Stripping Phenomenon in Thick Pavement Top Layers

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ABSTRACT: Most of the heavily trafficked French roads, like thick pavement structures, are now thirty or forty years old. Since construction, top layers only, have undergone one or more repair operations. Traditional rehabilitation works consist in overlaying the old wearing course or in milling it before covering it with a new overlay. For a few years, unusual deteriorations in highway structures, like pothole series or top layer delamination, have appeared. These phenomena generally occur after winter and more precisely during rainy events. The purpose of this paper is to investigate three cases of degradations observed for both rehabilitation types. The mechanics of the action causing upper layer deteriorations has to do with freeze-thaw processes combined with humidity and traffic. Nevertheless, other causes can add further to pavement degradation long before any surface deteriorations appear. The presence of water near the surface, for instance, can explain some of the damages observed. The fatigue of the layers during hot weather periods can also be at the origin of damages, even though rutting is more traditionally expected as a consequence of fatigue. Deterioration processes are discussed and illustrated by results from a study conducted on the LCPC's circular test track facility revealing some fatigue phenomenon at the level of the first interface when the weather is hot, which, combined with traffic and rainy, wintry conditions, can weaken top layers and lead to their quick degradation.

KEY WORDS: Field case, pothole, water, interface.

1 INTRODUCTION

The bigger part of the French highway network, made principally of thick bituminous semi-rigid or composite pavements has been built thirty or forty years ago. Several rehabilitation campaigns have since been conducted consisting in replacing the old wearing course by either removing or overlaying it. Consequently, sections with an initial hydraulic base course are nowadays covered with a non-negligible thickness of hydrocarbon layers so that they behave like thick pavement structures. For a few years, some of these pavements present increasing surface degradations, which are not *a priori* due to the usual mechanisms of degradation (base course fatigue, permanent deformations). For instance, surface deteriorations, like potholes or stripping of the wearing course in patches, appear over long sections without forerunners and within a very short lapse of time (a few days sometimes) at the end of the winter period (Kandhal and Richards 2001, Mauduit et al. 2007).

Faced with such problems, road network management authorities have called on the scientific community for long-lasting maintenance solutions. The risk that these degradations appear on still intact sections or on nearby roads has also to be assessed. Therefore, three cases of surface degradations occurred rather suddenly over long sections of roads in rainy and wintry conditions are described. The parameters involved in these sudden phenomena and the potential triggering mechanism at work during freezing-thawing are discussed. A certain number of other mechanisms that can have contributed to weakening the multilayer medium made up of all the pavement former wearing courses are also presented. Finally, among these, pavement interface wear is particularly examined and illustrated by the experiment carried out on a pavement structure in alternately cold and hot weather conditions using the circular test track facility. We particularly concentrate on the description of the deformation signals from the upper part of the structure.

2 PATCH STRIPPING IN SURFACE COURSES

This section is a factual description of three recent actual cases of deteriorations appeared on pavement surfaces at the end of winter. The first case dates back to 2005 in the northeast of France. On this pavement, the last maintenance operation had consisted in milling the old wearing course and overlaying a new one. The second case took place in the East of France in 2007. The first deteriorations of the third appeared in 2008 in the South of France after the old wearing course had been covered by a new one.

2.1 North-East France Case (year 2005)

The traffic of the pavement described here is 2,700 HT a day. This road is a semi-rigid pavement structure with a 40 cm thick base course of hydraulic bound materials. Nowadays, after several maintenance campaigns, it remains about 20 cm of hydrocarbon materials : 4 cm of Thin Asphalt Concrete (TAC) dating from 2000, 1 to 2 cm of Thin Asphalt Concrete (TAC) dating from 1996 and left after the planer, on two layers (2 x 7cm) of Semi Granular Asphalt Concrete (SGAC). Local eruptive materials (microdiorite) are used, the adhesiveness of which is sometimes weak as regards the binder and often requires an additional adhesion agent. The road lies within a region cut by valleys where the continental climate is characterized by cold and humid winter times.

The degradation survey carried out in 2005 reveals clean transverse and longitudinal cracks at wheel track level on the traffic lanes throughout the 2.5 km of the section considered. The first 500 meters of the section also present extensive repair works and significant branched longitudinal cracking. Previous deflection measurements, however, had not shown any particularly structural failure sign. During winter 2005/2006, many potholes, which made emergency repair sometimes several times a day necessary, appeared in a few days (Figure 1). These 5 to 12 cm deep and several square decimetre large potholes were numerous, close to each other and located on the climbing lane, preferentially on the lane wheel tracks.

The samples extracted from the pavement after degradations had appeared show that the hydraulic bound base course is in very good condition whereas the cracked and crazed wearing course rests on two degraded layers.

(a)

(b)

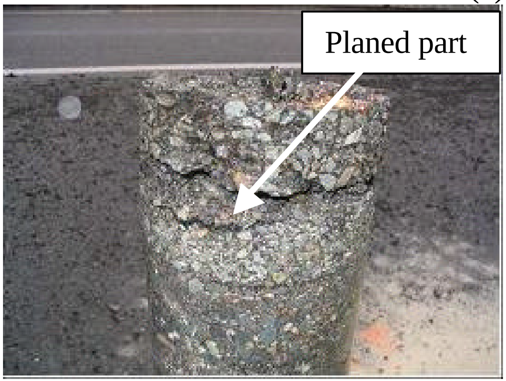

Figure 1: Pavement whose wearing course is laid on a planed surface.
(a) Potholes in chains (b) Damaged binder course under the wearing course.

2.2 Northern France Case (year 2007)

The pavement configuration here is straight with an upward slope and a superelevation of 2.5% in direction 1 and a downward slope with similar opposite superelevation in direction 2. It lies in flat open country with a continental climate characterized by excessive thermal and hydrous amplitudes. In 2006, nearly 8,000 HT a day were counted. The structure of the pavement, built in 1976, is a composite gravel-cement mixture, on which several maintenance campaigns have been carried out. Today, the gravel-cement composite structure is covered by 19 cm of hydrocarbon bound material in both traffic directions: 7 and 9 cm of SGAC dating from 1976 and 1992, respectively and a VTAC of 2.5 cm with a void content generally higher than 15% implemented in 1997.

During winter 2007/2008, potholes developed within a very short lapse of time requiring frequent and urgent repairs (Figure 2).

(a)

(b)

Figure 2: Pavement whose the drainage system is unsatisfactory.
(a) Pothole repair (b) Core sample showing base and sub-base in good condition.

Tack coat layers are visible and correctly proportioned. Porphyritic pavement material, systematically combined with an adhesion agent, is used. The hydrocarbon binder found in the wearing course is elastomer-bitumen whereas grade 35/50 bitumen is used for lower layers. The pavement condition survey conducted in 2006 has produced deflection and curvature radius measurements, which demonstrate the very good mechanical performances of the pavement. The presence of some longitudinal and transverse surface cracks in both traffic directions had been reported at that time but, finally, proved superficial after core samples had been taken.

Pothole dimensions could exceed one square decimetre, be 6 to 8 cm deep and were found on both the slow and the fast lanes over a linear section of nearly 3 km. They were principally located at the lowest point of the longitudinal section where there is no water outlet.

2.3 Southern France Case (year of disorder appearance: 2008)

In this case, a new wearing course has been implemented over the old one. Traffic is 3,000 HT a day. The region, where the pavement lies, is subject to very hot periods in summer and cold ones in winter. The pavement was built in 1990 on a sound formation roadbed with 20 cm of untreated graded aggregate, 12 cm of bituminous-bound graded aggregate and 7 cm of semi-granular asphalt concrete surfacing. In 2000, resurfacing operations to add a 7 cm further SGAC layer for the mechanical reinforcement of the pavement and the renewal of the surface texture were carried out. Works went on without problem after a tack coat was spread on the former wearing course. Nowadays, rutting is moderate (5mm) and the pavement does not present any structural weakness. However, since 2008, crazing phenomena with a pronounced longitudinal crack (Figure 3) is observed at wheel track level. Furthermore, in rainy, wintry conditions the surface material tends to come off.

(a) (b)

Figure 3: Longitudinal crack at wheel track level on the slow lane.
(a) Initial crack (b) Crazing evolution.

(a) (b) (c)

Figure 4: Core sample taken at longitudinal crack level.
(a) The first interface is detached whereas the first layer is cracked straight down.
(b) View from above the wearing course. (c) View from below the wearing course.

Crazed zones evolve into a surfacing consisting of small separate blocks, which, in rainy wintry conditions combined with heavy traffic, can come off the road and require many selective repairs.

The core samples taken on the newly formed longitudinal cracks show that cracks do not go deeper than the first interface (Figure 4a). The photographic view of the wearing course from above shows an open crack with a few spalls (Figure 4b). The view from below the course, on the other hand, reveals that the crack is wider opened than at the surface (Figure 4c). Cracking probably started from the bottom of the wearing course long before appearing at the surface and then spread upward across the whole thickness of the layer.

3 DISCUSSION: ABOUT FACTORS AND MECHANISMS AT THE ORIGIN OF THE DETERIORATIONS

The issue for the financing authorities, which consists in finding the best durable repair techniques for the damages and preventing their appearing on still intact sections, implies to determine and understand the mechanisms at their origin. This knowledge will make it possible to work out a set of maintenance rules to hinder or even eliminate negative effects, on the one hand, and identify at risk situations on the whole network, on the other hand. Unfortunately, the major difficulty facing this diagnosis is the current inadequate knowledge of the phenomena. The key idea of this discussion is to propose a certain number of hypotheses as regards factors and mechanisms potentially responsible for the degradations described in the previous section. There is probably some factors and one triggering mechanism.

For at least two of the three cases described above, the degradation phenomenon starts very suddenly (a few days at the most, sometimes less than 24hrs) and spreads over long linear sections. Moreover, for all three cases, the degradations appear after rainy, wintry (freezing/thawing) periods preferentially on wheel tracks.

That leads us to think that there is a “triggering mechanism” for degradation appearance, which sets in action when some of the factors mentioned above are combined (freezing/thawing cycles, presence of water within old and new surface layers and a certain amount of traffic). Today, however, this mechanism is not clearly identified yet.

It, however, incited us to revive studies to examine water-saturated bituminous asphalt behaviour during freeze/thaw cycles searching notably for swelling effects as a result of the freezing front. These fronts, indeed, can be the cause of differential strain and stress, which can damage pavement structures. Some recent experimental results of the literature obtained with homogeneous bituminous asphalt specimens confirm this assumption (Mauduit and al. 2010). They reveal that the action of freeze-thaw cycles, with thermal amplitudes ranging from -10 to +10 °C, on water in contact with a bituminous mixture can produce swelling phenomena up to 150 µdef or more depending on the saturation of the mixture. Additional laboratory research work is currently being carried out on multi-layer bituminous asphalt beam specimens.

However, besides the revelation of the mechanism, the major difficulty is the adequate knowledge of its implication in the pavement degradations observed. With this aim in view, the problem ranges from on extreme, i.e. the mechanism alone is to blame for the degradations, to the other where it would only give prominence to an already highly deteriorated situation.

More work needs to be carried out in order to answer the question and to start being able to quantify it. The fact that, despite identical features throughout their length, the linear road sections in question are not affected entirely, tends to prove that the triggering mechanism does not act alone.

From the analysis of the three cases reported above, we can propose the following additional causes:

- milling the surface course may weaken the new surfacing support,
- the obvious lack of pavement drainage may be at the origin of binder stripping due to the long-term contact with water of the upper layers,
- possible fatigue of the upper layer under shear stress during hot periods at the level of the first interface.

The first case demonstrates that, in certain conditions, milling the upper part of the pavement before laying a new wearing course can weaken the first interface. The mechanical action of the planer, whose speed is sometimes too high, can be the cause of microcrack formation within the remaining underlying layer evolving under the action of traffic (Figure 1b). Planing also implies that the lowest part of the former wearing course can sometimes remain on the pavement when milling depth is not deep enough. This remaining 1 or 2 cm thick layer certainly constitutes a weak point for the structure. It can, indeed, suffer from a deficiency in compaction. Moreover, at the bottom of the new course, there are not one but two interfaces, between which a thin, bitumen layer where infiltration water can accumulate, is found. In rainy, wintry conditions, this zone close to the pavement surface is *a priori* particularly sensitive to freeze-thaw cycles.

The problems observed in the second case are obviously arising from the absence of a satisfactory pavement drainage system, for which long-term adverse effects are well known (Apul et al. 2002). A poor or non-existent drainage system, not carefully designed geometry, a locally unfavourable road configuration (low points, superelevation transition zone, for instance) are as many parameters connected to pavement construction or operating, which can cause the stagnation of runoff water within the pavements. Whole portions of road are then exposed to stripping and its ensuing damages: segregation of the binder/aggregate pair, delamination, spontaneous water-in-bitumen emulsion phenomenon, etc. (Kiggundu et al. 1988, Hicks, 1991, Castenada et al., 2004a 2004b). Material coming off can increase under the action of traffic.

As suggested by Kandhal and Rickards, 2001, a lack of "asphalt breath" is a different way by which we get water damage. Before to apply the 2.5 cm VTAC, the 9 cm SGAC have been trafficked, micro-cracked and aged, the ingress of moisture was balanced by the egress in the form of vapour. After the spread of the tack coat and the warm VTAC, during heating period, probably succion came in voids of SGAC drawing water from the interface below. The SGAC voids became in saturation and water could not expel under traffic. So, excessive pression is created which lead, soon or late, to stripping.

Several preventing solutions are possible:

- pavement condition survey to detect saturated zones within foundations (visual survey after rain events, use of radar, etc.),
- treatment of the spotted zones with suiting materials and measures,
- improvement of already available laboratory tests in order to ameliorate the water resistance qualification of pavement materials and interfaces.

In the third case, the new wearing course, implemented by resurfacing, presents, ten years later, some longitudinal cracks mainly located on the wheel tracks. Cracking quickly develops into crazing while some pieces of surface material come off in rainy and wintry conditions. According to the cores taken on the first longitudinal crack, that crack is only on the height of the upper layer. As described in section 4, shear fatigue effects on the upper part of heavily-trafficked pavements (bottom of the wearing course/tack coat/top of the binder course), especially during hot periods, could be the long-term cause of the longitudinal cracking observed. The phenomenon occurs although the tack coat is good as shown by the core samples of case n° 3 taken on and off of the wheel tracks. The crack probably starts at the bottom of the wearing course and go up to the top, then water can go down in the interface. The traffic has a knead action on tack coat with water which set out in emulsion. So the interface can become debonded. The table 1 summarizes the many parameters implicated in surface course weakening processes.

Table 1 : Parameters involved in degradation processes (some of the situations presented have not been met in any of the three cases described here)

<table>
<tr><td colspan="2">Conditions of the triggering mechanism
Saturation of the bituminous mixture, temperature variations, freezing/thawing cycles, traffic (assumption regarding the mechanism: differential swelling of saturated bituminous layers)</td></tr>
<tr><td colspan="2">Long-term risk factors for surface wear</td></tr>
<tr><td>Material parameters
- Bituminous mixture bad water resistance
- Poor quality tack coat (a priori non-met situation)</td><td>Maintenance work parameters
- Planing
- Conditions and characteristics of the formation roadbed
- Layer thickness</td></tr>
<tr><td>Climatic parameters
- Pluviometry, risk factor regarding water accumulation within road foundation
- High temperatures (apart for rutting phenomena)</td><td>Operating parameters
- Traffic
- Defective water drainage systems
- Road salting during wintry periods (thermal shock, salt effect on material quality)</td></tr>
<tr><td colspan="2">Structural parameters
Multi-layer structures (superposition of old/new surface courses)
Numerous interfaces
Material differential behaviour</td></tr>
</table>

4 BRIEF SURVEY OF SURFACE COURSE BEHAVIOUR

This section presents a study conducted using the LCPC's circular test track facility to examine an instrumented pavement very similar to case 3 pavement structure (Figure 5a). An interesting finding of this experiment is the partly unexpected behaviour of the first interface, which varies significantly depending on the temperature.

The objective of the test is to examine stress on both side of the wearing course/binder course interface on a thick pavement structure (Figure 5b). The moving load consists of a large wheel triple axle equipped with type 385/65 R 22.5 Dunlop tyres. The gauge of wheel is 138 cm. Transverse and longitudinal gauges are embedded in the lower part of the BC layer and in the upper part of the binder course (Binder Course 1- BiC1). Temperature sensors are placed at all the interface levels within the structure. Structure implementation conditions are satisfactory. The tack coat quality between each layer is good with a residual bitumen content of 300g/m^2 within the emulsion. The pavement reference deflection value is 30 1/100 mm under a 130 kN dual wheel axle at 15°C for a load velocity of 3.5 km/h. For recording the signals, the triple axle is positioned so that the load is applied with the middle of the tread of tyres passing right above the sensors placed inside the pavement. The load applied by each wheel is 42.5 kN at a speed of 42 km/h. Measurements are carried out for both temperature profile presented in Table 2.

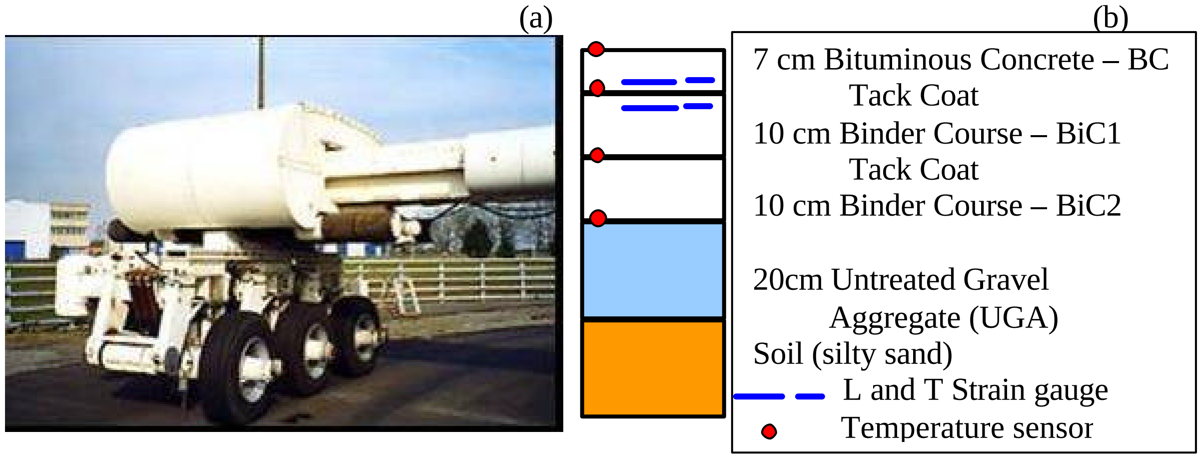

Figure 5: Configuration of the LCPC's circular test track experiment
(a) Large wheel triple axle running gear (b) Pavement structure and instrumentation.

Table 2: Temperature profiles within the pavement structure

Depth	Profile 1 02-27-09 (10:10)	Profile 2 06-04-09 (15:30)
0 cm	10°C	43°C
-7 cm	9°C	41°C
- 17 cm	9°C	34°C
- 27 cm	9°C	29°C

The charts of the recording instruments plot the deformations measured at the bottom of the wearing course (Figure 6) and at the top of BiC1 (Figure 7) for both profiles. The curves display some significant microstrains with opposite signs on both sides of the interface at high temperatures. They reveal some displacements of the layers despite the tack coat good adhesive capacity as proved by the core samples extracted from the pavement at the end of the test. On the other hand, in cold or temperate conditions, the deformations are much smaller and correspond to contraction or very small traction effects at the bottom of the wearing course, and to contractions in the upper part of the binder course.

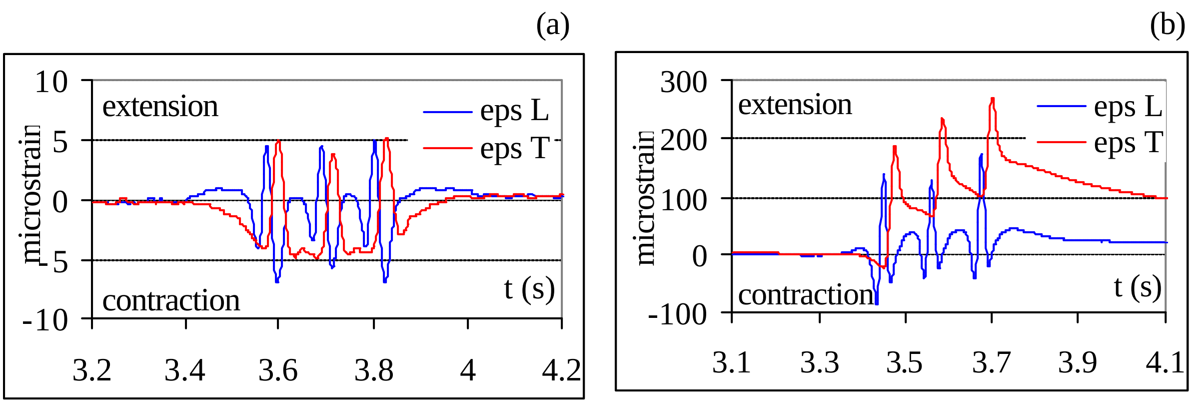

Figure 6: Microstrain signal at the bottom of the BC course.
(a) Microstrains for profile 1. (b) Microstrains for profile 2.

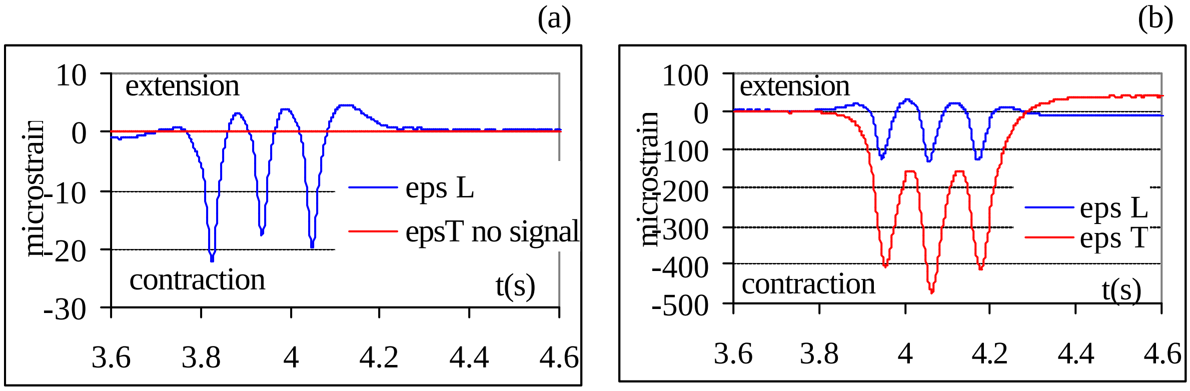

Figure 7: Microstrain signal at the top of the first binder course.
(a) Microstrains for profile 1 (b) Microstrains for profile 2.

As expected, multi-layer elastic simulations show that such measurements correspond to what could be called "quasi-stuck" behaviour. The measurements then prove that the "mechanical efficiency" of the tack coat is highly dependent on the temperature. Consequently, as confirm by the simulations carried out with a "sliding" interface, this could account for in-traction fatigue crack initiation at the bottom of the wearing course and at the level of the wheel tracks, when the temperature is high. Eventually, resulting macroscopic surface cracking can then appear.

Figure 6b presents transverse deformation values 1.6 times higher than longitudinal ones, which could account for longitudinal cracking. However, it is also possible, in these conditions, that a fatigue event with delamination specific of the interface is being observed. Elastic structural computations using the Alizé software (Autret et al. 1982) (www.lcpc.fr) or viscoelastic ones using ViscoRoute software (Chabot et al. 2010, Chupin et al. 2009) performed with data sets corresponding to the temperature and interface conditions described, confirm the argumentation. They also can be used to clarify the demonstration through a comprehensive study of strain and stress fields.

5 CONCLUSIONS AND PERSPECTIVES

Three cases reporting deteriorations appeared on pavement surfaces during winter in rainy and freeze/thaw conditions have been presented and discussed.

In order to come up to the expectations of the road network management authorities as regards long-lasting maintenance solutions and the risk that these degradations spread to still intact sections, improving our understanding of the phenomenon is essential. Case families described here reveal some common factors (traffic, water, freezing/thawing cycles and probably also the influence of a triggering mechanism linked with all these parameters and still badly identified). The possibility that a differential swelling mechanism starting between variously water saturated bituminous layers under the effect of a freezing front is considered. Some studies are currently being carried out to confirm this assumption. However, the problem is probably increased by the action of a certain number of other causes generating long-term damages within upper layers and interfaces. Among them, the study of the temperature effects on surface course behaviour through the experiment carried out using the LCPC's circular test track has made it possible to highlight the impact of a possible damaging mechanism in relation with hot conditions. Even with satisfactory adhesiveness characteristics, i.e. the capacity of a body to withstand normal tensile stress, surface courses can slide one upon the other when the temperature is high. Going deeper into this hypothesis, which may account for the fatigue phenomena appearing within the wearing course, is necessary with further laboratory or in-situ measurement campaigns.

More work also needs to be carried out to develop specific auscultation processes to detect risk areas (Castenada Pinzon, 2004). Radar surveying, for instance, could be used not just to control layer adhesion or thickness but also to detect the accidental presence of trapped water.

AKNOWLEDGMENTS

Special thanks are due to J.M Piau, Scientific Co-Director, LCPC Nantes for useful suggestions. Sincere thanks are due to the staff of LRPC Autun who have directly or indirectly contributed to this work.

REFERENCES

Apul, N., Gardner, K., Heighmy, T., Benoit, J., Brannaka, L., 2002. *A review of watermovement in the Highway Environment : Implications for recycled Materials Use*. Recycled Materials Resource Center, University of New Hampshire, Durham NH 03824, United States.

Autret, P., Baucheron de Boissoudy, A., Marchand, J.P., 1982. *ALIZE III Practice.* Proc. 5th Int. Conf. Structural Design of Asphalt Pavements pp 174-191, Delft, The Nederthlands.

Castaneda Pinzon, E.A., 2004. *Contribution de méthodes non destructives à l'évaluation de l'effet de l'eau sur les enrobés bitumeux.* Thèse de Doctorat de l'Université de Nantes, France.

Castaneda, E., Such, C., 2004. *Evaluation of Moisture Sensitivity of Bituminous Mixtures By a Complex Modulus Approach*. Transportation Research Record: Journal of the Transportation Research Board, 1891, 62-67. TRB, National Research Council, Washington D.C, United States.

Chabot, A., Chupin, O., Deloffre, L., Duhamel, D., 2010. *Viscoroute 2.0: a tool for the simulation of moving load effects on asphalt pavement*. RMPD Special Issue on Recent Advances in Numerical Simulation of Pavements. Cachan, France.

Chupin O., Chabot A., 2010. *Influence of sliding interfaces on the response of flexible pavement.* 6th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control, Turin, Italy.

Hicks, R.G., 1991. *NCHRP Synthesis of Highway Practice 175: Moisture Damage in Asphalt Concrete.* TRB, National Research Council, Washington D.C, Unites States.

Kandhal, P., Rickards. I., 2001. *Premature failure of asphalt overlays from stripping : cases histories*. 70, 301-343, Proceedings of the Association of Asphalt Paving Technologists. Clearwater, Florida, United States.

Kiggundu, B.M., Roberts, F.L., 1988. *Stripping in HMA Mixtures : State-of-the-Art and Critical Review of Test Methods***.** 88-2, National Center for Asphalt Technology, Auburn University, Alabama, United States.

Mauduit, C., Hammoum, F., Piau, J.M., Mauduit, V., Ludwig, S., Hamon, D., 2010. *Quantifying expansion effects induced by Freeze–Thaw cycles in partially water saturated bituminous mix : Laboratory Experiments.* EATA Parma. Italy.

Mauduit, V., Mauduit, C., Vulcano-Greullet, N., Coulon, N., 2007. *Dégradations précoces de couches de roulement à la sortie des hivers.* Revue Générale des Routes et Aéroports, N° 858, 67-72. Paris, France.