Full Scale Tests for the Assessment of Wear of Pavement Surfaces

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ABSTRACT

The paper deals with the assessment of wear of road surfaces subjected to traffic. Full-scale tests were performed by means of LCPC Carousel facilities to simulate passages of truck tires under pure cornering maneuver. Three types of road surface were tested. Up to 800 000 passages were performed and measurements of tire and road characteristics were carried out at different wear stages. Results were presented in term of evolution of skid resistance as well as macro- and microtexture of road surfaces. Tire wear was simply assessed by tire groove depth evolution. Discussion was focused on the relationship between evolutions of road surface microtexture and tire groove depths to assess road aggressiveness vis-à-vis tire wear.

The study is part of European TROWS project that the main objective is to derive experimental and numerical tools to predict tire and road wear.

INTRODUCTION

TROWS (Tire and ROad Wear and Slip Assessment) is a European Community-funded project, which started in April 2000. Its main objective is to make a significant step forwards in the prediction of tire and road wear. Nine partners from 5 countries participate to the project, which fields of expertise include design, manufacturing and characterization of tires, roads and vehicles.

The work dealt with in this paper is part of experiment-based investigation to derive wear laws for roads. Research methodology is shown in the figure 1. Validation of theoretical laws requires experiments performed at two levels:

- Material level, which is related to laboratory polishing tests on road specimens;
- Road level, which is related to laboratory full-scale tests and on site tests.

Laboratory and on site tests are underway and results obtained from full-scale tests are reported in the following paragraphs. The main objectives of these tests are:

- To see how surface characteristics vary with traffic;
- To see which type of surface is aggressive vis-à-vis tire wear.

DESCRIPTION OF LCPC CAROUSEL AND FATIGUE TEST TRACKS

It was decided by TROWS partners to perform full-scale tests on LCPC Carousel facilities. By this way, road wear is induced by pure cornering maneuvers. The LCPC Carousel was developed for research on the mechanical behavior of road structures subjected to heavy traffic. Reports can be found in *(1)(2)*. Evolution of pavements during its whole service life (15 to 20 years) can be reproduced from a few-month-long experimental program.

The test site is located at LCPC Center of Nantes and composed of three 40 m-diameter circular tracks, one of which being shown in the figure 2. By this way, during tests on one track, pavement construction can be carried out on the two others.

Loads are applied on the pavement by means of four-arm carousel (Fig. 2). On each arm, various loading conditions can be configured:

- One semi axle with one single- or twinned-wheels;
- Two semi axles (« tandem ») with two single- or twinned-wheels;
- Three semi axles (« tridem ») with three single-wheels.

The applied load can vary between 40 and 135 kN using single wheel and « tridem » respectively. Value of the mean radius of rotation of each arm can be chosen from 15 to 20 m by 0.5 m-step. During the rotations, lateral displacement by 0.10m step of the wheels around the mean radius is possible. Pavement can be then loaded on a wider band than the tire width.

EXPERIMENTAL PROGRAM

Description of road surfaces

Three types of road surface were investigated (the numbers provide the maximum aggregate size in millimeter):

- 14mm-dense asphalt concrete (DA14);
- 10mm-very thin asphalt concrete (VTA10);
- 6mm-very thin asphalt concrete (VTA6).

Selection of the mixes is supported by the fact that they are representative of actual surfaces under traffic in France and that variations of their skid resistance according to traffic are significantly different *(3)*. Wearing courses were laid on 19 m-radius circle of 3 m wide (Fig. 3). Existing support representative of usual pavement structures was employed.

Since tests were performed on the same test track, it was decided to carry out two successive experiments: the first experiment dealt with DA14 surface and the second dealt with VTA6 and VTA10 surfaces. For the first experiment, 7 cm-thick layer of dense asphalt was laid on the whole test track (Fig. 3). For the second experiment, the test track was divided into two halves on which 2.5 cm-thick layer of the very thin asphalt mixes was laid (Fig. 3).

Adaptation of LCPC Carousel for pure cornering maneuver

For both experiments, tandem configuration was employed for carousel arms. On each tandem, two single truck wheels having the same weight were mounted with different yaw angles. The required vertical loads and yaw angles are summarized in the table 1.Yaw angles were obtained by rotating the bogie with respect to the carousel arm (Fig. 4). Actual angle values were calculated by measuring the distances d1 and d2 between a straight line passing through the wheel median plan and the outer side of the test path (Fig. 4). Checking of actual values of the yaw angles was done at the end of the experiments. For the first experiment, significant difference was noted between measured and required values. The difference is due to non-negligible plays in the mechanical assemblies. In order to preserve the same wear condition for both experiments, expressed as the sum of absolute values of yaw angles, it was decided to modify the required angle values for the second experiment. The actual values are presented in the table 1.

New tires were used at the beginning of each experiment. Inflation pressure was fixed to 0.75 MPa. The rotation speeds were fixed to the following values:

- 6.5 rotations per minute from 0 to 10 000 rotations;
- 8.5 rotations per minute from 10 000 to 180 000 rotations;
- 6.5 rotations per minute from 180 000 to the end of the experiment.

Lateral displacements of the wheels were adjusted to wear the pavement on 34.5cm-wide band. The width of the tire contact area is of 24 cm wide.

Test performing

Test duration and wear state definition

It was decided to run 200 000 rotations for each experiment. Pavements were then subjected to 800 000 passages. Measurements were carried out at different wear states in order to establish evolution curves for tire and road characteristics. Wear states are expressed as the number of rotations; the initial state is expressed as 0-rotation stage. Eight wear states were defined: $0 – 10^4 – 3\ 10^4 – 5\ 10^4 – 10^5 – 1.8\ 10^5 – 1.9\ 10^5 – 2\ 10^5$. Tolerance of ± 2000 rotations was given to the number of rotations at which the Carousel arms are stopped for measurements.

Acceleration of wear process

In order to speed up the polishing of road surfaces, it was decided to spread abrasive materials on the pavement during the last 20 000 rotations. The abrasive materials are the same as those employed in the British Polishing Test (BPT) to assess the polishing resistance of aggregates. They are composed of fine sand and fine emery. In

BPT tests, sand is first introduced together with water during 3 hours, then replaced by emery during 3 further hours. For TROWS program, it was decided to keep the same chronological order and to introduce each abrasive during 10 000 rotations. Existing equipment was mounted on one Carousel arm (Fig. 5). By this way, abrasive was spread continuously on the tracks during the rotations. Spreading was carried out without water.

Assessment of tire and road characteristics

At each wear state, the Carousel arms were stopped and measurements were carried out on tires and road surfaces. The whole measurements lasted after 1 ½ to 2 days after which rotations were restarted until the next wear states. The whole measurement program is summarized in the table 2.

Assessment of tire characteristics

Evolution of each tire was assessed by groove depth measurement, which was done by means of displacement gauge at four cardinal areas of each tire. At each area, four groove depths were measured; they are located at predefined spots named W, X, Y and Z (Fig. 6).

Assessment of road characteristics

Evolution of road surfaces was assessed by friction and texture measurements. Two types of measurement were carried out:

- Dynamic measurements along the test track central line (Fig. 3);
- Static measurements at 6 predefined areas uniformly marked along the test track (Fig. 3). Measurement areas for the first experiment, where the wearing course was laid on the whole test track, were located on one half of the track (Fig. 3).

Dynamic texture measurements were performed by means of manually pushed device equipped with laser sensor (Fig. 7), giving ISO mean profile depth (MPD). Averaged 1 m-values were registered from which the mean was calculated to give the MPD of the test surface.

Static texture measurements included sand patch measurements, giving mean texture depth (MTD), and profile measurements, giving information about sharpness of surface asperities. MTD values registered at the six areas are reported and averaged to give the MTD of the test surface. At locations n° 2, 4 and 6 (Fig. 3), nine parallel profiles were measured. They are 1.2 m-long and spaced every 10mm (Fig. 8). Profiles were sampled every 0.1 mm, giving information about the macrotexture. At locations 2 and 6, one 0.2 m-long profile is sampled every 0.01 mm (Fig. 8). By this way, information about microtexture of test surface was also collected. Profile measurements at the microtexture scale are time consuming and are not compatible with time constraints of the experimental program. That is why microtexture information was not recorded at every wear state.

Profiles were analyzed using the motif combination method. Motif is defined as the part of the profile between two peaks (Fig. 9). The mean depth R of the motif is defined as the mean value of the depths R_1 and R_2. The width of the motif AR is the horizontal distance between the peaks. A second analysis is performed on the envelope profile composed of segments connecting all the peaks. Respective motifs are defined and the mean depth and width are expressed respectively as W and AW. Ratios R/AR and W/AW were calculated for each profile. They were then averaged over the total number of profiles at each area (9 for the macrotexture and 1 for the microtexture) to give values representative of the area, then averaged over the total number of areas (2 to 3) to give representative values of the test surface.

Static friction measurements were performed by means of British Pendulum. Surface was wetted before release of the slider. Five swings were performed, from which the mean value was calculated and reported as the pendulum test value (PTV) of the test area. Values registered at the six areas are reported and averaged to give the PTV of the test surface.

Dynamic friction measurements were performed by means of manually pushed device (Fig. 10). The slip ratio of the measurement wheel is 15%. Surface was wetted continuously by means of 2 mounted water reservoirs. Friction values are registered every 4cm then averaged to give 2 m-values. Measurement on each track delivered about thirty 2m-values, from which the mean was calculated.

RESULTS

Evolution of tire characteristics

Survey of tire characteristics was done only between 0 and 180 000 rotations. Unexpected aspects were obtained on 7 tires – 4 in the first experiment and 3 in the second – where rubber debris is stuck to tire treads. Debris size increased with number of rotations and it was not possible to separate debris from the tire. Those tires were discarded from the analyses.

Survey of groove depth evolution was possible on tires C1, E1, F1, H1 for the first experiment and A2, C2, E2, F2, H2 for the second experiment (Tab. 1). Groove depth differences between the beginning (0 rotation) and the end of the experiment (180 000 rotations) are presented in the table 3. Value at each spot is the average of four readings at the cardinal areas. Linear decrease of groove depth with the number of rotations was observed. Results show that tire wear is more severe on the inner side than on the outer side and central bands wear more than external bands.

Evolution of surface characteristics

Evolution of surface characteristics was assessed by means of visual examinations and variations of friction and texture features.

Visual examination

Surface binder film was rapidly suppressed under the rotation action. The surfaces seemed then to be covered by a very thin film from 10 000 rotations. It is not sure whether the film is composed of rubber or a mix between rubber and other materials. The surface was smooth by touch and hydrophobic (water drops had characteristic shape of oil drops).

Compaction of the surfaces was observed during the first wear states. After 30 000 rotations, all surfaces presented some rutting (1 to 2 mm). Aggregates of DA14 wearing course were lain flat by the tires. For the second experiment, it was observed some pulling out of aggregates on two wearing courses VTA10 and VTA6. Visually, surface evolutions were rapid up to 30 000 rotations then stabilized after.

Friction evolution

Friction evolution is presented in term of PTV evolution (Fig. 11); dynamic friction measurement showed the same tendency. General tendency shows a decrease of PTV with wear. Skid resistance seems to be less affected by traffic on very thin asphalt surface than on dense asphalt surface. Actually, friction loss between 0-cycle state and 180 000-cycle state is about 40 % for DA14, and only 12% for VTA6 and almost negligible for VTA10. On very thin asphalt surfaces, PTV values stabilized at 0.6. On dense asphalt surface, PTV was very high at the initial state, but decreased rapidly to values lower than 0.5 at the end of the experiment.

Adding of abrasive speeded up the decrease of PTV values (Fig. 11). Smoothing of surface asperities due to abrasive particles was probably the main cause of skid resistance loss. Dense asphalt surface was mostly affected by fine abrasive, whereas very thin asphalt surface was affected by both abrasive types. Additional friction loss due to abrasives was about 10% for all surfaces.

Texture evolution

Mean depth
Evolution of MTD is shown in the figure 12. A similar tendency was observed for MPD. The decrease of MTD on the graphs corroborates the compaction effect. After 50 000 rotations, MTD of the very thin asphalt stabilized, whereas MTD of the dense asphalt increased. This secondary roughening effect could be due to the fact that aggregates in the dense asphalt were moved by the tires and re-arranged in the wear track. It would be more difficult to move aggregates in the very thin asphalt, since less sand is included in the mix giving a more rigid skeleton.

Sharpness
Evolution of R/AR at the macrotexture scale is shown in the figure 13. Evolution of W/AW is not shown since the same tendency was observed. Sharpness at the macrotexture scale might be a quantitative way to assess the

mean orientation of the aggregates. Missing points on the DA14 graph are due to technical problems encountered on the profile-measuring device at the beginning of the first experiment.

Values of R/AR decreased rapidly from the first rotations then stabilized, meaning that aggregates were lain flat rapidly by the tires. Evolution of sharpness does not seem to depend on the surface type; values at given wear state are almost the same for all surfaces.

Evolution of R/AR at the microtexture scale is shown in the figure 14. Sharpness at this scale quantifies the aggressiveness of the surface, which affects tire wear and tire/road friction. Microtexture sharpness of DA14 and VTA10 wearing courses decreased with wear duration, whereas the VTA6 surface maintained its microtexture. Values obtained after 180 000 rotations are almost the same for all surfaces. Adding of the abrasive decreased drastically the surface aggressiveness: about 30% loss was recorded for very thin asphalt surface. This result corroborates the friction evolution after abrasive adding (Fig. 11).

Influence of road surface microtexture on tire wear

Surface analysis at the microtexture scale (Fig. 14) showed higher sharpness for very thin asphalt surface VTA10 compared with VTA6 and dense asphalt DA14 surfaces. Tire wear should be then more pronounced on VTA10 surface. Comparison between the first and second experiment was then carried out for tires subject to the same normal load and yaw angles, that means, C1 was compared to C2 and so on (Tab. 3). Since wear was not uniform on tire tread width, separate comparisons were done for the spots W, X, Y and Z.

It can be seen from table 3 that, except the tires F, groove depth difference between 0 and 180 000 rotations was more important on very thin asphalt compared with dense asphalt. Results from table 3 confirm then surface analyses. However, it should be noted that results from the second experiment take into account the overall influence of VTA10 and VTA6. Interpretation related to aggressiveness of road surface vis-à-vis tire wear should be then supported by further investigation.

CONCLUSIONS

The main objective of the experiments carried out on the Carousel test tracks is the assessment of tire and road wear under pure cornering maneuvers. Different loading configurations (normal load, yaw angle) were tested on three road surfaces. The main conclusions from the experiments are the following:

- Traffic induced first compaction of the surfaces and lie flat the surface aggregates. These effects decrease the surface mean depth. Rutting was then formed in the wear track, mainly at the end of the experiments, and re-arrangement of surface aggregates could be observed, mainly on the dense asphalt.
- Thin film is formed rapidly after the departure of binder and covered the road surface. The film is hydrophobic. Its composition is not defined; it might be a mix between rubber and other materials such as road material debris and dust.
- Surface skid resistance decreased with the number of passages. Friction loss is more important on dense asphalt wearing course (40%) compared with very thin asphalt wearing course (10% or less).
- Surface macrotexture decreased with traffic. Texture depth reduction can be related to the compaction effect exerted by the tires.
- Surface microtexture decreased with traffic. It is not clear whether the evolution was due to smoothing of asperity angularity or to the fact that the thin film progressively covered the road surface.
- Microtexture of very thin asphalt wearing courses is well maintained under traffic. It could explain the fact that tire wear is more severe on this type of surface than on dense asphalt surfaces.

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FIGURE CAPTIONS

TABLE TITLES

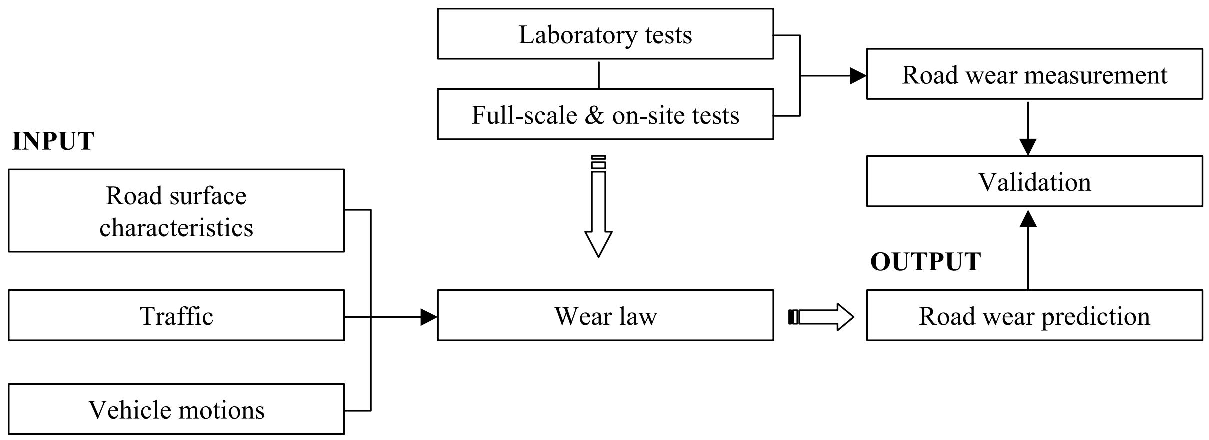

FIGURE 1 Research methodology for deriving wear laws for roads.

FIGURE 2 LCPC Carousel and fatigue test track.

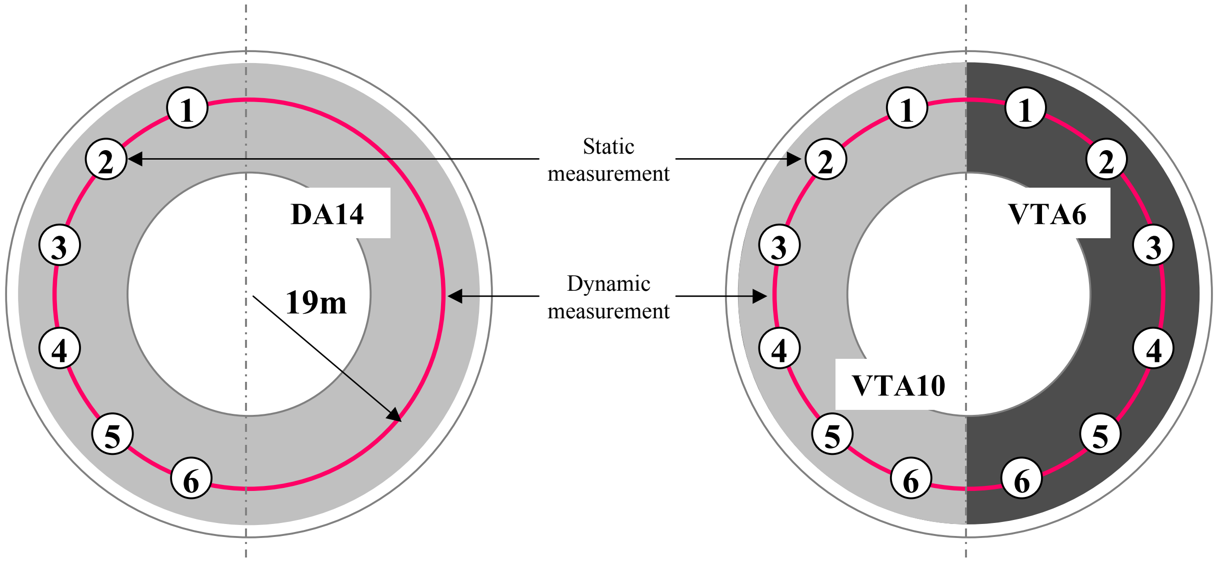

FIGURE 3 Description of test surfaces.

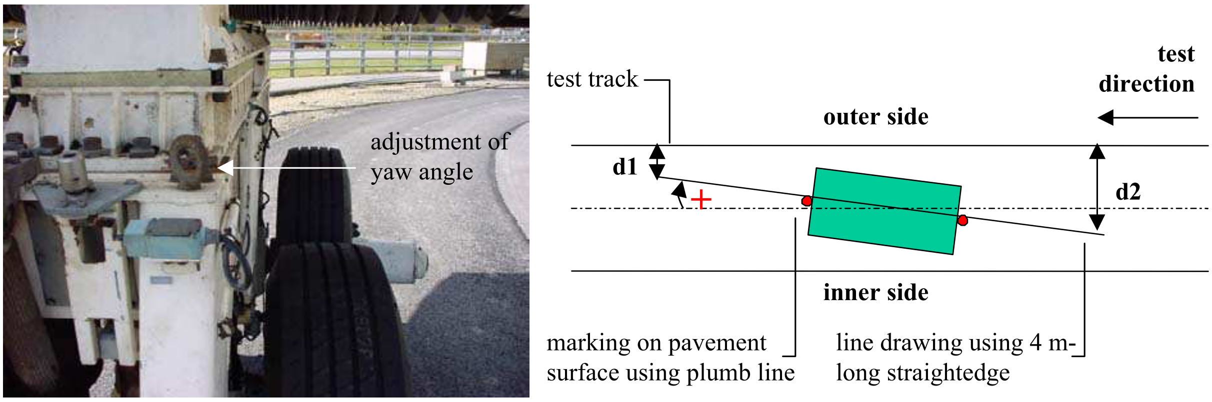

FIGURE 4 Carousel tandem and adjustment of yaw angles.

FIGURE 5 Set up employed for spreading of abrasive.

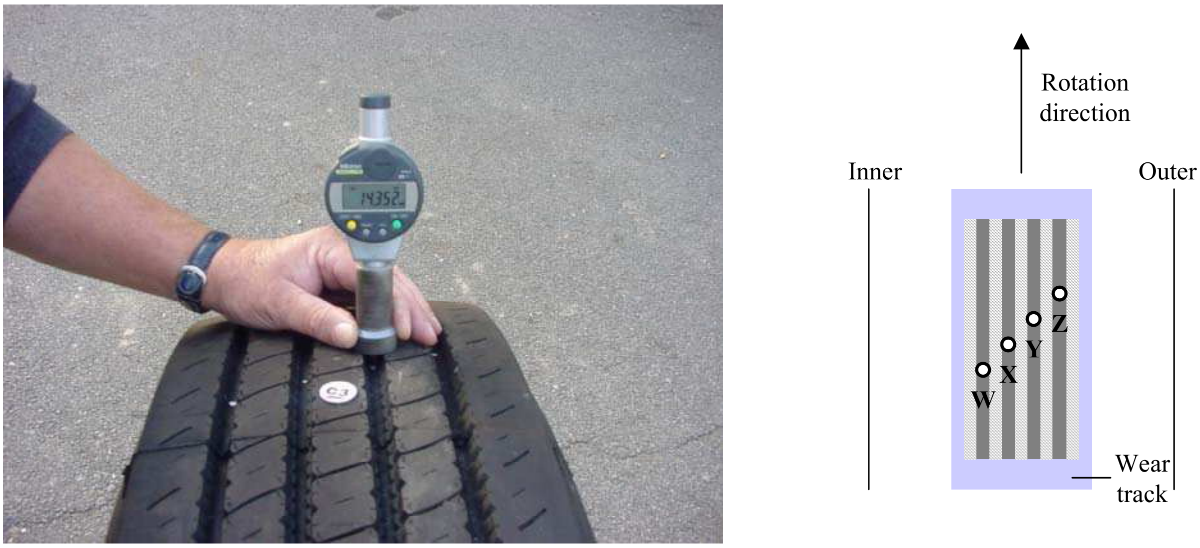

FIGURE 6 Locations for groove depth measurements.

FIGURE 7 Mobile device for mean profile depth measurement.

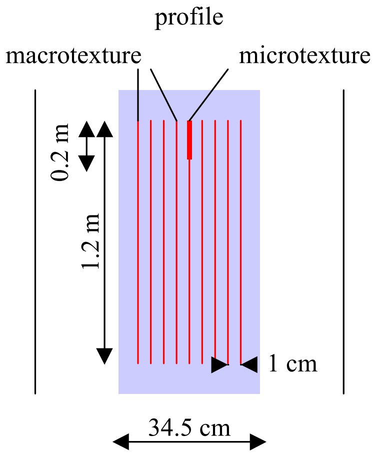

FIGURE 8 Laser device for profile measurement and location of profiles.

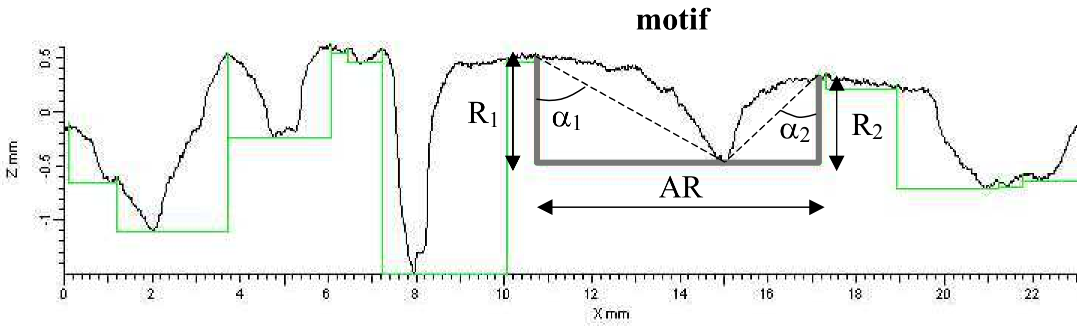

FIGURE 9 Profile motif definition.

FIGURE 10 Mobile device for dynamic friction measurement.

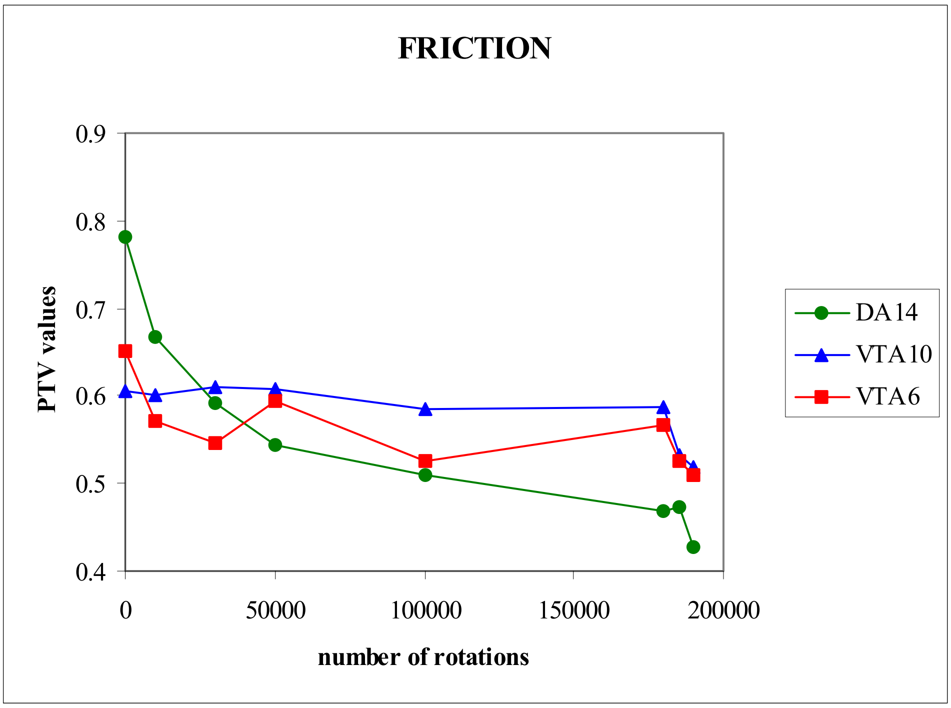

FIGURE 11 Evolution of British Pendulum friction values with the number of rotations.

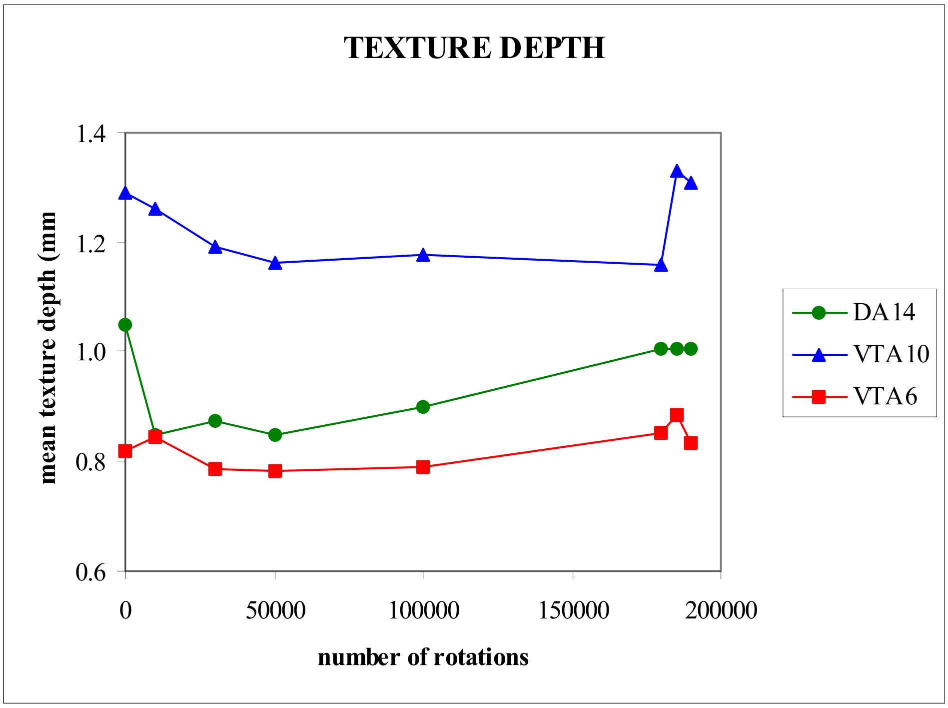

FIGURE 12 Evolution of mean texture depth with the number of rotations.

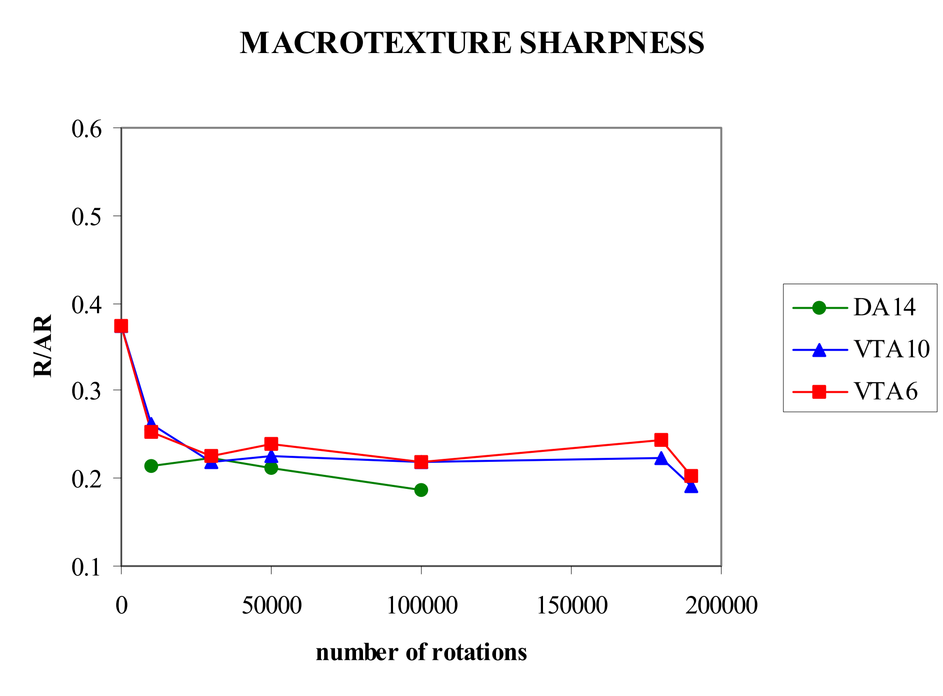

FIGURE 13 Evolution of macrotexture sharpness with the number of rotations.

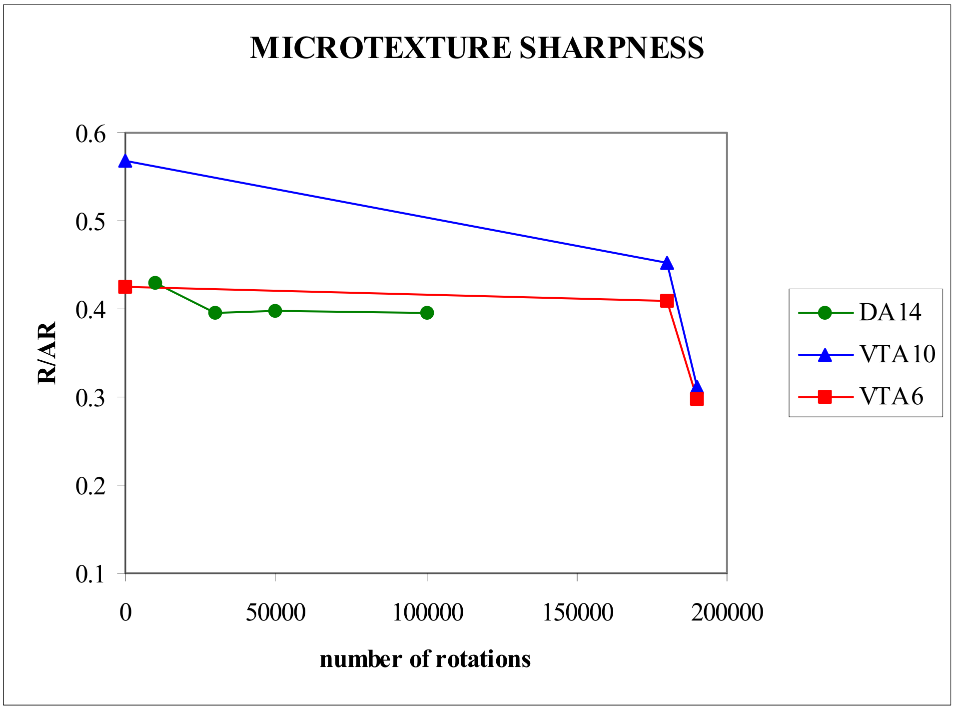

FIGURE 14 Evolution of microtexture sharpness with the number of rotations.

TABLE 1 Required Tire Loads and Yaw Angles

First experiment (Dense asphalt concrete DA14)			
Wheel	Vertical load (kN)	Yaw angle (°)	
		Required	Actual
A1	30	+0.3°	-0.3°
B1	30	+0.5°	+0.2°
C1	35	+0.5°	+0.4°
D1	35	-0.3	-0.4°
E1	35	0°	+0.6°
F1	35	+0.3°	+0.7°
G1	37.5	+0.5°	+0.4°
H1	37.5	+0.3°	+0.4 °
	Sum	+2.7°	+3.4°
Second experiment (Very thin asphalt concrete VTA10 and VTA6)			
Wheel	Vertical load (kN)	Yaw angle (°)	
		Required	Actual
A2	30KN	+0.6°	+0.7°
B2	30	±0.4°	±0.4°
C2	35	+0.4°	+0.4°
D2	35	0°	0°
E2	35	+0.6°	+0.7°
F2	35	+0.7°	+0.7°
G2	37.5	±0.4°	±0.4°
H2	37.5	+0.6°	+0.5°
	Sum	+3.7°	+3.8°

Note: Values ±0.4 ° mean that at every stop for wear assessments, the yaw angle changed alternatively from – 0.4 ° to +0.4 ° until the end of the experiment.

TABLE 2 Measurement Program

Location	Type of measurement					
	Texture				Friction	
	Macrotexture sharpness	Microtexture sharpness	Mean Texture Depth	Mean Profile Depth	Pendulum	Mobile device
1			✓		✓	
2	✓	✓	✓		✓	
3			✓		✓	
4	✓		✓		✓	
5			✓		✓	
6	✓	✓	✓		✓	
Track				✓		✓

TABLE 3 Reduction of Groove Depth After 180 000 Rotations

First Experiment						
Tires	Load (kN)	Yaw angle (°)	Groove depth difference (mm)			
			W (inner)	X	Y	Z (outer)
C1	35	+0.4 °	1.826	0.853	0.598	1.126
E1	35	+0.6 °	2.453	1.400	1.250	1.942
F1	35	+0.7 °	3.992	2.679	2.336	2.966
H1	37.5	+0.4 °	2.031	1.091	0.791	1.429
Second Experiment						
Tires	Load (kN)	Yaw angle (°)	Groove depth difference (mm)			
			W (inner)	X	Y	Z (outer)
A2	30	+0.7 °	2.810	1.830	1.623	1.967
C2	35	+0.4 °	1.945	1.373	1.282	1.956
E2	35	+0.7 °	4.473	2.715	2.403	2.916
F2	35	+0.7 °	2.726	1.820	1.721	2.068
H2	37.5	+0.5 °	1.970	1.490	1.422	1.933