# Use of LPC Wheel-Tracking Rutting Tester To Select Asphalt Pavements Resistant to Rutting

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The last survey carried out in 1991 on the French road network shows that, for the last 15 years, the roads have behaved very well as far as surface rutting is concerned. Less than 1.5 percent of the motorway network is affected by rutting defects. The phenomenon is limited and confined to particular areas. The explanation of this favorable situation lies in the awareness as early as 1970 of the rutting problem due to heavy traffic, which led to the design of a laboratory test, the Laboratoires des Ponts et Chaussées (LPC) wheel-tracking rutting tester. This test, whose mechanical and dynamical conditions are as close as possible to those generated in the pavement, is performed at a rather high temperature (60°C). The test has allowed the determination of different types of material behaviors and the definition of limit values (used in standards) allowing a good quality of the road. These specifications have been confirmed by correspondence between performance in the wheel-tracking rutting test and behavior on site. Moreover, the influence of test parameters and the mixture on the stability level of the mixes has been estimated. Interlaboratory tests, carried out in 1992 in conformity with ISO Standard 5725, confirmed the first estimates obtained in pretests, that is, very good repeatability values. New applications of the test have been used for the study of special asphalt mixes, study of the behavior of waterproofing systems for bridge decks, and analysis of the evolution of the macrotexture of very thin surface layers (20 or 30 mm). However, because of a significant increase in heavy traffic, new studies will be performed this year on the LPC circular fatigue test track in Nantes, France. At the same time, comparison studies on test devices and rutting depth prediction calculation models will be made, particularly on the finite element computation model CASTOR.

For nearly 20 years, the performance of French pavements with respect to rutting has been rather good: the latest surveys of the technical network by the Laboratoires des Ponts et Chaussées (LPC) (1991) and by motorway operators (Union des Sociétés d'Autoroutes à Péage, USAP, 1990) show that less than 1 percent of high-traffic roads have ruts exceeding 1 cm depth.

These highly encouraging results are attributed to

- Awareness by highway engineers of the negative impact of rutting on users' safety and comfort, which has led to the introduction of a loading simulation test based on the LPC wheel-tracking rutting tester for the selection of mixtures that resist permanent deformation;
- Arrangements in the design (alignment rules), construction (selection of materials, powerful production and compaction plant), and inspection (checks that the properties of the materials conform with the mixture design) of road structures; and
- The development of specific mixtures to combat rutting effectively at particularly sensitive sites (use of special polymer-based binders, "structuring" fibers, and plastic).

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## DESCRIPTION OF EQUIPMENT AND TEST PRINCIPLES

The rutting test is described in AFNOR Standard 98253, in application since December 1991.

For practical mix design studies, a wheel-tracking rutting test (*1*) is used; it measures the rut created by the repeated passage of a wheel over a prismatic bituminous concrete sample. The laboratory simulation of the rutting phenomenon must approach actual pavement stress conditions so that the result obtained can provide one of the selection criteria for a mix design. The test is associated with the LPC wheel-tracking rutting tester (Figure 1), which can test two samples simultaneously, on two separate frames, at a fixed temperature.

There are 72 such testers in service, most of them in France (23 in government laboratories and 22 used by road contractors and oil companies). The rest are abroad, in Europe (Germany, Switzerland, Austria, Italy, etc.), the Americas (United States and Brazil), and Africa (Morocco, Saudi Arabia, Cameroon, etc.).

### Presentation of the Test

#### *Sample*

The sample (Figure 2) is a plate measuring 500 × 180 mm with a thickness of 100 mm or 50 mm. It is placed in a metal frame and rests on a steel base plate. The assembly is placed in the rutting tester. The test may be carried out on a sample taken from an actual pavement; however, the test plate is generally prepared in the laboratory and compacted in its frame by using the LPC laboratory-tired compactor using two level compaction procedures.

**FIGURE 1 Wheel-tracking rutting test machine.**

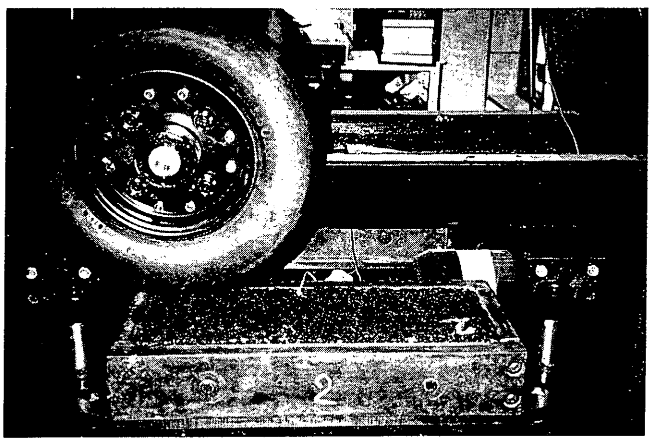


**FIGURE 2 Detail of wheel and sample.**

Two samples are compacted and tested for each compaction level. Density is measured with great precision at three depth levels before the test, often using the LPC vertical gamma densitometer bench; different points are measured for each depth. However, another measurement can be made (geometric density or density in water). This criterion is very important in evaluating the results.

*Wheels*

The wheels of the tester are fitted with smooth tires (400 × 8) inflated to a pressure of $6 \times 10^5$ Pa and loaded to 5,000 N. The wheels pass over the center of the sample twice per second, executing an alternating movement with an amplitude of 205 mm. Load time at the center of the plate is approximately 0.1 sec, comparable with roadway loading conditions. Pressure readings should not deviate from specified pressure by more than 5 percent.

*Temperature*

Temperature is regulated by circulating hot air through a probe placed in the sample. The variation of temperature scatter in the sample plate does not exceed ±2.0°C for bituminous concrete. The test temperature selected is 60°C for all bituminous concrete, but the equipment has a range of 35°C to 65°C. The test temperature is chosen to be relatively high to reproduce the most unfavorable pavement conditions. In summer, temperatures close to 60°C can be frequently observed for 4 to 6 hr.

A rut is defined by the relative percentage of reduction in the thickness of the plate in the wheelpath. Measurements are taken by using a depth gauge with a resolution of 0.1 mm; the gauge reference point is linked to the sample-holder frame. Measurements are taken for five transverse profiles spaced at 75-mm intervals, each characterized by three points in the rut 25 mm apart. For the test sample, the rut is represented by the mean of 15 measurements. The initial profiles are obtained after 1,000 cycles cold, giving good contact between sample, frame, and base plate. The test is terminated after 30,000 cycles unless rut depth exceeds 15 percent, but the test can be carried out for a greater number of cycles (e.g., 100,000). The test is stopped after different numbers of cycles to measure the rut.

*Results*

Figure 3 shows an example of results obtained 1 week after procurement of the materials. To evaluate rutting sensitivity, the mix designer takes into account not only the rut depth occurring after a certain number of cycles at a specified job site void content, but also the shape of the rutting curve (Figure 3) used to calculate the model CASTOR and the sensitivity of this curve to variation in void content.

*Precision of the Test*

An interlaboratory test organized in the second quarter of 1992 in accordance with ISO Standard 5725 was performed with the participation of 12 government and private (road contractors' and oil companies') laboratories, including two outside France (Switzerland and Austria). The test program consisted of four repetitions of the test (with one repetition being the mean of two elementary tests). The material tested was a bituminous concrete used in the wearing course, maximum size 10 mm (0/10), that demonstrated average behavior in the rutting tester, namely, a rut depth of 7 to 8 percent at 30,000 cycles.

The statistical processing of the data from the test program has been only partially completed at this writing (the analysis

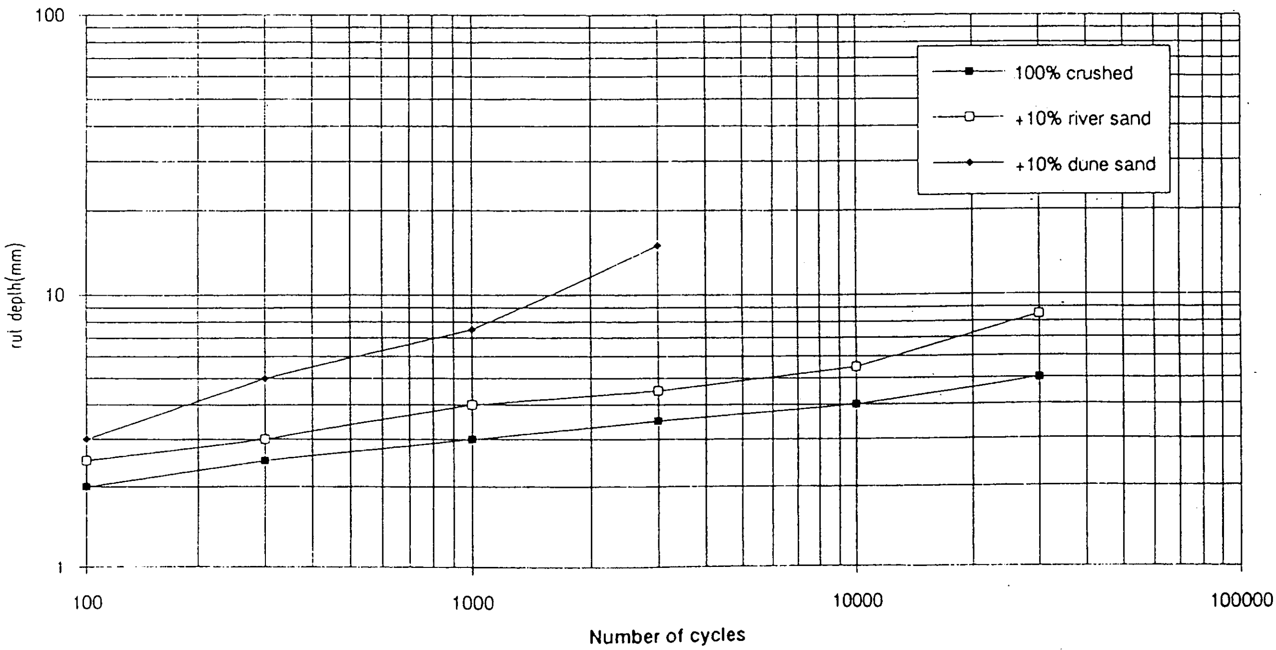



**FIGURE 3 Example of results—effect of the addition of dune sand or river sand on rut depth.**

covers only nine laboratories). The following values have been found: repeatability, $r \approx 1.1$ (percent of rut); reproducibility, $R \approx 1.4$.

The significant difference between two tests is 15 to 20 percent in relative value for a rut depth of 7 percent (or, more precisely, a difference of 1.5 mm of rut is needed to differentiate two materials tested on a plate 100 mm thick with 8 mm rutting).

This level of precision is equivalent for rut depths between 5 and 7 percent. But the dispersion is a little higher for the start of the test (at 30 cycles, the depth of rutting is 2.7 percent, $r \approx 0.7$, and $R \approx 0.9$); this result appears logical since it corresponds more closely to placement of a material in a phase where rutting is practically nonexistent.

In these results, which qualify only the rutting test (all production and compaction in a single laboratory using LPC equipment, insulated 80-L mixer, LPC laboratory-tired compactor), it can be seen that the reproducibility of the test is very good. These results confirm the preliminary cross-tests performed 10 years ago.

### Measurement of Evolution of Macrotexture

Very thin bituminous concrete (VTBC) materials (applications 20 to 30 mm thick) are used in new pavements or for the maintenance of correctly designed pavements that are in good structural condition to obtain good skidding resistance. This resistance must last as long as possible under repeated loads. To assess the evolution of VTBC macrotexture and to guide the choice of the characteristics of VTBC composition, these materials are subjected to a test simulating passages of loads using the LPC rutting tester, with slightly modified operating arrangements.

The plates are prepared on a nonrutting substrate that generally consists of a coated material with a high modulus (including a very hard binder of penetrability class 10/20 in 1/10 mm). After bonding by a tack coat, the VTBC material is applied in the thickness planned for the site.

The test sample is prepared in the LPC plate compactor using a high level of compaction and a smooth tire tread at the end of the test to produce a macrotexture that closely resembles the one that will be obtained on site. The sand patch texture depth (SPTD) method is used to measure the texture depth on the plate. Half the quantity of sand specified in Standard NFP 98-216-1 is used.

The simulation is performed with 3,000 cycles at 60°C. The change in geometrical roughness is measured by another SPTD test in the wheel track under the conditions defined above. This measurement is valid only if the deformation of the plate is less than 5 mm.

The specifications concerning the change in macrotexture of VTBC defined in Standard NFP 98137 limit the reduction of the sand patch texture depth to 50 percent to ensure adequate durability of the structure in service.

Three classes of material are defined: rutting, nonrutting with unacceptable change of texture, and nonrutting with preservation of texture. Examples of results are as follows:

- On VTBC with a 0/6 mixture, 2/6 gap, including 0.3 percent organic fibers and 6.3 percent grade 60/70 bitumen: initial SPTD, 0.9 mm; SPTD at 3,000 cycles, 0.8 mm;
- On antirutting-coated materials with a 0/14 mixture, structured by addition of 1 percent plastic waste, coated with 5.2 percent grade 40/50 bitumen (Figure 4, transverse section): initial SPTD, 0.9 percent; SPTD at 30,000 cycles, 0.88 mm; and rut depth, 5 percent.

This coated material exhibited very good resistance to rutting while maintaining its surface texture.

## APPLICATIONS OF LPC WHEEL-TRACKING RUTTING TESTER

### Studies and Mixture Design

The French mixture design methodology calls for the rutting test to be performed in the following cases: (*a*) study of an entirely new design and (*b*) use of designs on pavements where the loadings are large (large heavy-vehicle traffic, more than 500 vehicles of more than 5 tonnes payload per direction), where traffic is channeled, and on gradients (exceeding 3 percent), winding roads, and so forth.

The rutting test is also recommended if the mixture of the coated materials entails a high compactibility, for example, when certain sands are used (e.g., ground sand, round sand).

### Checks of Conformity

The rutting test can be used as a quality control for coated materials when work is started at a site where there is a risk of rutting, to check that there are no great differences between the design mixture and the site that might be caused by

- Components (aggregates, binder) different from those of the design,
- Storage conditions (in particular for sands with high fines content), or
- Means of production that favor workability (some drum mixer-dryer plants use porous materials).

These checks, always very useful, can in some cases lead to adjustments of the mixture to meet rutting resistance requirements.

The rutting test has been used successfully several times to determine the corrective action necessary to change the behavior of a material susceptible to rutting, which may be detected either in the course of the job or after commissioning. The treatment has consisted of hot recycling of the coated rutting-susceptible materials by the addition of precoated aggregates, with the composition being adjusted on the basis of rutting test results.

### Mixture Design for Special Coated Materials

The rutting test is widely used to analyze the effect of changing the characteristics of the binder or the mastic on the stability of a coated material in the development of mixture designs for special coated materials or for coated materials with a high modulus and very good antirutting properties. The classifications that have been established in the laboratory have been checked in some cases by work at sites where a control or reference formula could be found.

For example, coated materials were reinforced by the incorporation of plastic waste (see Figure 4); it was found that the division of the rut depth in the rutting test by a factor of 2 to 3 with respect to the control formula (without plastic waste) was borne out on site by the total absence of deformation, whereas the control exhibited deformations of 1 to 1.5 cm (findings made after 2 years on a bus lane at the approach to traffic lights). These many observations have clearly shown the utility of antirutting coated materials (i.e., those exhibiting a rut depth of less than 5 percent at 30,000 cycles and 60°C).

However, the comparative studies performed on special coated materials with regard to the effects of special binders, their composition, their proportion, and the level of compaction of the materials have not necessarily led to systematic improvements in rutting. It appears that the so-called "special" binders (bitumen polymers/bitumen fibers) must exceed a minimum threshold of modification to be able to endow the coated material with reinforced stability properties.

### Tests on Waterproofing Layers

The rutting test is used to study deformation of "high-speed" waterproofing layers developed by road contractors. These sand-bitumen complexes, extensively filled with polymers and covered with thick surface dressing of polymer binder, are applied on bridges using conventional equipment (paver, spreader, compactor). Given the deformation properties of the material, it is appropriate that its behavior in the presence of the definitive wearing course be examined in advance (*2*).

The test is performed on a plate that has the following composition: concrete substrate, waterproofing complex to be tested, and wearing course. The test is performed at 45°C.

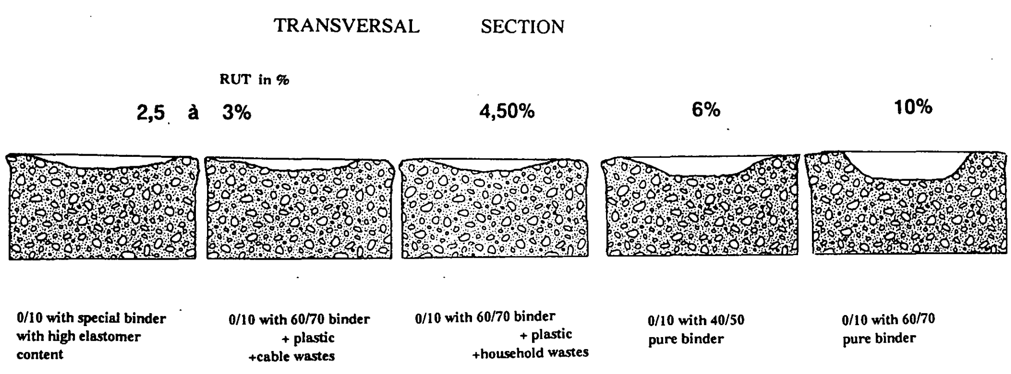



**FIGURE 4 Influence of special bituminous mixes.**

This temperature was selected to allow for the particular thermal environment on a bridge and the thermal protection provided by the wearing course and with a view to using the same specification as for semigranular coated materials (thickness placed 60 mm), namely, less than 10 percent rutting at 30,000 cycles.

Currently, the complexes (five different contractors' products) that meet these specifications perform very well on site. The oldest jobs now date back 4 or 5 years.

## RUTTING SPECIFICATIONS FOR BITUMINOUS PRODUCTS

Specifications for the allowable percentage of rutting for different coated materials appear in the Product Standards, Series NFP 98 130 to 98 141, issued in 1990–1991.

The characteristics of the test and the selection criteria are as follows:

- The test is performed at only one temperature, 60°C;
- The thickness of the plate is 10 cm for layers >5cm thick, 5 cm for layers ≤5 cm thick, and equal to the thickness of use (2 to 2.5 cm) for VTBC materials (the specification concerns the durability of the macrotexture); and
- The maximum values (Table 1) are fixed at a given number of cycles, which depends on the type of coated material for the site density. These values are obtained by interpolating the percentage of rutting measured between two plate compaction energy levels (most often determined in the LPC laboratory-tired compactor) that bracket the site density. This is to allow for the density effect on rutting resistance.

These specification thresholds are the result of the correspondence that has been established among the many laboratory findings using the rutting tester and observations made in the field.

Analyses have determined, as a function of the characteristics of the site (heavy traffic, type of environment), the degree of deformation that should not be exceeded to ensure good stability of a given type of coated material. This empirical approach has led to the specification of characteristics for bituminous materials taking into account the position of the material in the structure, the thickness of placement of the surface layers, and the distribution of loads.

### Position of the Material in the Structure

A road base is subjected to lower temperatures (about 10°C) than a surface course. Previously, the rutting test was performed at 50°C and the specification was 10 percent at 30,000 cycles. Knowledge of the influence of temperature on the test result and the aim of improving rutting resistance slightly have led to the threshold of 10 percent at 10,000 cycles but at 60°C.

High-modulus coated materials must have very good rutting resistance, so a specification a little more demanding than that for surface layers has been devised. These materials are often covered with thin or very thin layers, so thermal protection is slight, and the temperature conditions are close to those of the surface (number of cycles, 30,000).

In reality, these materials exhibit a better rutting resistance than specified by the standard; it is common to attain less than 5 percent at 30,000 cycles. This value is often used in certain motorway contracts requiring an antirutting solution.

### Thickness of Placement of the Surface Layers

The level of deformation from which there may be safety problems for users starts at 1 cm. In consequence, the percentage of rutting should be judged against this criterion. For thin bituminous concrete, larger percentages of rutting are acceptable because the plate is thinner; thus, the depth of rutting will still be at an acceptable level (less than 1 cm or 25 percent with a layer thickness of 4 cm; two limits are defined, 1,000 and 3,000 cycles).

On VTBC, coated materials that have surface characteristics similar to those of the German stone mastic asphalt, good skidding resistance is obtained by means of a marked macrotexture that must be durable. The rutting test, simulating the passage of rolling loads, is performed to evaluate the durability of the texture. The first test consists of limiting the maximum deformation to 5 mm to allow measurement of the sand patch texture depth and characterize its evolution. Beyond this deformation, it is believed that VTBC materials lack the stability needed to preserve a durable roughness.

### Distribution of the Loads

Bituminous concretes for airfield pavements are subjected to a small number of loads and are not channeled, so materials that are less stable with respect to rutting can be accepted; the level of 10 percent is required for 10,000 cycles only.

Currently, studies are in progress to evaluate the effects of the increasing aggressiveness of the loads generated by single wheels and the steady increase of truck (HGV) traffic. The results may lead to more stringent specifications for singular zones (such as HGV lanes on gradients, which are especially vulnerable).

## INFLUENCE OF TEST AND MIXTURE DESIGN PARAMETERS

It is very difficult to establish correlations between the test and mixture design parameters and the sensitivity to rutting evaluated by the rutting tester that are valid for all materials studied. However, it has been possible to identify broad trends, the variation of which should be adjusted according to the degree of sensitivity to rutting of the material but the direction of variation of which is the same in all cases. The results described below constitute orders of magnitude that serve to qualify the pertinence of the test and to guide choices in the composition of materials that are not subject to rutting or that have a slight tendency to rutting.

### Temperature

The main studies conducted (*3*) concern bitumen-treated granular materials with good rutting resistance (the test can

TABLE 1 Maximum Values of Allowable Rutting Percentage in Coated Materials

| Type | Domain of use | Number of cycles | Maximum % rutting |
|---|---|---|---|
| Bitumen-treated granular, 0/20 or 0/14 | subbase roadbase | 10,000 | ≤ 10 |
| Bituminous concrete, 0/14 or 0/10, thickness 60 to 80 mm | base course wearing course | 30,000 | ≤ 10 |
| Bituminous concrete thin layer, thickness 30 to 40 mm | wearing course | 1,000<br>3,000 | ≤ 10<br>≤ 20 |
| High-Modulus Coated Material, 0/14 or 0/10, thickness 80 to 100 mm (generally based on hard grade 10/20 binder) | base course roadbase | 30,000 | ≤ 8 |
| Bituminous concrete, 0/14 or 0/10 for airfield pavement, thickness 50 to 70 mm | base course wearing course | 10,000 | ≤ 10 |
| Very Thin Bituminous Concrete (VTBC), 0/14, 0/10, or 0/6, thickness 20 to 25 mm | wearing course | 3,000 | deformation < 5 mm<br>reduction of SPTD < 50% |

be continued up to 100,000 cycles without rutting exceeding 8 percent). An increase in the test temperature of 10°C (measured in the core of the material) causes a lateral translation of the rutting curve (percentage of rutting versus number of cycles in log-log coordinates) representing a factor of 10 in number of cycles; the same percentage of rutting is found at 50°C and 100,000 cycles as at 60°C and 10,000 cycles. This is for a temperature range from 42°C to 60°C. Regulation of the enclosure makes it possible to hold the temperature to within ±2°C (value confirmed in the interlaboratory tests).

Tests on bituminous concretes that are slightly more sensitive to rutting are under way to evaluate the influence of a smaller variation in temperature (5°C, for example).

### Thickness of Plate

Thickness does not have a direct influence, since at the same level of voids content, the same value of the percentage of rutting (depth of rut/initial thickness of plate) is found to within 1 percent, whatever the thickness of the plate. Thickness is only a secondary parameter acting on the more or less great ease of arrangement of the internal skeleton and therefore of the voids content and the texture of the sample. Thus, to avoid getting too far away from the domain of use of the materials and, for a given energy of compaction, to keep the voids contents in the sample fairly close to those at the site, two standard thicknesses have been selected.

### Voids Content for a Given Composition and Compaction Force

The voids content is one of the factors that most influences a material's sensitivity to creep. Generally, the graph of the percentage of rutting versus the voids content has a parabolic shape whatever the type of material, and there is a range of voids content (often between 3 and 7 percent voids) for which the material is most stable. Therefore, there exists an optimal level of filling of the intergranular voids by the bitumen, where deformation resistance is obtained by effective immobilization of the grains with no lubrication effect by the binder.

The curves on the graphs will be more or less accentuated according to the degree of sensitivity of the material to creep (an unstable material yields a curve that changes rapidly). Figure 5 shows these tendencies. For different thicknesses and forces of compaction, it is indeed the voids content that determines the material's response to creep.

Given the importance of the voids content to the results of the test, it can be understood why the tests are performed at two voids content levels that bracket the level expected at the site to interpolate the percentage of rutting. This method does not, therefore, lead to underestimating the risk of rutting (as might an overly bold extrapolation).

### Mode of Production of Sands

A 1989 study of the use of bar mills in quarry crushing installations to produce a sand containing between 16 and 18 percent filler showed that this mode of crushing affects, as a function of the percentage of ground sand, the sensitivity to rutting of the coated materials produced. A 0/14 mixture consisting of 28 percent crushed sand undergoes a 50 percent increase in the percentage of rutting when this sand is replaced by a ground sand made from the same rock. The level of rutting reached was in this last case very close to the specification threshold (9 percent rutting at 30,000 cycles).

Increasing the proportion of ground sand is very harmful to the stability of this coated material. Exceeding a critical threshold of 32 percent leads to a very sharp amplification in rutting (12 to 18 percent rutting at only 3,000 cycles). This sudden change of behavior shows that the zone of transition between a stable material and a material liable to rutting is very narrow.

Further tests consisting of changing the type of 2/14 gravel while preserving the 0/2 ground sand have led to the same conclusions, indicating that it is in fact the mode of preparation of the sand, as well as the critical proportion of sand, that underlies the phenomenon of rutting in coated materials (results confirmed by assessments of behavior on site).

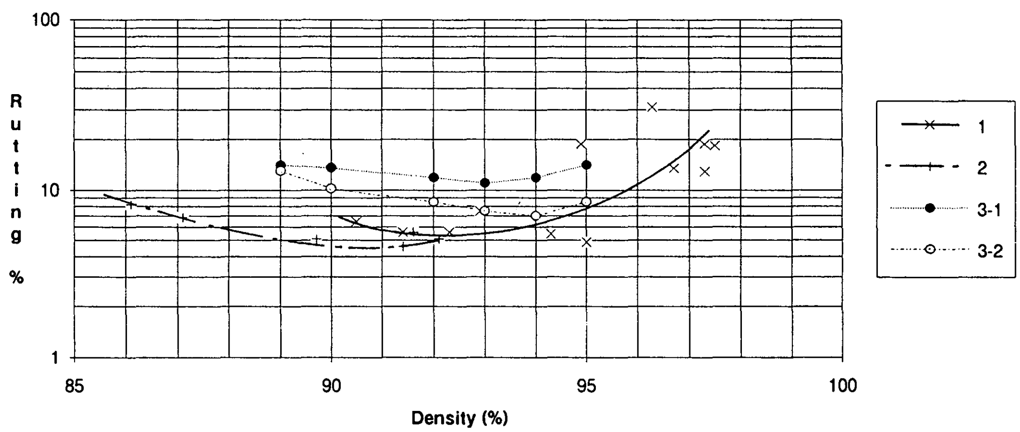
This material was selected for the investigation (on the LPC's circular fatigue test track at Nantes in 1992) of the influence of the mode of loading (single wheel or paired wheels) on the behavior of four coated materials differentiated by type of binder.

Similar effects have been found with rotary table crushers, the principle of which is to reduce the size of the materials by mutual attrition of the grains. The aggregates have highly blunted edges, and their spherical shape makes the granular skeleton less resistant to permanent deformation.

### Angularity

For a given composition, the rutting test clearly reveals the degree of crushing of alluvial materials (see Figure 5), and it can be used to determine the degree of crushing of a material for its behavior to be judged adequate (further crushing contributing no significant gain of stability) (*4*).

For coated materials, this means reduction of all of the blocks entering the crusher [crushing index 100 (IC100)]. The




| Key | Number of cycles | Formula | Composition | Sensitivity |
|---|---|---|---|---|
| 1 | 1000 | BC 0/6 for chip coating (solid rock) | 0/3 limestone 68%; 4/6 Diorite 32%; total fines 11%; 60/70 bitumen 7,0% | very high |
| 2 | 30000 | BC 0/10 Semi-granular(solid rock) | Continuous grading; 0/2 sand 35%; total fines 7,5%; 60/70 bitumen 5,7% | low |
| 3-1 | 30000 | BC 0/14 Semi-granular (Moselle alluvial) | Continuous grading; 0/5 sand 50%; total fines 8%; 60/70 bitumen 5,8%; crushing index IC30 | high |
| 3-2 | 30000 | " " | " crushing index IC100 | moderate |

**FIGURE 5 Effect of density and angularity on rutting.**

material is then called fully crushed. There is a reduction in rutting of 30 to 50 percent when the crushing index changes from 30 to 100. For bitumen-treated granular materials, this reduction of blocks may be limited to 30 percent (IC30). However, the use of these alluvial materials should be avoided when the site is especially vulnerable to the problems of rutting, because even if means to improve the rutting behavior of these materials are available, they are still more sensitive to deformations than materials made from massive rock. This shows that it is possible to adjust the aggregate parameter of mixtures both by mode of preparation and by recomposition.

### Grading Curve

With regard to grading, the results (*3*) are only fragmentary, and no general conclusion can be drawn concerning the effects of the respective proportions of the different grading classes.

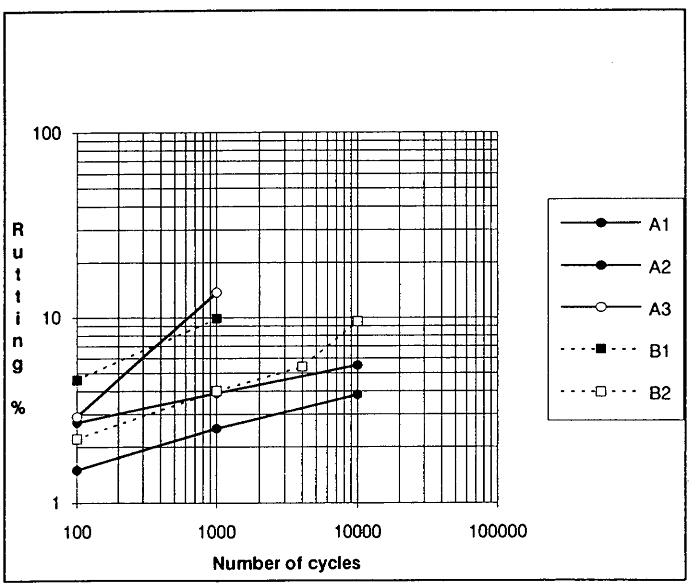
However, the following tendencies have been observed:

- Reducing the 0/2 sand content approximately 5 percent (and slightly increasing the voids content) reduces the rutting depth at the end of the test by 15 to 25 percent.
- Increasing the proportion of coarse aggregates systematically results in better rutting behavior.
- Introducing a gap in the grading curve, even a small one (2/4 or 4/6), generally contributes to instability, a reason why these mixtures are restricted to use in thin and very thin layers, where their great workability promotes optimal placement, leading to good cohesion properties.

Studies using the rutting tester can help optimize these gap-graded mixtures in two ways. The first is by evaluating the increase in the risk of rutting that results from the attempt to achieve better compactibility through the size of the gap. For example, a 0/14 coated material of the same mineral type and with the same type and proportion of binder but in one continuous mixture, another having a 2/6 gap, and a third having a 2/10 gap with highly variable voids content (5.8, 3.9, and 2.1 percent, respectively) exhibited very different sensitivities to rutting. At 100,000 cycles the depths of rutting are 35 percent greater for the second mixture and more than 250 percent greater for the third mixture than for the first. The second way is by classifying mixtures of the same compactibility according to their rutting resistance. For example, mixtures with similar voids content, obtained by different granular recompositions (gap, fines content, percentage of sand), but the same binder content can lead to depths of rutting that vary by a factor of 1 to 2, making it possible to optimize the mixture with respect to its rutting resistance. Moreover, the combination of two factors, such as the introduction of a 4/6 gap and the incorporation of 10 percent round sand, makes the material very unstable (Figure 6).

### Type and Proportion of Binder

In the example mentioned previously, it was shown that the use of special binders could significantly correct a material's sensitivity to rutting. The use of a bitumen highly modified by an SB polymer—grafted in the same proportion as the




| Key | Formulation | % Sand | River sand | % Filler | Binder | Percentage |
|---|---|---|---|---|---|---|
| A1 | 0/14 continuous - solid rock (La Noubleau) | 32 | / | 7,7 | Pure 60/70 | 4 |
| A2 | - | - | - | - | - | 5,3 |
| A3 | - | - | - | - | - | 6,6 |
| B1 | 0/14, 2/4 gap - solid rock (La Noubleau) | 36 | 10% | 7,9 | Pure 60/70 | 5,35 |
| B2 | - | - | - | - | Modified SB | - |

**FIGURE 6 Influence of grading curve and binder type and content.**

basic binder (60/70 class)—although failing to duplicate the properties of a material suitably formulated to resist rutting, helped to halve rutting at 1,000 cycles, allowing the use of this material for applications in thin layers (Figure 6).

It would therefore seem always to be possible to improve rutting behavior to some extent by using a modified binder, but one should first attempt to study improving stability by action on the aggregates to optimize the mixtures, since the aggregate parameter has in some cases more influence than the binder, whether through its proportion or its type.

These are the conclusions of a study performed in 1987 (*5*) on three aggregates and three pure bitumens, in which it was shown that for a straight-run bitumen, one of the criteria of characterization was the ring and ball temperature (RBT), which in some cases should be completed by the thermal susceptibility (Penetration Index IP), in particular when the value of the RBT is far from 60°C (temperature of the rutting test). The value of the RBT seems in this case to correlate rather well with the depth of rutting for a given mixture that is at all sensitive to rutting (upper limit of specifications).

It has been found that a variation in RBT of 5°C to 6°C (range of consistency of a class of bitumen) can have a significant effect on the behavior of the mixture, since it can account for up to 20 percent additional rutting. This indicator is necessary but far from sufficient to evaluate the behavior, especially since the evolution of the RBT of the binder during coating and placement is also a factor of influence. The rolling thin-film oven test seems to provide useful information about some responses to the rutting tester and under traffic when the aggregate is somewhat porous or the binder changes rapidly (rapid evaporation of some solvents).

Since the effect on rutting of increasing the binder content is not proportional, there exists a critical level of filling of the voids by the binder beyond which the material becomes unstable. But any increase necessarily leads to an increase in the depth of rutting (Figure 6).

## LABORATORY AND SITE CORRESPONDENCE

It is not possible to establish a correlation (in the statistical sense of the term) between the results obtained in the laboratory and the behaviour in situ for the following reasons:

- The rutting test was developed to reproduce the most severe loading conditions encountered on roads and to reject or correct mixtures judged unstable, whose use might lead to a risk of rutting. There are therefore rather few cases of rutting allowing statistical analysis.
- Loading conditions on the road are not known with enough precision to define the degree of aggressiveness (there are no recorded data on the temperature at various levels of the structure of coated materials, the number and distribution of loads, the effects of dynamic loads, the configuration of speeds, etc.).
- The means of measuring deformations were relatively cumbersome and could not be used in the continuous mode. Only isolated and therefore fragmentary information could be obtained. (The situation has evolved thanks to the SIRANO multifunction investigation system, in particular with a laser profile measurement device.)

However, sufficiently detailed analyses have been done in a few cases to establish correspondences between the observed effects and identify tendencies deduced from laboratory tests on samples that had rutted on site. The main conclusions are the following:

- In general, when the specifications concerning the rutting of a coated material are met in the mixture design, no rutting is found on site.
- In the opposite case (i.e., when rutting of these formulations is observed), it is found that one or more parameters have changed with respect to the laboratory study. The change may be a change in the source of the bitumen, accidental pollution of the binder, materials from a quarry having large heterogeneities (presence of fault or weathering of the rock), or an "evolutive" production process (for example, mixture of materials from a jaw crusher and a bar mill or a gyratory crusher), or a poor evaluation of the density of the material.

This makes it necessary to use in the test procedure the materials that will actually be used on the site (checks at the start of the job sometimes prove necessary) and to comply with the values specified in the standards, which are minimum values; the design engineer may impose more stringent requirements for a site where there is a high risk of rutting.

Samples taken from rutted zones (rutting of 15 to 25 mm on sections of 1 to 4 km) systematically give values that are substantially below specifications, and often rutting is between 12 and 18 percent after only 3,000 cycles, sometimes even less in a few cases of particularly unstable materials (the test must be stopped at 300 cycles).

The classification established by the rutting tester between stable and rut-sensitive materials is in fact found to be valid in the field.

Currently, the criteria defined in the standards for traditional conditions and those recommended by some project engineers or laboratories in very special cases (based mainly on experience with the materials and with the conditions of exposure and evaluation of HGV traffic and its rate of growth) satisfy the managers of the road network.

## CONCLUSION AND PROSPECTS

For a score of years (the LPC rutting tester in its current form was introduced in 1973), many laboratory studies and findings using the rutting test have made it possible to correctly specify the proper selection criteria for mixtures resistant to rutting, specification thresholds for the different domains of use of the mixtures, and the main evolutionary tendencies in the factors of influence bearing on the test and the composition of the mixtures.

The test is covered by a French standard (AFNOR). It is currently used by government laboratories and by road contractors and oil companies for mixture studies of bituminous materials.

All of these factors help to explain the good performance of French pavements with respect to the phenomenon of surface rutting on all high-traffic roads. However, given the very large and regular increase of heavy-vehicle traffic (*6*), both in number (by a factor of 3 in 5 years) and in level of aggressiveness (modification in the last 3 to 5 years of the distribution of loads, larger payloads, and the shift to the single wheel), in the last few years there has been a growth in rutting of bituminous materials (base and wearing courses) at difficult sites (gradients, truck lanes, intersections with traffic lights) on French high-traffic pavements.

This change in behavior has led to a comparative study at the LPC's circular fatigue test track at Nantes with a view to examining

- The influence of a single wheel compared with that of dual wheels,
- The influence of the composition of the material on rutting resistance [four materials are tested differing only in type of binder: straight-run, conventional (60/70 grade); hard (10/20 grade); modified by SBS polymer; and special to combat rutting], and
- The possibilities offered by various test methods for characterizing rutting (static, dynamic creep, rutting tester) and calculation models that predict rutting on site.

In the course of this program, new experiments will be performed on the LPC rutting tester to improve knowledge of the influence of the mode of loading (pressure, load, and speed of passage). A new process of continuous measurement of the evolution of the rut during the test will be developed using the technique of laser sensors with image analysis.

A procedure to validate the CASTOR design program associated with the LPC rutting test will be undertaken (*7,8*). This design program is a two-dimensional finite-element model describing the passage at constant speed of a wheel on a structure with viscoplastic behavior. The solution methods yield the pavement surface deformation of the courses. These mechanical analysis methods use the elementary properties of the material (reversible and irreversible constitutive laws); the LPC rutting tester is used as an element in the linear fitting of the creep curve for the bituminous materials in the structure [the curve of evolution of rut depth versus the number of loadings is linear in log-log coordinates, having the form $P_0 = A(N/1000)^a$].

Applications include studies to check the design of pavement structures or their predicted behavior and studies of maintenance for rutted pavements by regraveling or partial replacement of the pavement. The various simulations allow selection by comparative analysis of the best arrangements given the residual characteristics of the old pavement modeled and the viscoplastic properties of the new material.

This calculation tool must today be regarded as a complementary means of investigation. The studies and methods will add to our knowledge of the laws of behavior of bituminous materials in permanent deformation, allowing a judicious choice of techniques according to the stresses expected to be imposed on the structures.

## REFERENCES

1. J.-P. Grimaux and R. Hiernaux. Utilisation de l'orniéreur type LPC. *Bulletin de liaison des Laboratoires des Ponts et Chaussées,* numero spécial V, 1977.
2. *Surfaçage de tablier, entretien et réparation.* Guide de chantier. STER, 1981.
3. R. Hiernaux. L'orniéreur type LPC. *Journée des LPC.* Dijon, France, 1989.
4. A. Panis et al. Stabilité des enrobés bitumineux pour couches d'assise ou de liaison, réalisés avec des granulats alluvionnaires plus ou moins anguleux. *Bulletin de liaison des Laboratoires des Ponts et Chaussées,* No. 174, Juillet 1991.
5. B. Barbe. Effet des facteurs bitume, granulats, et composition des mélanges sur la résistance à l'orniérage des enrobés en laboratoire. *Revue Générale des Routes et Aérodromes,* 1988.
6. M. Faure et al. Orniérage des mélanges bitumineux. *Revue Générale des Routes et Aérodromes,* Juin 1992.
7. J. P. Marchand et al. Cracking in Wearing Courses. *Proc., 5th International Conference, Structural Design of Asphalt Pavements,* Vol. 1, Delft, the Netherlands, pp. 741–757.
8. M. Goacoulou. Calcul de structure à l'orniérage: Programme CASTOR—Méthode de prévision des déformations permanentes dans la structure bitumineuse. *Bulletin de liaison des Laboratoires des Ponts et Chaussées,* No. 156, 1988.