. Whereas the stiffness values obtained in-situ for material C are in line with those measured on laboratory cured samples, the predicted values turned out to be far too optimistic in the case of material B. For this particular material, a specific reason for this may have been that the laboratory investigated material proved to be somewhat different from that finally encountered on-site.

The still limited number of available data on both laboratory cured and comparable field cores does thus not yet allow to make any firm conclusion as to the validity of the accelerated laboratory curing procedure applied in this study. With the exception of material B, the procedure proved however to at least predict the adequate ranking between materials. For the time being, there are thus no objective reasons to change the adopted curing procedure and it has been decided to keep it for future comparisons to in-situ behaviour. The importance of being fully representative of field curing conditions has also to be put into perspective considering the paramount impact of void contents.

4. 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 led to a better understanding of the limits of applicability of the cold in-place recycling technique as performed with the Wirtgen 2200 CR machine. Those are summarized hereafter.

4.1 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. Adequate milling conditions, i.e. number and state of grinding teeth, drum rotation speed and, especially, a correct translation speed in relation to milling depth can have a significant impact on mainly the larger aggregate sizes and thus enhance compaction and evenness of the recycled layer [5].

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 in-situ recycling process. Although the machine allows milling depths up to 180mm, our experience confirms the recommendations already given in the SETRA Guidance document [2], 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 job. 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. Another key requisite for a quick and large increase in cohesion is 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 the material 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. An early and good understanding of these givens is then essential for a correct appraisal of 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.

4.2 Field of use

As it is shown in § 3.2, the stiffness values likely to be reached by cold in-place recycled materials when observing the rules of “good practice” discussed in § 4.1 range from about 3500MPa to 4500MPa (15°C-10Hz). These relatively modest values (in comparison to the values of 5000 to 7000MPa typically obtained for hot wearing course mixes) 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.

5. ENVIRONMENTAL IMPACT

5.1 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).

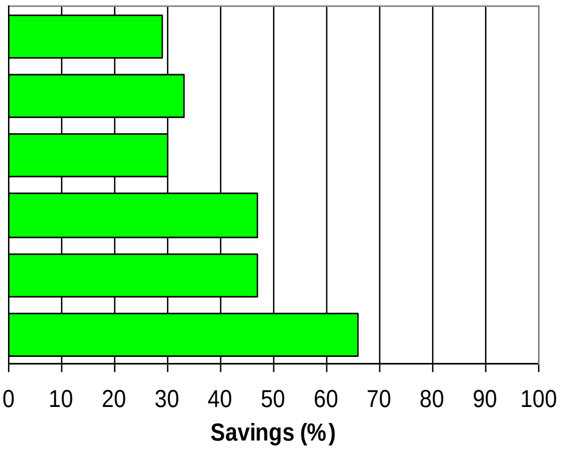
5.2 Environmental impact – Case history N° 1.

The first case history corresponds to a typical “Class III” (see § 2.2) 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 2.

Table 2 – 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	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	*Savings : In-situ recycling / base case*
(1) Depletion of natural resources ADP (kg Sb equ.)	**-29%**
(1) Energy consumption (MJ)	**-33%**
(1) Emission of greenhouse gases (kg CO2 equ.)	**-30%**
(2) Consumption of virgin aggregates (tons)	**-47%**
(2) Direct fuel consumption (l fuel equ.)	**-47%**
(2) Local road transport (ton.km)	**-66%**



(1) Indicator calculated according to the rules set by NF P 01-010 standard of Dec. 2004

(2) GAÏAʙᴇ specific indicator

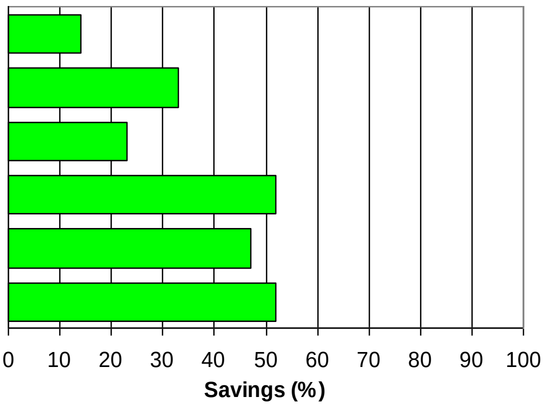
5.3 Environmental impact – Case history N° 2.

The second case history corresponds to the case of a degraded surfacing (50mm of bituminous materials) laid on top of an 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 § 2.2). 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 II 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 foamed bitumen	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	*Savings : In-situ recycling / base case*
(1) Depletion of natural resources ADP (kg Sb equ.)	**-14%**
(1) Energy consumption (MJ)	**-33%**
(1) Emission of greenhouse gases (kg CO2 equ.)	**-23%**
(2) Consumption of virgin aggregates (tons)	**-52%**
(2) Direct fuel consumption (l fuel equ.)	**-47%**
(2) Local road transport (ton.km)	**-52%**



(1) Indicator calculated according to the rules set by NF P 01-010 standard of Dec. 2004
(2) GAÏABE specific indicator

6. 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.

All these substantial advantages can however only be secured if the in-situ recycling technique is also fully mastered from a technical point of view. Dedicated research and continuous monitoring activities have allowed us to better understand the actual performance one may expect from cold in-place recycled materials. The main factors influencing this behaviour have 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. Several tracks for improving test methods and in particular for assessing the curing behaviour of cold recycled materials have also 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.

Taking advantage of all these advances while staying within 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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