Investigation of Rutting of Asphalt Surface Layers: Influence of Binder and Axle Loading Configuration

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The increasing proportion of trucks with wide single-wheel axles makes asphalt pavements more vulnerable to creeping of the surface layers. Experiments on the circular test track of the Laboratoire Central des Ponts et Chaussées (LCPC) and laboratory tests focused on the effect of the type of binder [three asphalt-coated materials (a straight-run, conventional 50/70 grade bitumen; an SBS-polymer-modified bitumen; and the Shell Multigrade bitumen) and a very thin asphalt layer on a high-modulus coated material (hard bitumen 10/20 grade) were compared], the effect of the axle loading configuration (a wide single-wheel axle versus a traditional dual-wheel axle), and the capability of various laboratory tests (LCPC wheel tracking rutting test, static and dynamic creep tests) to rank the materials according to their resistance to rutting as observed on the test track. The observations made on the asphalt pavements and the results of the tests on the binders and the asphalt-coated materials are described. The higher aggressiveness of the wide single-wheel axles on the test track is discussed.

Truck traffic is growing substantially on French interurban routes, particularly motorways (a threefold increase in 15 years). Over the past 5 years, there has also been a change in the truck types, and on motorways 50 to 60 percent of trucks now have five axles with single-wide wheels. These changes have led to larger effects on asphaltic materials (*1*).

To better understand the effects of these changes, a major research program was begun in 1992 combining experiments using the circular test track of the Laboratoire Central des Ponts et Chaussées (LCPC) at Nantes and laboratory tests. This investigation was conducted as a joint study grouping LCPC, the Shell Company, and motorway operating companies under the aegis of the Union des Sociétés des Autoroutes à Péage, represented by Scétauroute.

OBJECTIVES OF THE STUDY

The experiment focuses on the study of permanent deformation of the surface course. The following aspects are considered: the binder effect on the rutting resistance of the wearing course with an asphaltic material sensitive to deformation, the incidence of the axle load configuration (the effect of wide single wheels is compared with that of dual wheels), selective or predictive character of the laboratory tests performed on the binder (usual tests and complex modulus) and on the asphalt mixtures (LPC rutting tester and static and dynamic creep tests) by a direct comparison of the indicators yielded by these tests with the behavior observed on the circular test track, and the procurement of reference data for a later evaluation of rutting calculation models using the results of laboratory tests. With regard to the first item, the parameters of the four pavement sectors of the circular fatigue test track (thickness, density, and composition) were identical except for the type of binder. The comparison was made between an SBS-modified asphalt, a Shell Multigrade (MG) asphalt having a low temperature sensitivity, a hard class 10/20 asphalt, and a standard class 50/70 pure asphalt taken as a reference.

MATERIALS

Asphaltic Binders

The binders were chosen more or less in accordance with current practice for high-traffic pavements: for the asphalt base, a grade 35/50; and for the wearing course, the following:

- A 50/70 asphalt for the reference material (Sector I) even though current practice is tending toward grade 35/50;
- The Shell MG asphalt (*2*), recently developed to increase the rutting resistance of asphalt mixes while maintaining good behavior at low temperatures (Sector II);
- A hard asphalt traditionally used for high-modulus asphalt concretes (EME) (Sector III); and
- A binder modified by SBS, representative of an "average" product for this type of modified binder (3.8 percent of Cariflex type polymer as determined by infrared spectrometry) (Sector IV).

The binder identification tests were performed on the original binders before coating and after artificial aging in the laboratory (RTFOT), on the binders recovered by dissolution in trichlorethylene from asphalt mixes made in the plant before placement, and on the asphalt mixes sampled on the track after the experiment. The results of the tests are given in Table 1.

Complex moduli were determined on these binders. Figure 1, which deals only with the original binders, shows (*a*) curves in Black's space (phase angle versus modulus in logarithmic coordinates) for a frequency of 7.8 Hz and (*b*) isotherms (modulus versus frequency in log/log coordinates) at 25°C (mean tempera-

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TABLE 1 Summary of Characteristics of Binders—Original Condition, After Passage Through Plant, Recovered After the Experiment, Artificially Aged in RTFOT

	Pure asphalt, class 50/70	Shell Multigrade binder	Hard asphalt, grade 10/20	SBS-modified asphalt
Sector	**I**	**II**	**III**	**IV**
Origin				
Pen 25°C (1/10 mm)	63	52	15.5	55.5
RBT (°C)	50.5	60.5	70.5	58.5
LCPC PI	- 0.2	+ 1.1	+ 1.1	+ 0.1
PFEIFFER PI	- 0.5	+ 1.2	+ 0.4	+ 0.8
After production in plant	*	*	*	*
Pen 25 °C	45	36	13	46
Residual pen (%)	(71)	(69)	(84)	(83)
RBT	53	61.5	75.5	57
Δ RBT (°C)	(+ 2.5)	(+ 1)	(+ 5)	(≃ 0)
LCPC PI	-	-	-	-
PFEIFFER PI	- 0.7	+ 0.5	+ 0.8	+ 0.2
After recovery at end of experiment				
Pen 25°C	47	41.5	14.5	44
Residual pen (%)	(75)	(79)	(94)	(85)
RBT	55.5	60.5	76.5	58.5
Δ RBT (°C)	(+ 5)	(0)	(+ 6)	(0)
LCPC PI	+ 0.1	+ 1.5	+ 2.1	+ 0.9
PFEIFFER PI	- 0.1	+ 0.7	+ 1.2	+ 0.4
After RTFOT				
Pen 25°C	37	31.5	13	38.5
Residual pen (%)	(61)	(58)	(81)	(75)
RBT	59	70.5	75	61.5
Δ RBT (°C)	(+ 8.5)	(+ 10)	(+ 4.5)	(+ 3)
LCPC PI	+ 0.7	+ 2.0	+ 1.2	+ 0.2
PFEIFFER PI	+ 0.1	+ 1.8	+ 0.8	+ 0.7

* Shell tests

ture of the experiment), 40°C (approximately the maximum ambient temperature in the test track experiment, temperature of the creep tests), and 60°C (temperature of the tests with the LPC rutting tester).

In Black's diagram, the Shell MG binder appears as the most structured of the pure asphalts (Sectors I, II, and III). The SBS-modified asphalt exhibits a curve that is characteristic of this type of binder: at high moduli (high frequency or low temperature) the character of the basic asphalt is preponderant and the curve corresponds to a fairly unstructured binder, whereas at low moduli (low frequencies or high temperatures) the phase angle exhibits a plateau shape reflecting the lower sensitivity of the polymer binder.

Whereas there is little or no difference between the binders of Sectors I, II, and IV for the isotherm at 25°C, differences in behavior start to appear at 40°C. These differences are accentuated at 60°C, at which temperature the 50/70 asphalt exhibits the lowest modulus values.

The lower kinetic sensitivity found at 40°C for the MG binder in relation to that of the SBS-modified asphalt is confirmed at 60°C; its modulus of rigidity is also higher. However, the differences between these two binders are not very pronounced.

The hard asphalt (Sector III) exhibits the highest moduli in all cases. As an illustration, a modulus of 0.1 MPa at a frequency close to 10 Hz corresponds to a temperature of 55°C for the 50/70 asphalt (Sector I), 60°C for the SBS-modified asphalt (Sector IV), 62°C for the MG binder (Sector II), and 80°C for the hard asphalt (Sector III).

This gives a classification of the four binders in terms of increasing sensitivity to the combined effects of temperature and loading time.

Aggregates

The aggregates come from Cusset, the sand of which is produced by grinding. The rock is a rhyolitic tuff. The main mechanical and production properties of these aggregates are as follows: Los Angeles coefficient, 10 to 13; wet Micro-Deval coefficient, 4 to 9; and flatness coefficient (2/6 and 10/14 fractions), 15 and 13, respectively. These characteristics comply with the specifications for the production of asphalt mixes and exhibit no singularity.

The ground sand is produced in a bar mill from a 0/2 mm sand containing 13 percent fines. The mill yields a sand having a high fines content of 18 to 20 percent, but with grain edges that are particularly blunted and rounded. This is reflected by the sand flow test (standard NF P 18-564): ground Cusset sand, 35 s; crushed Cusset sand, 41 s (repeatability r = 1.2 s).

The fines produced by grinding have less "stiffening power" on the asphaltic mastic (increase of RBT due to the incorporation of 6 percent fines) than those produced by crushing (+14°C to 16°C for the ground sand, +19°C to 20°C for the crushed sand).

Composition of the Asphalt Mixes

The design of the mix of asphaltic materials was primarily based on the results of the LPC rutting tester. The objective was to define (*a*) for the road base, an asphalt concrete having a very good rutting resistance (no deformation of this layer was actually observed on the circular test track) and (*b*) a reference wearing course asphalt mix (Sector I) particularly sensitive to rutting. The mixture selected at the end of the preliminary tests was a 0/14 densely graded Cusset asphalt concrete with 32 percent ground sand including 1.5 percent added fines (total fines 7.5 percent) and 5.7 percent Class 50/70 asphalt. The corresponding rutting in the LPC rutting test was 11 percent after 3,000 cycles, whereas the standard for thick-layer asphalt concrete calls for less than 10 percent rutting after 30,000 cycles.

This mix is analogous to the case of a motorway site where a rut depth of 1.5 to 2 cm was observed after 2 to 3 years of traffic with a corresponding result of 12 percent rutting after 4,000 cycles with the LPC rutting tester.

Only the type of binder was changed for Sectors II and IV. For Sector III the proportion of hard 10/20 asphalt was raised to 6.0 percent since the wearing course consisted of a very thin asphalt concrete (VTAC, 2 cm) having a usual composition: 0/10 with 2/6 gap, crushed La Noubleau aggregates, with 25 percent sand and 6.0 percent SBS-modified asphalt.

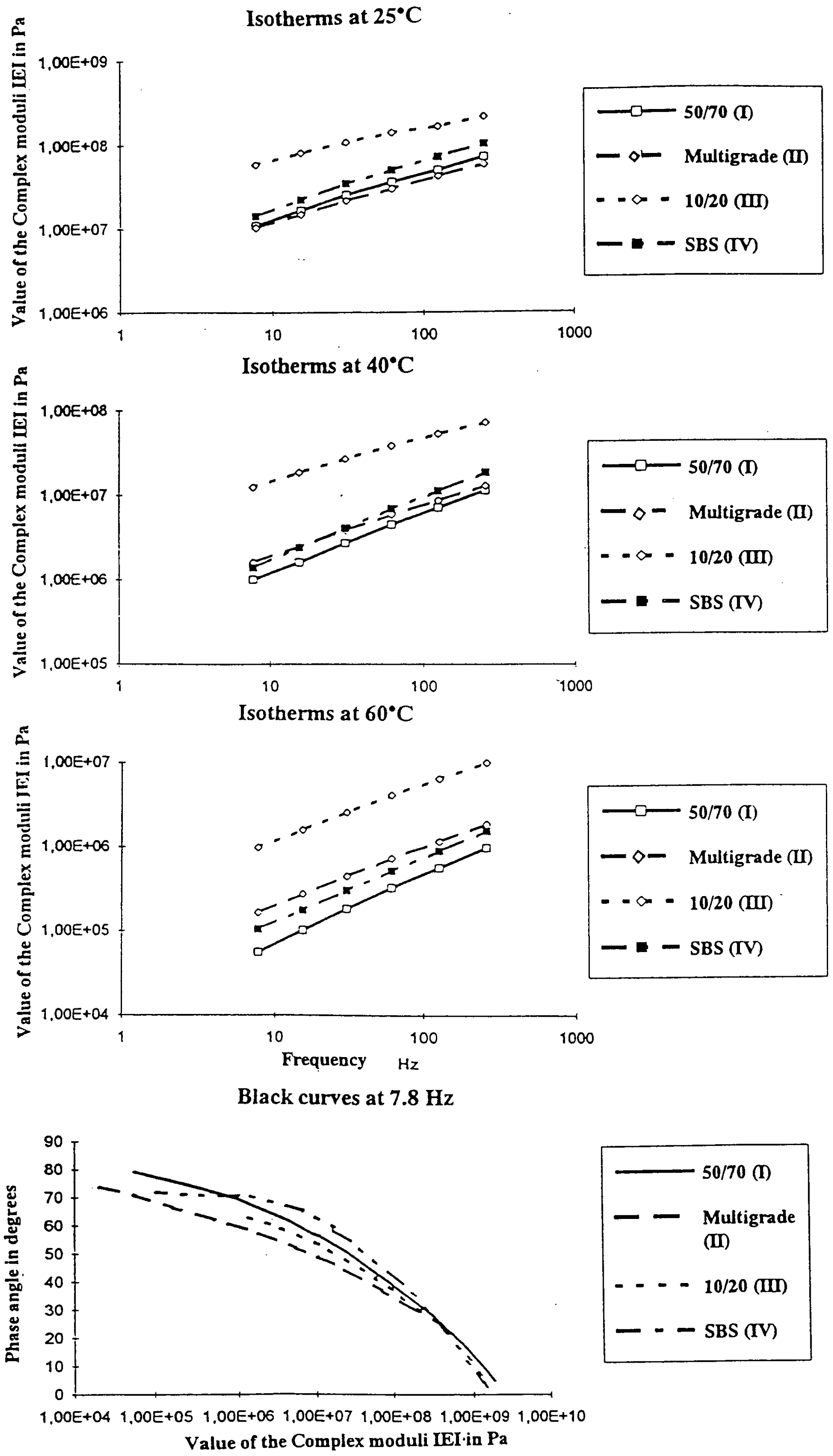


FIGURE 1 Isotherms of the binders' complex moduli at 25°C, 40°C, and 60°C and Black curves.

The gyratory shear press tests (standard NF P 98–252) confirm the high workability and compactibility of the materials due to the ground sand. Between 28 and 36 percent ground sand the voids content at 80 gyrations varies only from 4.7 to 4 percent. The rutting tests are performed at a voids content of 4 percent, which is the value also obtained for the pavements of the circular test track.

LABORATORY TESTS ON THE ASPHALT MIXES

Results with LPC Rutting Tester

In this standard test (NF P 98-253-1) performed at a temperature of 60°C, a slab of asphalt mix (10 cm thick here) is subjected to the passage of a rolling load (tire inflation pressure 0.6 MPa, load 5000 N) at a rate of one forward and return cycle per second. The graph, on log/log coordinates of the percentage of rutting versus the number of cycles, is generally a straight line for a material that is properly resistant to rutting. This test is an integral part of the French methodology for investigating asphalt mixes (*3*). The effect of the various parameters of the composition is determined on the 0/14 Cusset reference formulation with pure 50/70 asphalt.

Grading

Figure 2 shows the effect of the percentage of ground sand in the range 28 to 36 percent. It appears that below a threshold of 30 percent the mix exhibits good rutting resistance, since the test continued to 30,000 cycles with less than 10 percent rutting.

If the 2/10 Cusset coarse aggregates are replaced by La Noubleau aggregates, the rut depths are unchanged for the same proportions of ground sand. It is therefore the nature of the ground sand that results in the poor rutting resistance beyond a certain percentage of ground sand (30 percent) (*4*).

Binder

The type of binder is preponderant, as is shown by Figure 3, which gives the results for the four formulas tested on the circular test track. The SBS-modified, hard, and MG binders clearly improve the rutting resistance of the asphalt mixes. Whereas there is no difference between the SBS-modified asphalt and the MG binder up to 3,000 cycles, beyond this the SBS-modified asphalt exhibits a rut that grows rapidly. No decisive explanation has yet been found for this change of behavior.

Creep Tests on the Asphalt Mixes

Static Creep Test

This test consists of applying a static axial stress of 0.1 MPa on the upper part of a cylindrical specimen kept in water at a temperature of 40°C. The axial strain of the sample is recorded as a function of time (Figure 4). For conventional asphalts, a correlation has been found between rutting performance (measured using a laboratory test track developed by Amsterdam Shell Laboratory, KSLA) and two parameters drawn from this Smix/Sbit curve (slope and intercept).

Dynamic Creep Test

Since the static creep test presents some drawbacks for various types of mixes, a dynamic creep test was developed to take into account the recovery of the strain when the load is no longer applied. The principle of this dynamic creep test consists of applying a series of 0.1-MPa loads for 0.2 sec followed by rest periods of 1.8 sec. The test is typically performed at 40°C. The cumulative residual strain is recorded as a function of time (Figure 5).

EXPERIMENT ON LCPC'S CIRCULAR TEST TRACK

Description of Experiment

The experiment on LCPC's circular test track (*5*) was carried out on a pavement consisting of four sectors, the structures of which

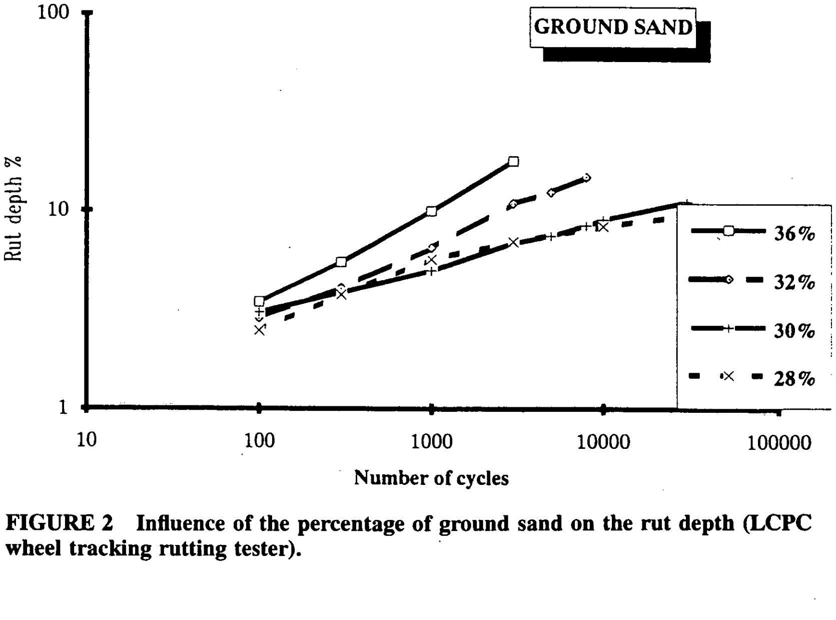


FIGURE 2 Influence of the percentage of ground sand on the rut depth (LCPC wheel tracking rutting tester).

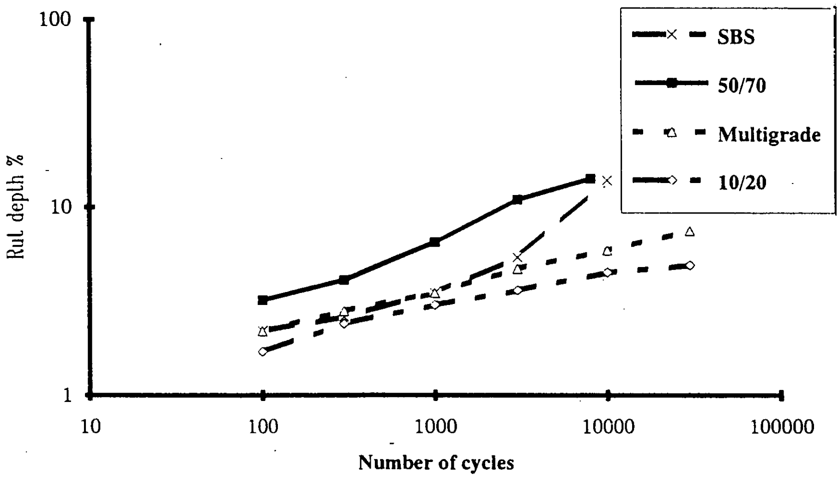


FIGURE 3 Influence of type of binder on rut depth (LCPC wheel tracking rutting tester).

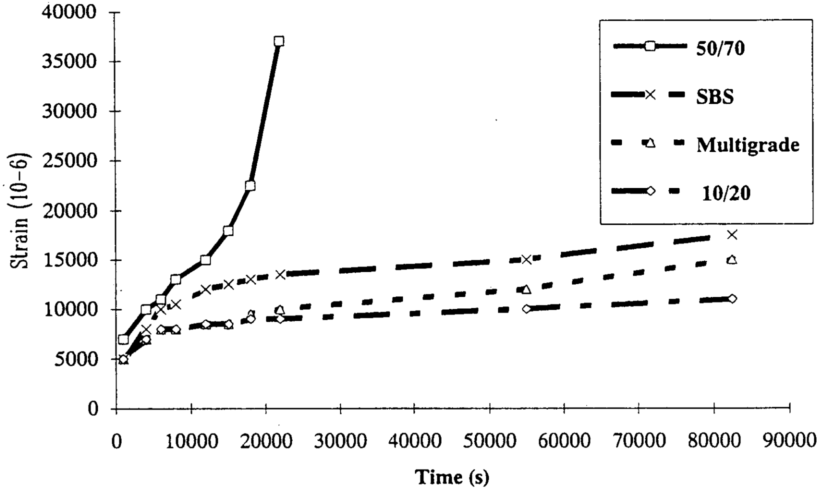


FIGURE 4 Results of static creep tests (Shell method).

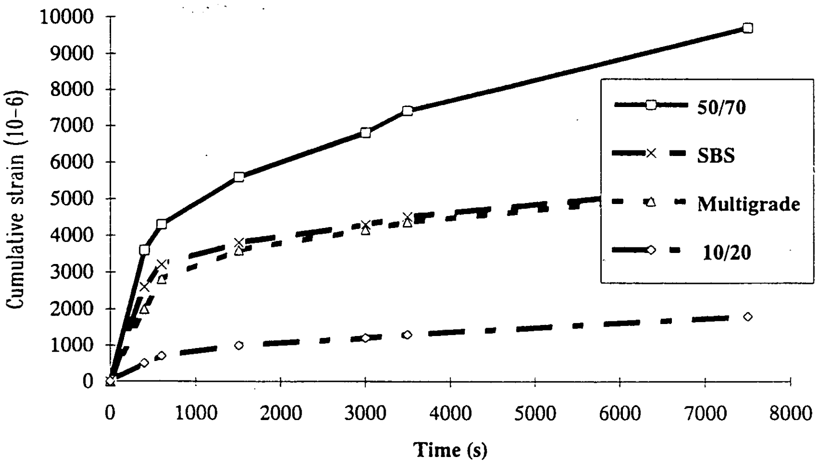


FIGURE 5 Results of dynamic creep tests (Shell method).

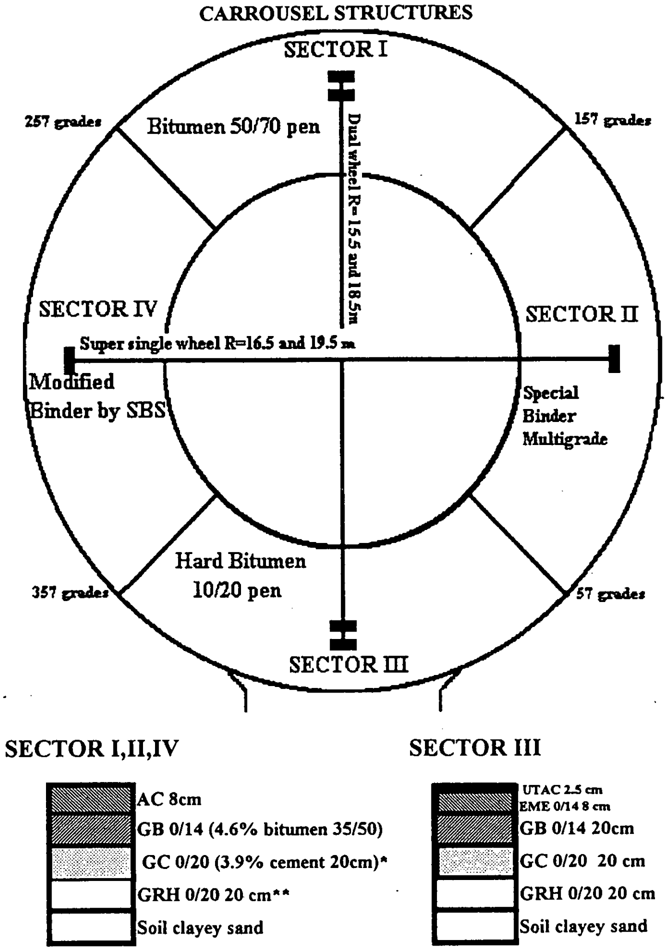
are shown in Figure 6. The experiment was conducted in two phases with two different configurations of the loading arms. For the first phase (202,000 loading cycles), the four axles traveling different paths had the following configuration: single wheels at radii of 16.5 and 19.5 m and dual wheels at radii of 15.5 and 18.5 m. The purpose of this arrangement was to judge the effect of the difference in traffic speed imposed by the simultaneous application of two loading arrangements.

For the second phase (from 202,000 to 250,000 loading cycles), the two axles equipped with wide single wheels were placed at the same radius of 19.50 m, and the two dual wheels at 18.50 m. The loads were 42.5 kN for the wide single wheel and 65 kN for the pair. The tire inflation pressure was 0.85 MPa. Under these conditions the imprint survey indicated the following: for the wide single wheel, a contact area of 636 cm^2 (mean contact pressure, 0.67 MPa); for the dual wheels, a contact area of 567 cm^2 per tire (mean pressure, 0.57 MPa).

For the first phase, the speed of rotation of the circular test track was fixed at 6.5 rpm. The tangential speed therefore varied from 38 km/hr at a radius of 15.5 m to 48 km/hr at 19.5 m. The width of the rolling strip swept was 0.75 m for the single wheel and 1.0 m for the dual wheels. For the second phase, the experiment was continued with the loads channeled and the speed of rotation reduced to 3 rpm.

Temperatures During the Experiment

The ambient temperature and temperatures at the surface and at various depths were monitored hour by hour for the duration of the experiment. Figure 7 shows the ambient temperature during the first phase versus the number of passages. There were fewer than 2,000 revolutions at more than 30°C ambient; the mean temperature was in the vicinity of 21°C. For the second phase, the temperatures were lower, always below 30°C, with a mean value of the order of 19°C. Values recorded at the surface were higher than the ambient temperature, up to 55°C.



*** Cement treated**
**** Untreated granular material**

FIGURE 6 Description of pavement sectors.

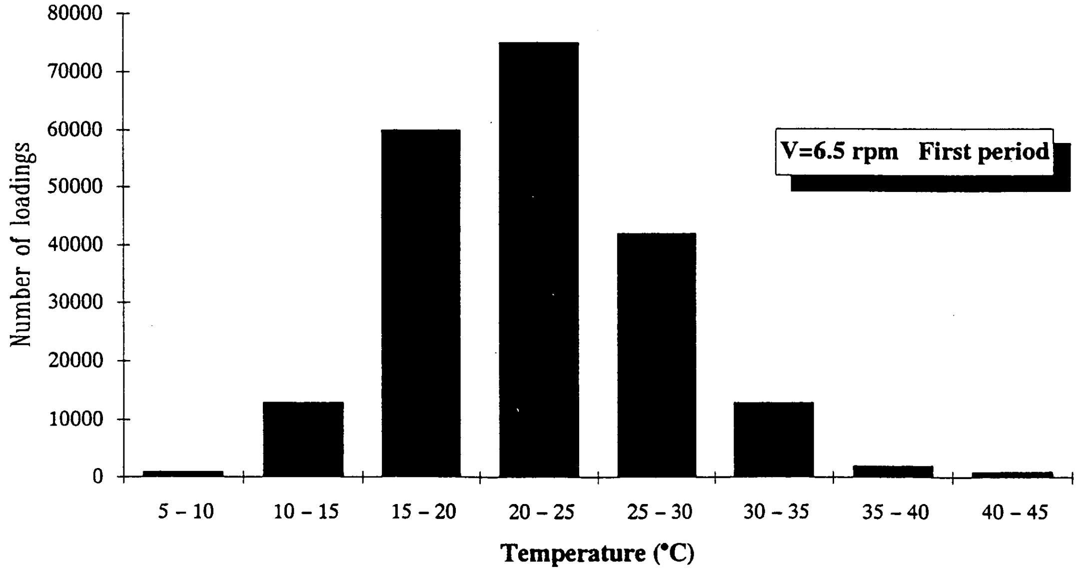


FIGURE 7 Description of ambient temperature.

Figure 8 shows when during the experiment the temperature at the middle of the asphalt mixes of the wearing course of Sector I exceeded 40°C. There were few such periods, for 1,000 passages toward 20,000 cycles and for 10,000 passages between 50,000 and 90,000 cycles total traffic.

Evolution of Rut Depth

Figure 9 shows, for the four sectors, the evolution of maximum rut depth (mean value of the maxima recorded on five transverse profiles per sector) for the wheelpath at the mean radius of 16.5 m (wide single wheel). Figure 10 shows the results for Sector I.

Table 2 gathers the rutting values for the four sectors and the four wheelpaths at the end of the first phase of the experiment.

The rate of increase of rut depth is greatest for the period between 20,000 and 91,000 loadings, which corresponds to the period of the highest temperatures. In the second phase, although the loads were channeled and the speed cut in half, there was practically no rut depth evolution. These two findings reveal the essential incidence of temperature.

First Analysis of Experiment Results

The foregoing data show that the rut depth depends on the configuration of the axle and on the radius of the path and does not increase regularly with the number of loadings (nonuniform temperature conditions over the duration of the experiment).

Since the temperature, the speed of translation of loads, and the axle configuration act in combination, it is difficult to make direct term-by-term comparisons without a global explanatory model. In a first analysis, an attempt is made here to isolate some tendencies by introducing several simplifying assumptions.

Comparison Between Sectors

The ranking of the sectors with reference to the rut depth is the same for all wheelpaths. Sector I, with pure 60/70 asphalt, exhibits the largest deformations, more than 12 mm. At the opposite extreme is the EME + VTAC solution, which exhibits the smallest deformations, between 3 and 5 mm. Sector II, with the Shell MG binder, and Sector IV, with the SBS-modified asphalt, exhibit similar intermediate performance, with deformations between 5 and 7 mm.

Influence of Loading Speed

Between 19,000 and 91,000 cycles, the increase of rut depth and speed vary roughly in inverse proportion for the materials of Sectors II, III, and IV. In the case of Sector I, for which the influence of the speed is more marked, the results may have been affected by the segregation recorded along the transverse profile when the asphalt mix was placed.

Influence of Axle Configuration

The 42.5-kN wide single-wheel axle turns out to be more aggressive than the 65-kN axle with dual wheels. The mean contact pressure of the former is 0.67 MPa, whereas for the latter it is 0.57 MPa.

To refine the comparison, it is first necessary to correct the observations for the influence of speed, because the paths are not the same. The period between 19,000 and 91,000 cycles will be considered here by interpolating, for each axle configuration, a rut depth for a radius of 17.5 m (traffic speed of 43 km/hr).

Table 3 indicates that the effect of the axle configuration depends on the material. The greater the aggressiveness of the wide single wheel in relation to that of the pair, the more sensitive the mix is to rutting. For the same number of axle loads, the ratio of rut depths ranges here from 1.1 to 1.6.

In a first analysis, the mean contact pressure is compared with the rutting depth by a relation such as the following:

$$(q/q_0)^\alpha = d/d_0$$

where

q = 0.67 MPa is the mean contact pressure of the single wheel,

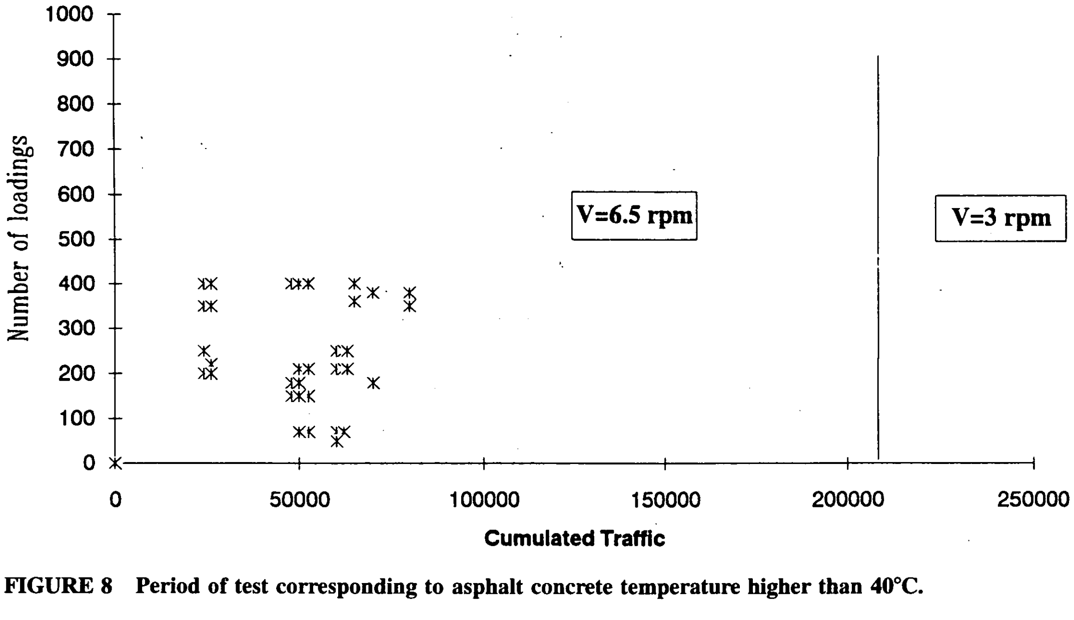


FIGURE 8 Period of test corresponding to asphalt concrete temperature higher than 40°C.

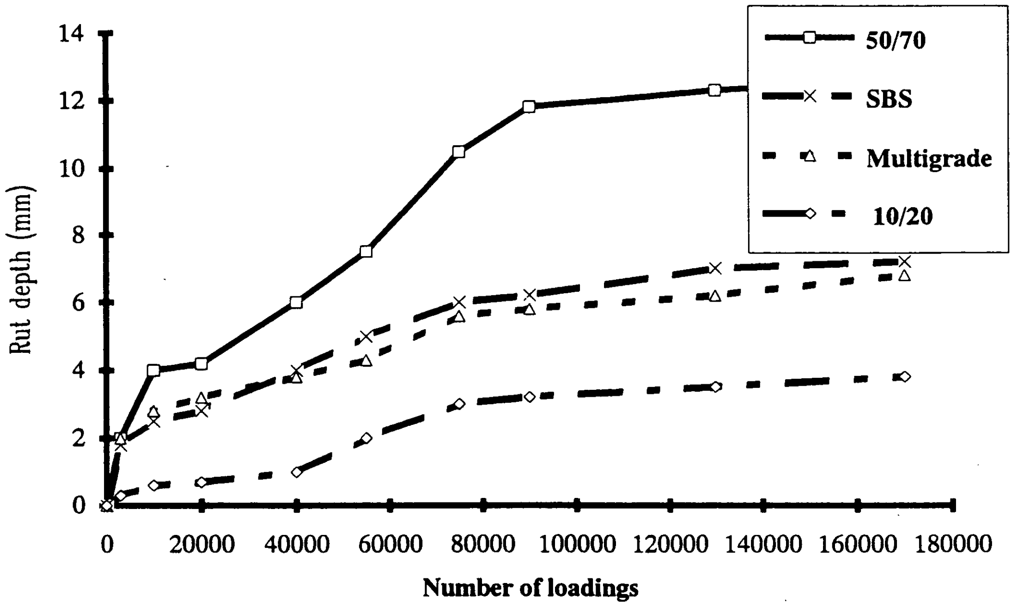


FIGURE 9 Test track results: rut depth evolution on the four sectors (wide single wheel, r = 16.5 m, V = 40 km/hr).

q_0 = 0.57 MPa is the mean contact pressure under a wheel of the pair,
d = rut depth produced by the single wheel, and
d_0 = rut depth produced by the dual wheels.

Hence α ranges from approximately 1 for asphalt mixes made with hard or modified binders to 3 for the mix made with 50/70 asphalt on Sector I.

Comparing the aggressiveness in terms of rutting of a 210-kN road trailer on a tridem axle with wide single wheels with that of the same load carried by a tandem axle with twin wheels, with $\alpha = 2$ to be representative of common asphaltic materials, we find that the tridem axle is roughly 1.5 times as aggressive as the tandem axle (for the temperature conditions of the fatigue test track experiment).

COMPARISON OF RESULTS OF LABORATORY TESTS AND TEST TRACK EXPERIMENT

There is good agreement between the qualitative rankings yielded by the different laboratory tests on the binders and the asphalt

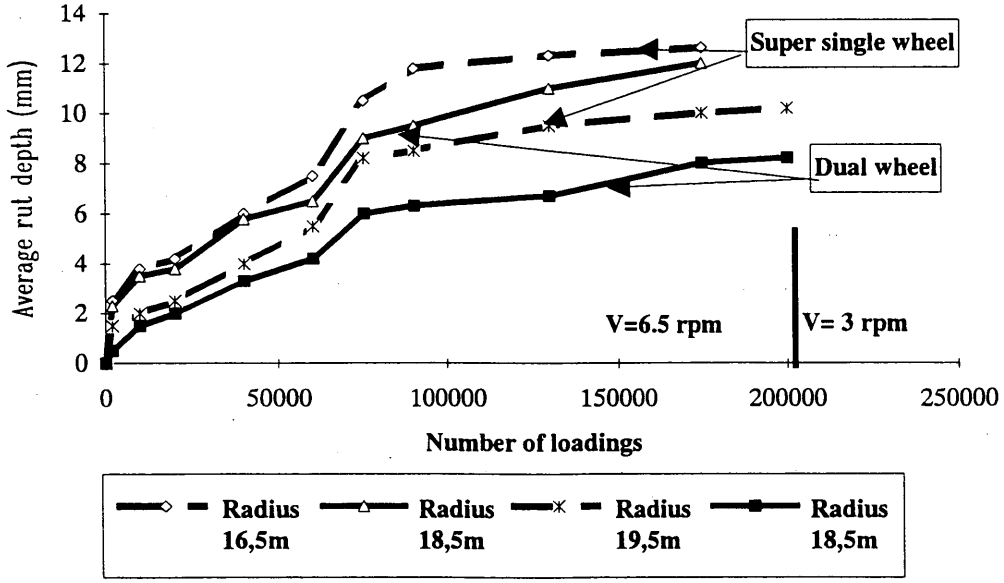


FIGURE 10 Rut depth evolution for Sector I.

TABLE 2 Rut Depths (mm) After 202,000 Loadings

	radius 15.5m J	radius 16.5m RS	radius 18.5m J	radius 19.5m RS
sector I 60/70 asphalt	11.8	12.6	8.2	10.2
sector IV SBS asphalt	6.7	7.2	5.6	6.9
sector II Multigrade	5.8	7.2	4.2	5.1
sector III EME + VTAC	4.9	3.7	2.9	4.7

J: dual wheels RS: wide single wheel

mixes and those corresponding to the deformations obtained on the test track. It is more difficult to judge the results of the tests in quantitative terms, since there are still only a limited number of observations.

Tests on Binders

In a first analysis with the pure asphalts (50/70, 10/20, and MG binder), the RBT turns out to be a good indicator of sensitivity to rutting, but it is not sufficient *(6,7)*. Complementary tests measuring the complex modulus provide information about the structured character of the binder (or otherwise) and its temperature and kinetic sensitivity. For the four binders tested, classification by the isotherm at 40°C or 50°C at various frequencies agrees with the classification of the asphalt mixes on the test track.

Tests Using the LPC Rutting Tester

The classification correctly matches the behavior of the asphalt mixes made with pure asphalt of Sectors I, II, and III for all of the rutting curve. The asphalt mix of Sector IV including the SBS-modified asphalt, however, is difficult to characterize because its behavior changes during the test.

Creep Tests

As expected, the dynamic creep test appears to be more representative of what happens in the field. Indeed, a good correlation has been achieved (compare Figures 5 and 9). Thus, we can consider that this dynamic creep test shows promise for predicting the rutting performance of the types of mixes considered in the study.

TABLE 3 Estimated Rut Depths for a Single Path Radius of 17.50 m

Sector	I	II	III	IV
Dual wheels (J)	3.8	2.2	2.5	3.2
Wide single wheel (RS)	6.1	2.6	2.7	3.6
RS/J	1.60	1.18	1.08	1.12

CONCLUSIONS

This study has yielded useful knowledge of factors influencing rutting:

- The type of binder affects the improvement of the rutting resistance of an unstable granular mix. The use of a hard asphalt (grade 10/20) in an approach combining high-modulus asphalt mixes with wearing courses of VTAC is confirmed as very effective. It is routinely used on French motorways when the surface layer is also expected to make a structural contribution to the pavement. The use of an asphalt modified by SBS polymers or of the Shell MG asphalt gives the wearing course better rutting resistance than a pure asphalt of the same penetration class (50/70).
- The means of production of the sand is important to rutting resistance. A ground sand has many rounded edges and makes the asphalt mixes more workable. Above a certain proportion of ground sand, the asphalt mixes containing a "standard" asphalt of average grade (50/70) have a poor rutting resistance. The fines of this sand generally have a rather low stiffening power, and the mastic is more sensitive to temperature variations.
- Axles with wide single wheels are more aggressive than dual wheels. The rutting as a result of this effect also depends on the type of asphalt mix, and the more sensitive the asphalt mix is to rutting, the more pronounced the effect seems to be. However, it is still difficult to isolate from this single experiment a law of load aggressiveness.
- Use of the LPC rutting tester is valuable in ensuring that a mix will have a good rutting behavior insofar as it satisfies the standard specifications. It turns out that this test can also be used for determining the influence of the compositional factors of the asphalt mixes on rutting resistance. The test seems satisfactory for classifying asphalt mixes according to their sensitivity to rutting on site.
- The dynamic creep test, in which the loading cycle includes a rest period, is useful in establishing a ranking of asphalt mixes similar to what was observed on the circular test track.
- Characterization of binders by the complex moduli that reflect the combined effects of loading rate and temperature is useful. The observed tendencies in the sensitivity of the binders here are in agreement with their ranking according to the sensitivity to deformation of the asphalt mixes.

The processing of the results of this experiment is not completed. Tests for determining the rheological properties of asphalt mixes are still being carrried out. Studies based on the results of laboratory tests and using calculation models will follow, with the results of the experiment on the test track as a reference.

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