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# Laboratory evaluation of the resistance to tangential forces of road surfacing materials

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## ■ ABSTRACT

A new method for performing laboratory evaluations of the resistance to tangential forces of bituminous mixes used on wearing courses will be presented herein.

Tire-pavement surface contact mechanics have been taken into account for the purpose of reproducing, as accurately as possible, the effect of tangential forces generated at specific area throughout the road network. Phenomena associated with the indentation between tire rubber and to consists of aggregate asperities have also been incorporated. The new testing protocol calls for loading the surface of an bitumen mix with an inclined force. The cyclic action of this force causes sliding of the tread rubber on the surface of the specimen and generates a loss of aggregates that varies depending characteristics of bituminous mix. An assessment of the resistance to tangential forces based on specimen mass loss will be proposed. Using this test, it becomes possible to determine the effect of binder type on this resistance to tangential forces. Lastly, the change in specimen mass loss will be correlated with the properties of bitumen used here.

## Évaluation en laboratoire de la résistance aux efforts tangentiels des revêtements routiers

### ■ Résumé

*Une nouvelle méthode permettant d'évaluer en laboratoire la résistance aux arrachements des enrobés de surface utilisés dans les couches de roulement est présentée. La mécanique de contact pneumatique-revêtement est prise en compte, afin de reproduire le plus correctement possible l'effet de l'effort tangential engendré dans les points singuliers du réseau routier. Les phénomènes d'indentation de la gomme par les aspérités des granulats sont également pris en compte. Le nouvel essai sollicite la surface d'un enrobé bitumineux avec une force oblique. L'action cyclique de cette force provoque un glissement de la gomme sur la surface de l'éprouvette et engendre un départ de granulats plus ou moins important selon la composition du matériau. Une évaluation de la résistance aux efforts tangentiels à partir de la perte de masse de l'éprouvette est proposée. Avec cet essai, il est possible de déterminer l'effet de la nature du liant sur la résistance aux efforts tangentiels. Enfin, l'évolution de la perte de masse de l'éprouvette est reliée aux propriétés des liants bitumineux utilisés.*

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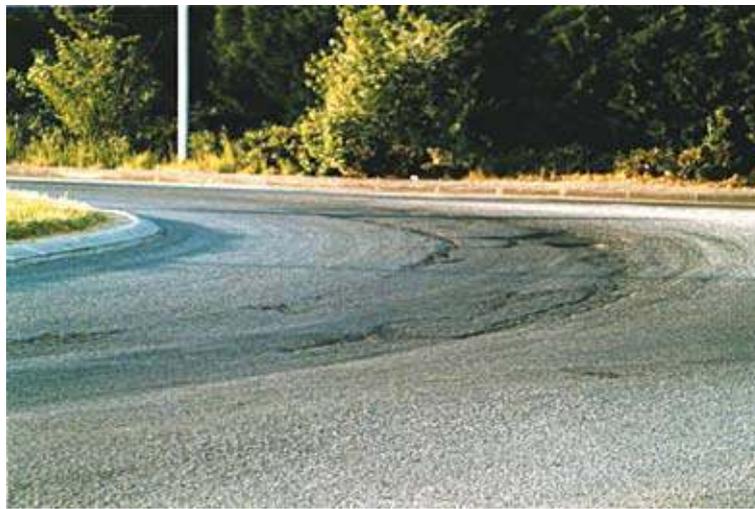
## INTRODUCTION

A pavement surface degradation phenomenon that may be observed at intersections, locations with turning movements, curved sections and other adverse geometric locations can be described by loss of aggregate stripping due to heavy truck traffic. The importance of this degradation depends on a large number of parameters, including road geometry, axle type, nature and surfaces characteristics of materials in contact (i.e. tire tread and bituminous surfacing material), as well as on environmental conditions.

The zones affected by this problem are not an of isolated cases, but instead every pavement surfacing over the road network may be subjected to intense tangential forces during driver maneuvers (braking, acceleration, direction change). These forces can either immediately cause a break in the mastic asphalt (this phenomenon can arise under cold conditions by means of brittle fracture or hot if the bonding energy proves insufficient [1]) followed by aggregate stripping, or they can produce progressive damage that in time wears away material (see Fig. 1a). As a general rule, an early-age evolution in macrotexture over the road cross-section is reflected by remove the bitumen present on aggregates and sometimes by a rearrangement of aggregates among each other without any material loss. However, an alternative type of aggregate rearrangement occurs faster and is influenced by tangential loadings. Under certain conditions, which still require more investigation, these tangential forces can also lead to forming of surface folds or, more simply, to a horizontal displacement of aggregates with or without material loss (Fig. 1b).

**figure 1**

*Effects of tangential forces at particular locations:  
a) Loss of aggregates on a roundabout  
b) Surface displacement of materiels observed near a red light*



a  
b

1

This rearrangement can be related with both the particle size distribution curve and bitumen characteristics. This rearrangement will be more pronounced with discontinuous mix designs (very thin bituminous mixes, porous bituminous mixes, etc.) than with continuous designs (semi-coarse asphalt concrete, etc.).

It is supposed that beyond a repeated repeated shear loading, a multitude of local cracks occur within high-deformation zones, which leads to loss aggregate at the surface of road cracks. These fractures can also arise in zones of heterogeneities that in some instances relate to paring conditions (lower density, local segregation, insufficient coating, existence of a longitudinal joint during paring, etc.).

These locations on road exposed to hearing traffic have been studied previously on several aspects relative to both road traffic congestion and the geometric design, but the mechanical aspect is not treated. The observations in many locations reveal surface damage since the first months of services. These locations p maintenance problems to road authorities and cause hindrance to drivers are to frequent maintenance works. These individual locations cause maintenance problems for facility managers and during the road repair/maintenance works.

## **SURFACING MATERIALS AT ADVERSE GEOMETRIC LOCATIONS**

Road surfacing materials are composed of a mix of aggregates and bitumen in proportions determined so as to satisfy a the durability performance and the surface properties such as skid resistance.

The distribution of local pressures within the contact zone depends on the characteristics of both the tire and the pavement surfacing material. For a car tire, the load-bearing area on a new road surface is between 70 cm<sup>2</sup> and 150 cm<sup>2</sup>. This vehicle develops local pressures of approximately 0.5 MPa on a relatively smooth texture and 4.5 MPa on a very rough texture. For a truck tire on the other hand, the load-bearing area ranges from 250 to 500 cm<sup>2</sup> and this type of tire develops local pressures of approx. 2 MPa on a relatively smooth texture and potentially in excess of 16 MPa with very rough texture [2].

The consequences of these local pressures on the evolution in surfacing material characteristics are numerous and manifested at various scales by the following phenomena: texture closing, binder film removing, aggregate polishing at the surface, rearrangement of aggregates depending on the season or traffic intensity, loss of aggregate on the surface damage, etc. In certain cases, some of these phenomena may appear in succession throughout the pavement service life.

The majority of these phenomena have not yet been studied in detail. Admittedly, research on the relationship between microtexture and friction on aggregate polishing [3], yet a multi-scale study that features coupling with physicochemical phenomena is still in the preliminary stages.

Other questions are raised on the distribution of stresses and strains within the tire-surface contact zone. To respond to such questions and determine the conditions that lead departure of aggregate, the mechanical contact problem needs to be correctly laid out and proceed by examining the strain field in the laboratory by using of the image correlation measurement technique [4].

Can the surface damage by loss of aggregate phenomenon presently be reproduced in the laboratory?

The discussion on evaluating wearing course durability at adverse geometric location points based on a laboratory test has not yet been entirely closed. Existing tests utilize either the principle of realistic wheel-surfacing contact tests in braking [5-7] or cornering situations (use of the LPC rutting tester with an imposed cornering angle of 5°) or the principle of unrealistic tests, such as the Cantabro test [8]. These tests present some fundamental differences in mechanical aspects and often use modified test conditions (reduction or ghe binder content, conditioning sample in water)

the empirical nature of these tests does not allow to understand the physical phenomenon or to determine which material property is concerned in the resistance to tangential forces.

In order to explore the relation between the properties of bituminous materials and the resistance to tangential forces. We have developed a new experimental device to reproducing actual mechanical conditions. To define the loading conditions associated with this new testing method, initial research has been performed in the thesis work by Hamlat [9], which focused on understanding the mechanical contact conditions between tire and surfacing material, at the scale of both the wheel and a tread element in direct contact with an aggregate.

## LOADINGS IN THE CONTACT ZONE BETWEEN TIRE AND SURFACING MATERIAL

The skid resistance between road surfacing and a tire is defined as the capacity to mobilize friction forces within the contact zone during driver maneuvers. In order to reproduce these friction forces in the laboratory, it is necessary to fully understand the conditions under which these forces are being created at the tire-surfacing material interface.

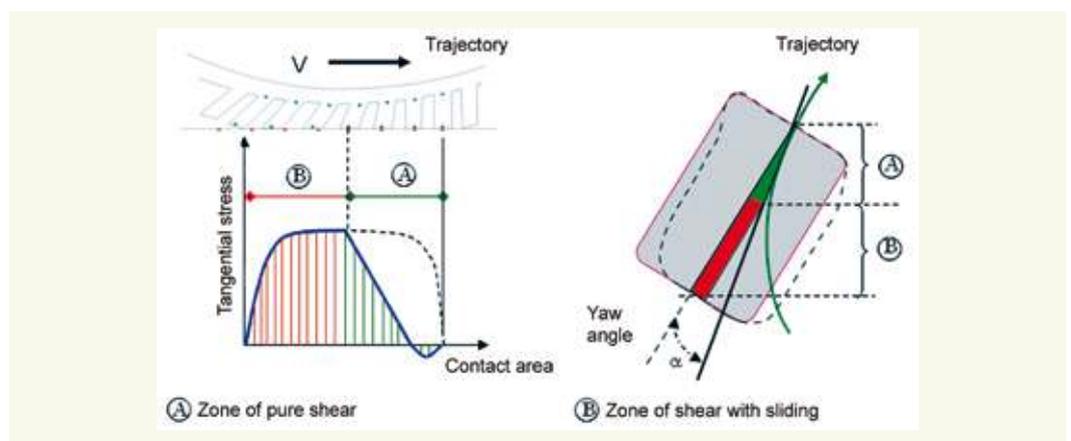
### ■ Description of contact at the scale of a tire

During a maneuver involving turning, braking or acceleration, a horizontal force is generated at the level of the tire tread. This force is accompanied by sliding at the interface with the surfacing.

Tangential stress within the contact area increases from front to back. Once it has reached a critical value equal to the product of the coefficient of friction multiplied by the normal stress, sliding occurs at the tread-pavement interface (Figs. 2a and 2b).

The contact area can be divided into two regions: a more proximate region of contact between tire tread and pavement positioned towards the front, and a region of sliding at the back [10]. The existence of these two zones has been described by Delanne [11]. The boundary between the shear and sliding zones depends on: the sliding rate or cornering, tire characteristics, axle type (simple, double, triple), and axle position (front, rear) [12,13].

**figure 2**  
Description of contact at the scale of a tire  
a) under braking conditions  
b) when executing a turning maneuver



### ■ Description of contact at the scale of a tire tread element

At the tread block scale, the friction force results from two mechanisms:

- adhesion results from molecular interactions occurring at a scale on the order of one-hundredth of a micron and gets magnified by sliding (energy mobilization subsequent to molecular chain vibrations); and

– indentation, which is the deformation of tread rubber by sliding on asperities of aggregates, with sizes varying from a centimeter to a micron.

According to the research performed by Persson [14], it can be considered that the proportion of molecular adhesion-based friction remains negligible in comparison with indentation friction.

A tread block submitted to increasing tangential loading produces pure shear at the interface with the supporting material. When the force reaches a certain threshold, the tread block starts to slide. The initial phase is characterized by static friction and the second by a kinematic friction reflecting the contact state.

The test proposed herein will account for these aspects relative to the contact of a tread element with road surfacing.

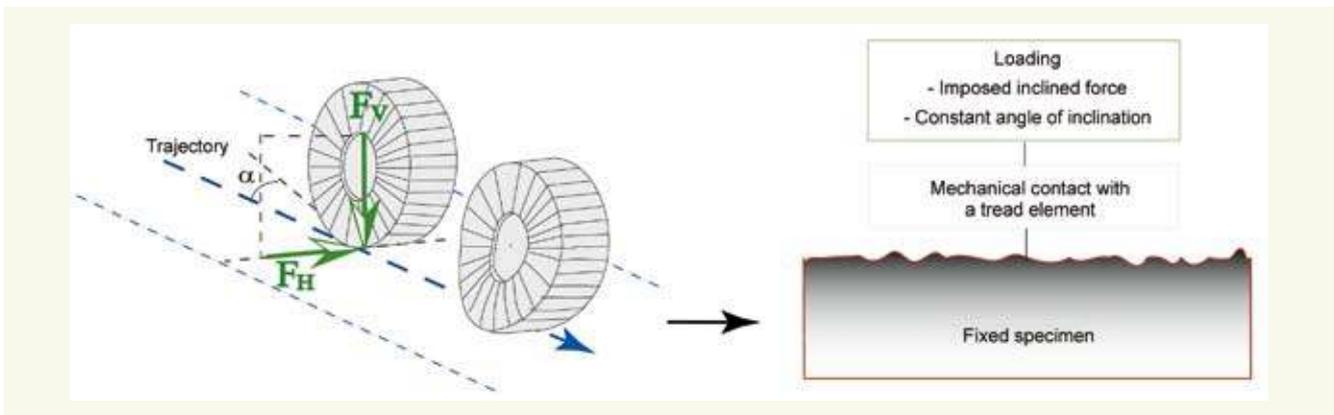
### ■ Principle adopted for the new test

A study of the contact between tire and surfacing material allows identifying with greater precision the loading system required to design a new test to be conducted in the laboratory; this test must be capable of reproducing the phenomenon of surface degradation by loss of aggregates (Fig. 3).

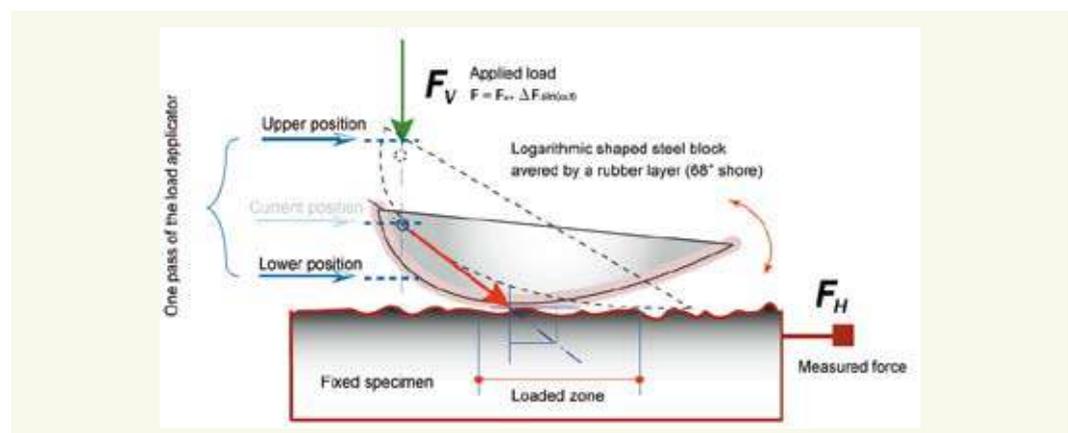
As opposed to typical tribometers, which impose a relative displacement, the new test proposed by Stéfani [15] makes it possible to maintain a controlled loading level regardless of the state of surface degradation. More specifically, use of a load applicator whose shape follows a logarithmic law enables holding the force pair ( $F_v, F_h$ ) at a near-constant ratio [16], independently of the logarithmic pad position (Fig. 4).

In practice, a cyclic contact force with no sign change and of a predetermined angle of inclination is imposed in order to cause surface degradation by means of loss of aggregate. The pad only slides in

**figure 3**  
Reproduction of tangential force in the laboratory



**figure 4**  
Principle of the test



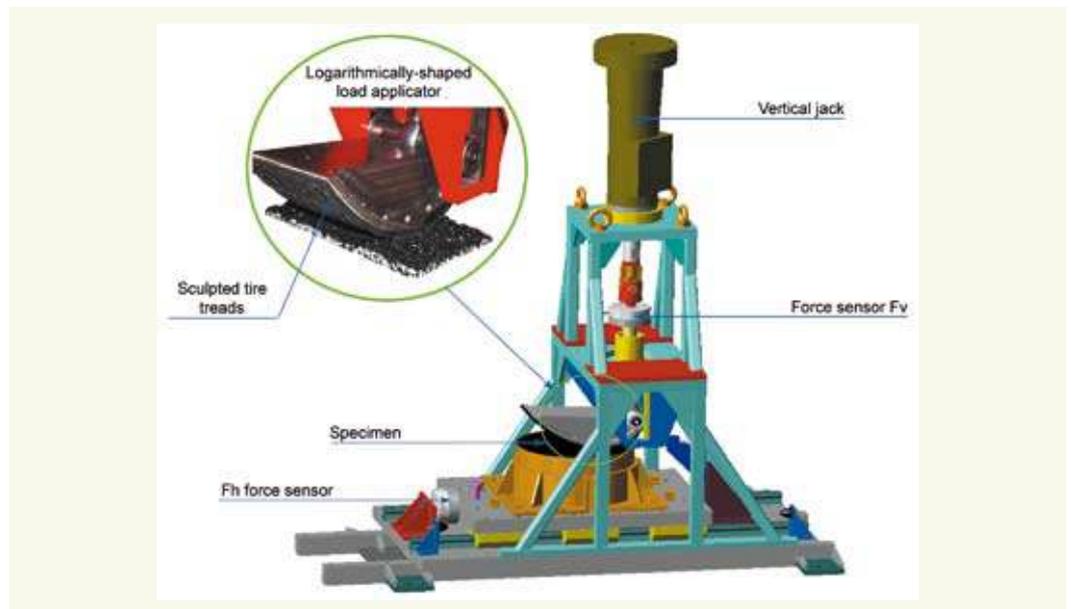
surges when such events arise, automatically shifting the contact zone towards the rear and ejecting debris in the opposite direction. In this manner, the pad successively attacks a number of narrow, long rectangular strips without the interposition of any debris. Once the jackscrew has reached its lower thrust bearing, the cyclic phase is stopped; this sequence corresponds to one pass of the load applicator.

## ■ Presentation of the experimental device

The device called a tribometer for road surfacing material (French acronym T2R) is a bi-axial hydraulic machine; it is composed of: a braced vertical column supporting both the load applicator and the hydraulic jackscrew, and a roller-mounted horizontal table capable of moving along two horizontal rails. This table can accommodate a parallelepiped specimen (185 mm x 247 mm) made in the laboratory using an LPC plate compactor, as well as an in situ core sample up to 300 mm in diameter. Specimen height does not surpass 150 mm.

The load applicator, whose width equals 140 mm, is coated by an 8-mm thick rubber layer with rheological characteristics close to those of tire treads (see Fig. 5). This rubber displays diamond-shaped sculptures and its hardness at room temperature is approximately 68 Shore degrees.

**figure 5**  
Overview of the testing device for evaluating the resistance to tangential forces



The PC controlled system calls for two types of servo controls, one for controlling the force, the other for logarithmic shaped block displacement, to be applied depending on the type of test.

The test of resistance to tangential forces consists of applying an average load representing the loading of a truck tire on the surfacing material. The sliding of tread rubber is obtained from modulating the vertical load around an average value.

The experimental device has also been equipped with force, displacement and temperature sensors. Displacement of the vertical jackscrew reflects the sporadic or repeated sliding of the LSB (logarithmic shaped block). The horizontal force acting upon the sample is recorded throughout the test, thereby informing on the state of mechanical contact between the rubber LSB (logarithmic shaped block) and the surfacing material being tested.

## DESCRIPTION OF A PULL-OUT TEST

### ■ Test protocol

The protocol contains three phases, one of which concerns disposal of the debris eventually produced during the loadings.

### A - Preloading phase

The rubber is placed into contact with the material surface by applying an imposed displacement and then driving the force higher in order to continue loading on the sample until reaching the required average vertical force. The necessary contact time remains on average equal to 40 seconds. Mechanical contact conditions depends of the state of the surfacing material, material contact stiffness and test temperature.

### B - Cyclic loading phase

Once the recommended limit has been reached, a sinusoidal loading is imposed with an amplitude set at 1/3 of the average force in order to ensure that the LSB (logarithmic shaped block) is well attached, i.e. at a stable sliding speed and with as much friction as possible. The average vertical load is set at 2,500 N so as to reproduce an apparent contact pressure equivalent to that produced by a truck, with the loading frequency equal to 1 Hz.

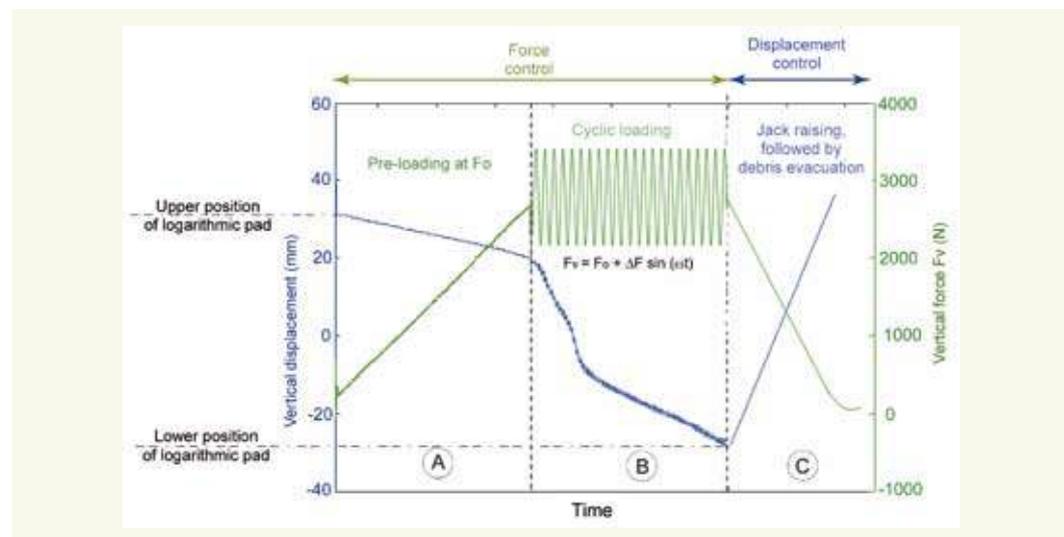
### C - Pad raising phase

The LSB (logarithmic shaped block) is replaced in the upper position, learning a space of 15 mm on the order of between the rubber and LSB the sample to evacuate wear debris eventually present on the sample by means of a compressed air-based ejection system. This phase takes approximately 10 seconds, following which the test is repeated using the same cyclic contact force.

This procedure described with all three phases can be repeated several times as necessary to obtain a certain level of surface damage (Fig. 6).

Remark: An average compressive force of 2,500 N is imposed with an amplitude of 833 N. Given that the LSB imprint area equals 43 cm<sup>2</sup>, the maximum apparent pressure amounts to 0.78 MPa.

**figure 6**  
Protocol for testing the  
resistance to tangential  
forces



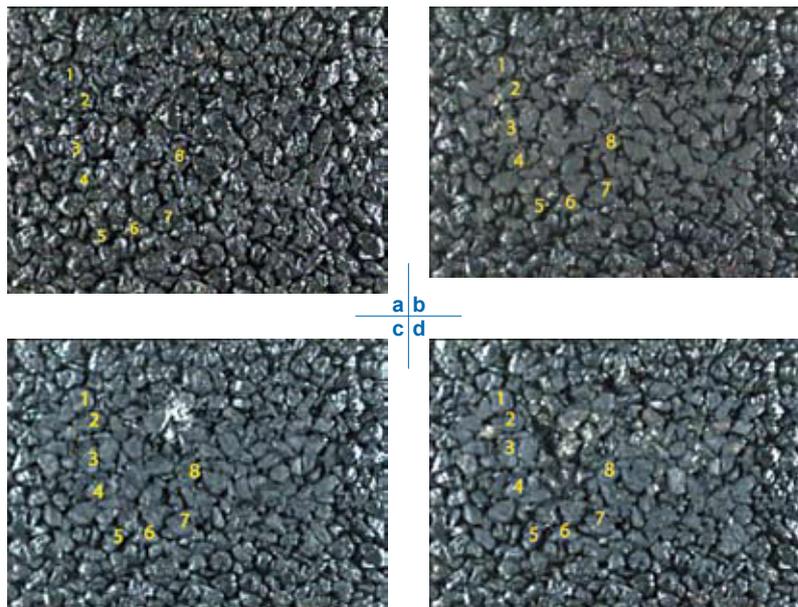
## ■ Presentation of a typical test

During a pull-out test and before the appearance of surface damage, aggregates displacements are observed on the surface of the sample. These movements can be easily observed on the images taken at various test times (Fig. 7).

Surface modifications are also observed, with cavities filled by the bitumen present at the aggregate surface. These changes is systematically observed before the first loss of aggregates and the delay times between the beginnings of the test and the first departure depends on the mechanical characteristics of the surfacing material.

Subsequent to the departure of an aggregate due to fracture within the mastic asphalt, the degradation phenomenon continues nearby and shear forces are transferred onto neighboring aggregates,

**figure 7**  
*Photographic monitoring  
of the surface of a sample  
during loading cycles*  
a) initial state  
b) after 1000 cycles  
c) after 3000 cycles  
d) after 10000 cycles



as indicated on the aggregates numbered 1 to 8, surrounding the degradation zone (Fig. 7). The importance of degradations, evaluated on the basis of mass loss, will depend on the mechanical characteristics of the road surfacing material.

### ■ Test repeatability

The study of pull-out test repeatability was conducted on a set of three BBTM (very thin bituminous mixes) 0/10 commonly used in France. The evolution in mass loss per loaded surface unit vs. cumulative number of cycles reveals that the repeatability is indeed acceptable provided the variations in room temperature, which likely disturbed the measurement results, have been taken into account. Moreover, the repeatability test on a BBTM 0/6 mix design could be performed under temperature conditions more compliant with this type of verification. The mass loss measurements after 15,000 cycles show that the relative error does not exceed 10%. It should be recalled that the rheological properties of bituminous materials are sensitive to temperature variations. These repeatability tests have once again demonstrated the need to strictly control temperature when running pull-out tests.

### ■ Interpretation of test results

During the initial cycles and before the appearance of the first degradations, the test set-up allows measuring various parameters, some of which describe the state of contact:

- an apparent friction indicator obtained from a ratio of horizontal and vertical forces [9,17];
- average sliding speed during the cyclic phase;
- contact stiffness during the cyclic phase; and
- energy dissipated by friction over a single cycle.

The other measurements recorded throughout the pull-out test allow to evaluate the effect of tangential forces on the sample for a set of well-determined test conditions, i.e.:

- per unit area in the wear zone,
- recording of calibrated images of the loaded surface at different time intervals during the test. This observation also enables tracking aggregate loss.

From the various observations and studies conducted by members of the Public Works Ministry's technical units on the resistance to tangential forces problem, it can be concluded that binder type indeed plays a vital role in the resistance to tangential forces. For this reason, pull-out tests were carried out on a group of binders with highly diverse characteristics.

## EFFECT OF BINDER TYPE ON THE RESISTANCE TO TANGENTIAL FORCES

### ■ Materials used

In order to assess the effect of binder type on the resistance to tangential forces, tests were performed on a very thin bituminous mixes (BBTM 0/10) commonly used on the road network. This material was produced in the laboratory using Noubleau aggregates (microdiorite) in accordance with Standard NF P 98-137. The test binders, also with very distinct characteristics, are those employed in road applications for wearing courses (see Table 1).

**table 1**  
*Characteristics of the asphalt binders tested*

Binder	Penetrability at 25 °C (NF EN 1426) (1/10 mm)	Softening temperature (NF EN 1427) (°C)	Cohesion on a pendulum ram compactor at 40°C (NF EN 13588) (J/cm <sup>2</sup> )	Tension on H2 specimen (5 °C and 100 mm/min) (EN 13587)	
				Yield stress (MPa)	Elongation at yield (%)
A (special binder)	61	96.2	1.15	0.5	19.0
B (BmP SBS)	37	64.8	0.65	1.5	16.0
C (Pure 35/50)	28	57.0	0.47	2.6	16.5
D (special binder)	14	78.0	0.22	3.5	16.0
E (epoxy bitumen)	0.5	Test not performed	Test performed, with no value	37.5	7.7

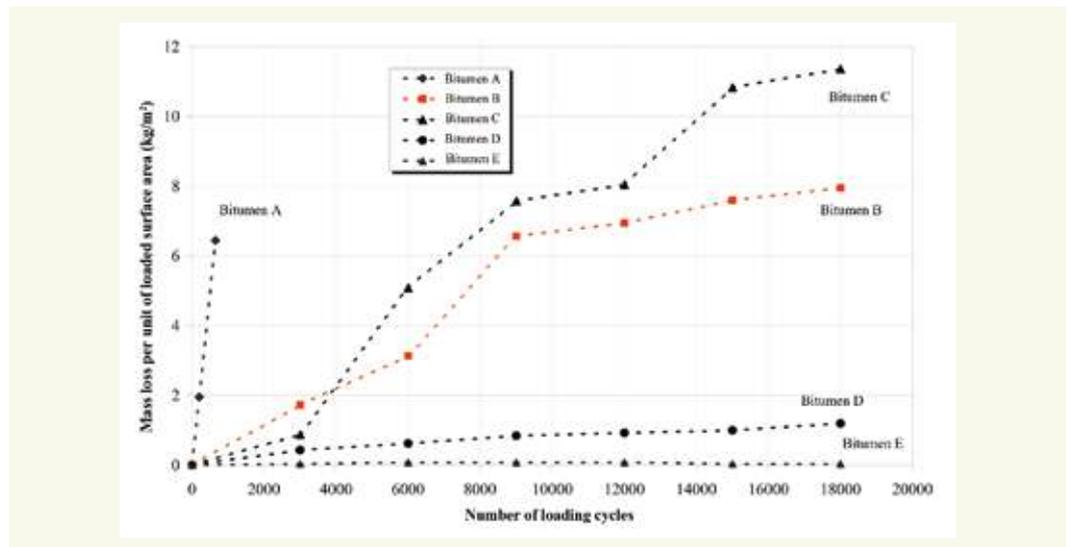
In order to obtain a plane and homogeneous surface of samples made with different binders, materials were compacted with a smooth cylinder in adopting a controlled energy compaction procedure (NF P 98-250-3). The density measured with the gamma densitometer varies only slightly from one specimen to the next, with the average lying between 78% and 80%. The specimen produced using epoxy bitumen has an average compacity of 86%.

The different binders display present an increasing stiffness from the least rigid (bitumen A) to the hardest (E). Binder E, an epoxy bitumen, offers greater stiffness than standard bitumen. Associated with calcined bauxite, this type of binder is used on the road network as a surface dressing in order to obtain a high skid resistance.

### ■ Test results

Tests were conducted according to the protocol described above at room temperature (18°C-20°C). The first time the LSB crosses, no aggregate loss is observed. The initial aggregate stripping occurs following a number of cycles that varies depending on the type of binder. After several thousand loading cycles, it is observed that the evolution in mass loss per unit of area in the wear zone differs from one sample to another (Fig. 8). With an imposed force, the vertical displacement of the LSB as well as the horizontal force applied at the sample surface are both recorded. The horizontal force does not vary considerably from sample to sample; in contrast, LSB sliding speed variations depend and seem to be correlated with sample rheological characteristics. The thesis work presented in [9] shows that this sliding speed is well correlated with the phase angle of the bituminous mix. Upon completion of a pull-out test, an examination of removed aggregates indicates that the mastic asphalt fractures; this assessment on a laboratory test is comparable with that of loss of aggregates on a wearing course at adverse locations.

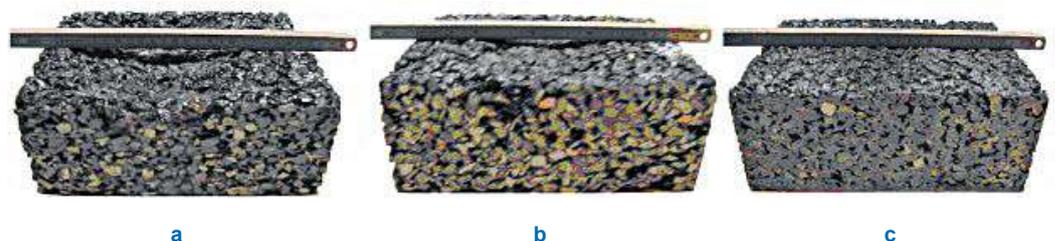
**figure 8**  
Evolution in mass loss vs.  
number of cycles at room  
temperature



Binder E made with an epoxy bitumen displays no mass loss. No modification to the surface state of the sample (Fig. 9c) has been detected. With bitumen D, mass loss is rather small with a relatively slow pull-out phenomenon. A few surface changes are noted with very limited aggregate displacement. On the other hand, an extremely rapid degradation of the specimen surface has been recorded with bitumen A (approximately  $10 \text{ g m}^{-2} \text{ s}^{-1}$ ). Bitumens B and C, whose penetration grade values are roughly equivalent, offer an intermediate evolution with a mass loss rate of  $0.5 \text{ g m}^{-2} \text{ s}^{-1}$  for bitumen B and  $0.7 \text{ g m}^{-2} \text{ s}^{-1}$  for C (see Figs. 9a and 9b).

A comparison of pull-out test results with intrinsic binder properties (modulus, cohesion, yield stress and elongation at yield, etc.) serves to analyze this type of degradation and highlights the main properties enhancing the resistance to LA. It has been noted that bitumen D, with a yield stress equal to 3.5 MPa and cohesion of  $0.22 \text{ J/cm}^2$ , resists better than bitumen A, which exhibits a lower yield stress by 0.5 MPa and higher cohesion by  $1.15 \text{ J/cm}^2$ . Binder E features a high yield stress (37.5 MPa). Cohesion measurements for this binder using the pendulum impact tester were not possible due to the fracture occurring at the interface between the bitumen sample and the cube. The specimens produced with this binder however did not experience any degradation from.

**figure 9**  
State of the VTAC 0/10  
specimens after conducting  
a pull-out test (18,000  
cycles)  
a) Specimen with binder C  
- Mass loss = 179.8 g  
b) Specimen with binder B  
- Mass loss = 125.8 g  
c) Specimen with binder E  
- Mass loss = 0 g

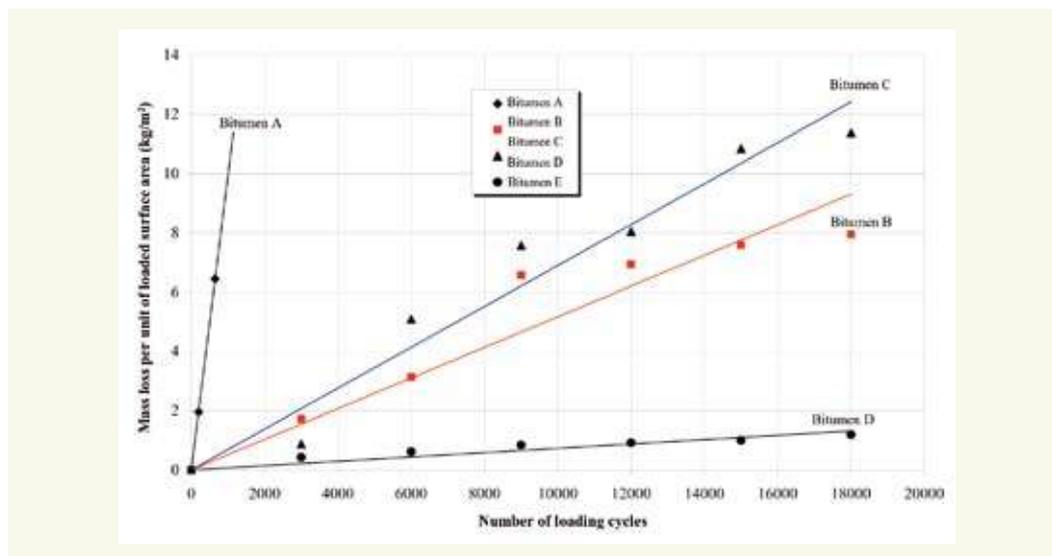


### ■ Comparison of pull-out test results with binder characteristics

As an initial approximation, the results from measurements derived using pull-out tests reveal that mass loss increases linearly with number of cycles. Figure 10 clearly shows the influence of binder type on mass loss; consequently, the straight line slope would seem to represent an intrinsic binder characteristic with respect to the resistance to tangential forces.

The mechanical characteristics of the binders listed in Table 1 provide quite relevant indications on the resistance to tangential forces. It appears that yield stress would allow explaining the pull-out tests. According to Table 1, the direct tensile test seems the most pertinent, to within a single

**figure 10**  
*Prediction of the evolution  
in mass loss using a linear  
function*



inversion between binders B and C. In contrast, the binder ranking based on cohesion values at 40°C is completely contradictory with the performance recorded using the T2R pull-out test.

These results constitute the first comparative elements between a performance test on an bituminous mix and a binder test; nonetheless, the utility of certain tests introduced on asphalt binders must be called into question.

It is observed that the pull-out test on bituminous mixes offers the possibility of providing valuable suggestions on binder performance with respect to surface degradations. It also appears that a comparison of the various types of tests yields a worthwhile approach, inasmuch as it serves to evaluate the pertinence of certain tests. Research must however be extended to other types of binders and other temperatures in order to better discern the relationship between binder properties and the resistance to tangential forces.

## CONCLUSION AND OUTLOOK

The test of resistance to tangential forces serves as a realistic and pertinent method for studying in the laboratory the resistance of surface mixes on roads in service under controlled conditions. The proposed test procedure features many advantages since it enables preserving a stable loading level regardless of the state of surface degradations. Load applicator control only requires a single jackscrew and the pull-out phenomenon only occurs in a single direction by means of loss of aggregate. The study potential is tremendous and interpretation of pull-out test results will enable responding to questions raised over material choices and mix optimization (particle size distribution effect, type of binder, role of the binder/aggregate adhesion, density effect, etc.).

The pull-out test may be used like a mechanical test specific to surface mixes in order to evaluate the effects of binder aging, the role of water and the impact of chemical products on the durability of surfacing materials. The comparative tests presented herein have made it possible to appreciate the contribution of this test procedure towards assessing binders in terms of their resistance to the tangential forces induced by surfacing materials. In reality, a binder mixed with fines forms a complex matrix, commonly called mastic asphalt; and it would be more beneficial to correlate the resistance to with the mechanical characteristics of this mastic asphalt.

Temperature control however remains essential to ensuring repeatability of the pull-out test and to enhancing test reliability.

In light of the results obtained, the new proposed test protocol provides a valuable tool for studying the mechanical and tribological characteristics of surfacing materials used on wearing courses for transportation infrastructure applications.

#### ACKNOWLEDGMENTS

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