

HOW CAN THE BINDER PROPERTIES INFLUENCE THE ROAD SURFACE DURABILITY? AN ADVANCED METHOD BASED ON THE BEARING RATIO CURVE



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Abstract

This paper presents an experimental procedure that allows evaluating the macrotexture durability of an asphalt concrete specimen by laboratory testing. The specimen surface is modified through the application of a sinusoidal repeated load at high temperature. The studied surface is scanned before and after mechanical solicitation using a laser profiler. Texture maps are analysed using 3D bearing ratio curve (the 3D extension of the Abbott curve (2D)). This 3D analysis enables to quantify macrotexture evolution under repeated traffic conditions and to evaluate the influence of both temperature and binder on this evolution.

Keywords: Safety, Macrotexture, Wearing course, Durability, Abbott curve.

Résumé

Ce papier présente une procédure expérimentale développée pour évaluer, en laboratoire, la durabilité de la macrotexture de la face supérieure d'une éprouvette en béton bitumineux. Pour altérer sa macrotexture, l'éprouvette est soumise à des sollicitations mécaniques cycliques à des températures élevées. Sa surface est scannée à l'état initial et après sollicitation à l'aide d'une station de mesure laser. Les données numériques fournies par la station laser sont ensuite analysées selon une méthode en 3D basée sur la détermination de la courbe de taux de surface portante (l'extension en 3D de la courbe d'Abbott (2D)). L'analyse effectuée permettra de quantifier l'évolution de la macrotexture après sollicitation cyclique et d'évaluer l'influence de la température et du liant sur cette évolution.

Mots-clés: Sécurité, macrotexture, couche de roulement, durabilité, courbe d'Abbott.

1. Introduction

Traffic safety is the main function of the wearing course which is the superior layer of the road. The traffic safety is a complicated phenomenon which depends on many parameters: pavement, tyre, driver, environmental conditions and others. This study is focused on the pavement role. The traffic safety is conditioned by the pavement/tyre skid resistance that is conditioned by the wearing course texture (Gothié, 2000), (Patte, 2005), (Cftr-info, 2005).

Surface stresses induced by vehicle loads (especially heavy vehicles) combined with environmental conditions, essentially temperature and water, lead to surface texture evolution along road surface life. Surface texture may take different aspects (depending on the stress applied and environmental conditions) including aggregate indentation, ravelling, polishing and many others (Cata, 1998). The progression in time of the texture induces a decrease of the pavement tyre skid resistance, which induces traffic safety deterioration. The continuous and rapid growth in traffic volume accelerates the safety deterioration and makes the use of classical techniques for wearing course inadequate in term of performance durability. With the increasing influence of sustainable development constraints, road constructors require thinner layers (consuming less materials) with longer service life and low need for reconstruction and maintenance. This was the reason for the development of new techniques and products like the construction of the thin wearing course using bitumen modified with polymers. Today, road constructors admit that this modification improves wearing course durability but they are unable to quantify accurately this improvement in number of years of wearing course life.

Three scales are available to describe wearing course texture : megatexture, macrotexture and microtexture (Cftr-info, 2005). Our study is focused on the macrotexture scale which refers to variations in the pavement surface within the range of 0.5 mm to 50 mm horizontally and 0.2 to 10 mm vertically. This scale is chosen since it is the scale which seems to be very influenced by the binder properties. The microtexture corresponds to irregularities on aggregate surface and its evolution can be related to the physical and chemical aggregate properties. The megatexture evolution is often related to structural defects in the pavement.

Different methods are used to evaluate the macrotexture in-situ, the most frequently used ones being the patch test (NF EN 13036-1) and the Rugolaser (ISO 13473-1). The patch test consists of spreading a known volume of glass beads (sand in the previous standardized method) on a pavement surface to form a circle, filling the surfaces voids with beads. The circle diameter is measured. Then an indicator called Mean Texture Depth (MTD) is obtained by dividing the volume of glass beads spread by the circle diameter. The patch test can be used only for local measurements. It has a poor repeatability and reproductibility since it depends strongly on the operator. The Rugolaser is a vehicle-mounted laser device that allows plotting a pavement profile which is used to calculate an Estimated Texture Depth (ETD) that can be empirically related to MTD (ISO 13473-1). The Rugolaser enables continuous measurement at high speed (up to 100 km/h). When these methods allow controlling the wearing course texture in-situ during the road service life, no efficient method currently exists to evaluate, with appropriate accuracy, the macrotexture and its evolution in laboratory. The work described in this paper aims at the development of an experimental procedure that is able to quantify to a fine detail the influence of the binder properties on the macrotexture evolution under loading and temperature actions.

2. Experimental procedure: Materials, Mechanical Solicitation and Surface Scanning

Two asphalt concrete mixtures are tested. These asphalt mixtures have the same composition: granularity (0/10), granulate nature (microdiorites) and voids and binder proportion. The main difference between these two mixes is the nature of bitumen. We have used a pure bitumen for the first mix and bitumen modified with polymers for the second one. For each asphalt mixture, six cylindrical core specimens are made in the laboratory. The specimen is 150 mm diameter and 40 mm height. The two groups of six specimens are cored from two asphalt concrete slabs (600 x 400 x 40 mm³) (1 slab / mixture).

The mechanical test is designed such as to modify the macrotexture of a cylindrical specimen of asphalt concrete through repeated uniaxial compressive sinusoidal loading at controlled temperature. The load is transmitted to the specimen surface via a rubber membrane (diameter: 100 mm, height: 10 mm). The applied stress amplitude value is 0.6 MPa. The solicitation frequency is 10 Hz. The test intends to simulate the granulate indentation produced at wearing course layer, resulting from the application of repeated vertical stresses on pavement by the tyres of heavy vehicles. This phenomenon is accelerated at high temperatures. Thus, two temperature levels are chosen for the test: 35°C and 60°C. The specimen is confined during the test (using a metal ring). The same rubber membrane is used for all tests. Laterally both repeatability and reproducibility of the test are checked.

The studied surface is scanned at the initial state and after mechanical solicitation (for different numbers of cycles), using a laser profiler. Scanning is made along one direction, i.e. profile by profile. Scanned maps are rectangular. Dimensions are 100 x 110 mm². Each map is composed of 1000 profiles and each profile is composed of 1100 points. The system provides both two and three dimensional presentations that allow a visual evaluation of the surface. For the evaluation of the macrotexture evolution, we have chosen to focus our comparison over the central zone of the specimen in which the boundary effects are negligible. The chosen zone is 60 x 60 mm² square size. Consequently, the studied surface contains 360000 points. It has been checked that this area can be considered as homogeneous regarding the granulate arrangement and that boundary effects can be neglected (Ech, 2007).

3. Analysis Method

3.1 Data Consolidation

The first stage of data processing consists in identifying and eliminating measurement errors (Ech, 2007).

The second stage of data consolidation consists of eliminating the drift effects due to the fact that the mean surface is not horizontal, which could bias the texture indicators values. This drift correction can be done either in 2D or in 3D. In 2D we determine the least squares line for each profile which becomes the reference line of the profile. For 3D analysis, the same logic is adopted but the surface is corrected relatively to a reference plane identified by the multiple least squares method.

After this data consolidation stage, it becomes possible to determine texture indicators by quantitatively describing the texture of the studied surface. Several texture indicators are presented and explained in (Ech, 2007). The method adopted in this study is based on the determination of the bearing ratio curve (also called Abbott curve).

3.2 Bearing Ratio Curve

Background (ISO 13565-2)

The Abbott curve (or bearing ratio curve) is generally used in tribology to facilitate the functional behavior evaluation of surfaces subjected to strong mechanical solicitation. The Abbott curve describes the increase of the bearing ratio with the depth of the profile, i.e. it gives for each elevation level the percentage of matter crossed by a line parallel to a reference line and located at this level. The standardized method (ISO 13565-2) recommends the use of the Abbott curve for the determination of parameters characterizing the functional behavior of the metallic surfaces subjected to strong mechanical stress. It forecasts the wear of the metallic surfaces according to three criteria including grinding, functioning and lubrication. A parameter is associated to each of these criteria. These parameters are R_{pk} , R_k and R_{vk} respectively.

The grinding criterion, based on R_{pk} , corresponds to the highest peaks which will be worn during the first operating hours of a surface. The grinding duration is conditioned by the peak volume and amplitude. The functioning criterion, based on R_k , represents the quantity of matter available during the functioning of the surface. An engine service life is conditioned by the presence of this quantity of matter. The lubrication criterion, based on R_{vk} , is in relation with deep valleys contained in a profile. These valleys are useful to retain a lubricant which is necessary to provide a correct functioning and to avoid the energy losses and seizing on an engine. These concepts, although elaborated in a different framework, can be useful in the road-tyre contact problem regarding skid resistance and drainage.

In this study, we suggest the use of the Abbott curve in order to analyze the macrotexture of asphalt mix surfaces. In this context, R_{pk} may correspond to the highest peaks which will penetrate in the tyre and whose a part will be worn off or polished under traffic, R_k to the principal working part of the surface subjected to vehicle load which conditions the tyre-surface contact and R_{vk} to the capacity of surface to evacuate or to store water.

Construction of the Bearing Ratio curve in 2D

Figure 1 is an example illustrating a profile (measured on the surface of an asphalt concrete specimen) and its corresponding Abbott curve. The Abbott curve gives the percentage of intersection between the surface located under the profile (filled surface) and a variable line which moves down in parallel with the reference line. The reference line (dashed line on Figure 1) is obtained by the least squares method. It can be seen, for example, on Figure 1 that we obtain 95 % of intersection when the moving line position is at an elevation of -1.2 mm.

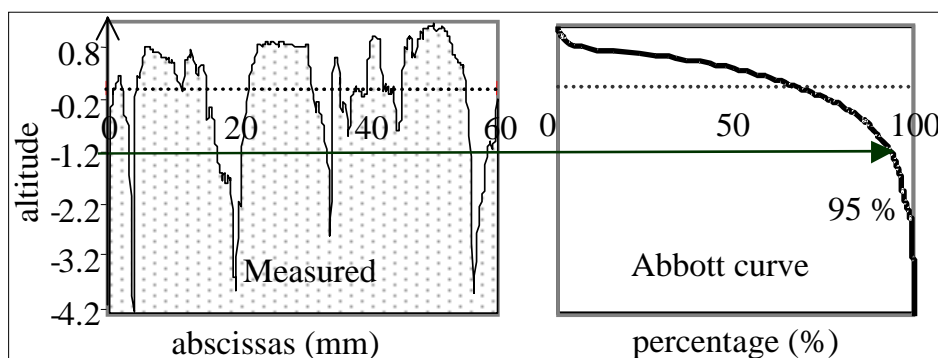


Figure 1 – Abbott curve or bearing ratio curve (2D analysis)

Definition and Construction of Bearing Ratio Curve in 3D

By analogy with the standardized method (ISO 13565-2) which is based on a profilometric analysis (2D), we propose a similar analysis in 3D, which is more realistic. In this case, the bearing ratio curve informs about the variation with elevation of the percentage of matter crossed by a plan moving in parallel with the reference plane. The considered reference plane is obtained by the multiple least square methods (applied to all the points of the surface). The method of determination of 3D bearing ratio curve can be simply summarized as follows.

Let E be the set of scanned points ($M(x, y, z)$) corresponding to the studied zone of specimen surface. The scanning steps chosen for the abscissa axis (x axis) and ordinate axis (y axis) are identical and equal to $100 \mu\text{m}$. The elevation range is $[H_{\min}, H_{\max}]$, where H_{\min} and H_{\max} are respectively the lowest and highest points of the studied surface. The elevation step chosen to build the curve is $100 \mu\text{m}$. For each elevation H_i comprised between H_{\min} and H_{\max} , the percentage of matter intercepted $P(H_i)$ is determined as follows:

$$E_i = \{M \mid M \in E \text{ and } z(M) \geq H_i\} \quad (1)$$

$$P(H_i) = (\text{Cardinal}(E_i) / \text{Cardinal}(E)) \times 100 \quad (2)$$

Now, to draw the intersection surface at an elevation H_i , we associate to each point M a column which has a section of $100 \times 100 \mu\text{m}^2$ and an elevation of $z(M)$. The intersection surface is obtained by projecting, on the reference plane, the sections of columns that have an elevation $z(M)$ higher than H_i . Figure 2 is an example of bearing ratio curve resulting from a 3D analysis. It shows the evolution of the surface of contact (S_c) with elevation. The points $H = 800 \mu\text{m}$ and $H = -10900 \mu\text{m}$ on bearing ratio curve respectively correspond to the highest and lowest points of the scanned surface.

The maps (presented on Figure 2) resulting from 3D analysis seem to be of great importance. These maps make it possible to see the "in-depth" evolution of surface structure. This might be a very interesting input to study the surface drainability and the voids connectivity and their evolution with the service life. It may also give new elements which can improve the pavement / tyre contact modeling.

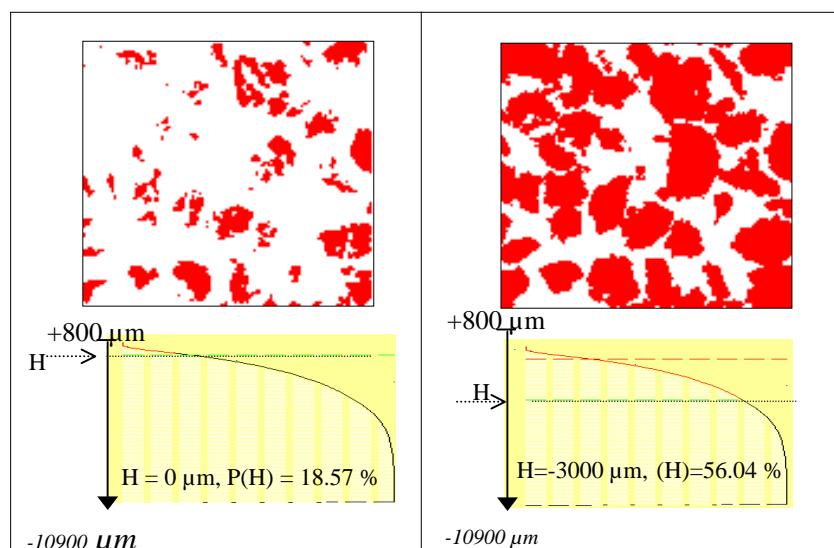


Figure 2 – In-depth evolution of texture and corresponding bearing ratio curve

Determination of Bearing Ratio Curve Parameters

The standardized method (ISO 13565-2) defines a list of parameters (Table 1) that can be determined from Abbott curve resulting from a 2D analysis. We have decided to draw an analogy in 3D and to determine the same parameters for the bearing ratio curve obtained with a 3D analysis. These parameters can have the same definition in 2D and 3D analysis. In fact, the choice to undertake 2D or 3D analysis influences the construction of the bearing ratio curve but doesn't influence the determination method of the Abbott curve parameters.

Figure 3 illustrates the determination method of these parameters (Bigerelle, 2007). One has to look for the 40 % wide portion of the curve that gives the lowest secant slope. The segment found is designated by [AB]. Let the line (AB) intercepts the 0 % and 100 % vertical axes at points C and D respectively. The difference of elevations between the points C and D is the first parameter R_k . Let E be the intersection between the horizontal line passing by C and the bearing ratio curve and F the intersection between the horizontal line passing by D and the bearing ratio curve. Now one determines the area A1 comprised between the line (CE) and the bearing ratio curve and the area A2 comprised between the line (DF) and the bearing ratio curve. The height of the triangle (CEG) which has the same area A1 is the second parameter researched R_{pk} . The height of the triangle (DFH) which has the same area A2 is the third parameter researched R_{vk} . The parameters Mr1 and Mr2 are respectively the abscissa of points E and F. Mr1 is defined as the fraction of surface which consists of small peaks above the profile plateau. Mr2 is defined as the fraction of surface which supports the loads during the service life. In this case, $100 - Mr2$ represents the fraction of the surface that can contain a lubricant. The drainage capacity will also be related to the connectivity between valleys, as it was seen on Figure 2.

Table 1 summarizes the physical signification of the Abbott curve parameters according to standardized method (ISO 1365-2).

If one compares Abbott curves of a metallic surface at two different times (t_a and t_b , $t_b > t_a$), one will find that curves are superimposed except the left portion of the t_b curve which will exhibit a magnitude smaller than the initial one, due to the peaks erosion between t_a and t_b . In the road context, the physical significance of the Abbott curve parameters R_k , R_{vk} and Mr2 should be modified: R_k could correspond to the amplitude of the tyre-road contact surface, R_{vk} to the depth of surface valleys that may contain or evacuate water. These two parameters decrease with time and will influence surface the pavement–tyre skid resistance and surface drainage.

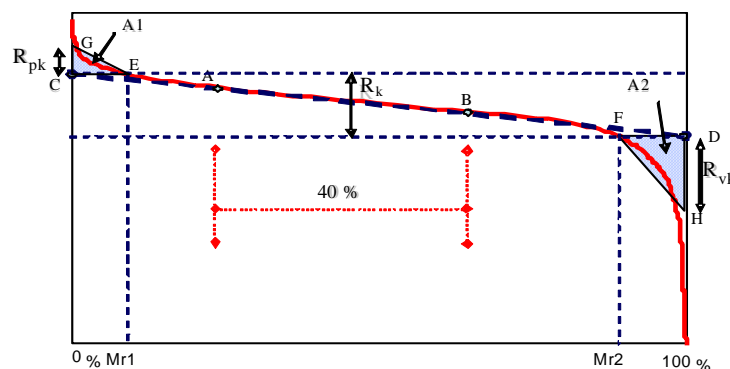


Figure 3 – Determination of Abbott curve parameters

Finally, Mr2 should be considered as the “fraction of the surface carrying the load at the time t” and not during the “service life” because Mr2 evolves with respect to the service life of the road (For a metallic surface Mr2 must remain constant during the service life).

Table 1 – Physical significance of Abbott curve parameters

Parameter	Physical significance (ISO 13565-2)
R_k	Depth of the working part of the surface
R_{pk}	Amplitude of peaks above the plateau
R_{vk}	Depth of valleys that can contains lubricant
A1	Area of the peak portion of the bearing ratio curve
A2	Area of the valleys portion of the bearing ratio curve
Mr1	Fraction of the surface corresponding to small peaks above the plateau
Mr2	Fraction of the surface carrying the load during the service life of the part
100 – Mr2	Fraction of the surface that can retain lubricant

The bearing ratio curve building and the parameters identification are done automatically by the software Tex3D that has been developed for this work. All parameters are obtained through a 3D analysis.

4. Experimental Results

Four series of three specimens have been tested (two bitumen types, each at two temperatures). The description of these series is provided in Table 2. Each specimen surface was scanned four times: before solicitation, at 800, at 20000 and at 100000 load repetitions.

Figure 4 shows both absolute and relative evolution of three Abbott curve parameters (R_{pk} , R_{vk} and R_k) with the number of load repetitions, for all series. For each series, we have highlighted the evolution of the average indicator determined from the three tested specimens. The three elementary values obtained from each specimen are also plotted on the graphics. In the case of relative evolution, 100 % corresponds to the initial value of the indicator. The relative evolution graphs eliminate the effect of material scatter and reveal more clearly existing patterns.

Table 2 – Definition of the tested series

Series	description	designation
Series 1	Specimens with pure bitumen solicited at 35 °C	SBP35
Series 2	Specimens with pure bitumen solicited at 60 °C	SBP60
Series 3	Specimens with modified bitumen solicited at 35 °C	SBM35
Series 4	Specimens with modified bitumen solicited at 60 °C	SBM60

It is seen from Figure 4 that R_{pk} increases with the number of cycles for all series. This increase seems to be influenced by both the temperature and the bitumen nature: R_{pk} increase is more significant for the specimens solicited at 60 °C than for those solicited at 35 °C. R_{pk} increase is also more significant for specimens with pure bitumen than for those with modified bitumen. The increase in R_{pk} can be explained by the presence of some points blocked on the surface (granulates which cannot indent). When the plateau of the surface

moves downwards after solicitation, these points remain immovable and become peaks relative to the whole surface. On a real road, we don't find such points. This can be explained by the presence of tangential stresses in situ (at the tire/pavement interface). These stresses don't exist in the laboratory procedure which allows applying only vertical stresses. The temperature influence is obvious where at 60°C the bitumen becomes more deformable. The curve allows quantifying this influence. For example, it was noted that after 100000 cycles, R_{pk} becomes 140 % of its initial value at 35 °C and 260 % of its initial value at 60°C.

The influence of bitumen nature is also illustrated on Figure 4. For example, it was noted that R_{pk} value at 60 °C is doubled, after 4000 cycles in case of specimens made with pure bitumen and after 9000 cycles with modified bitumen. It is believed that the use of modified bitumen makes the surface less deformable.

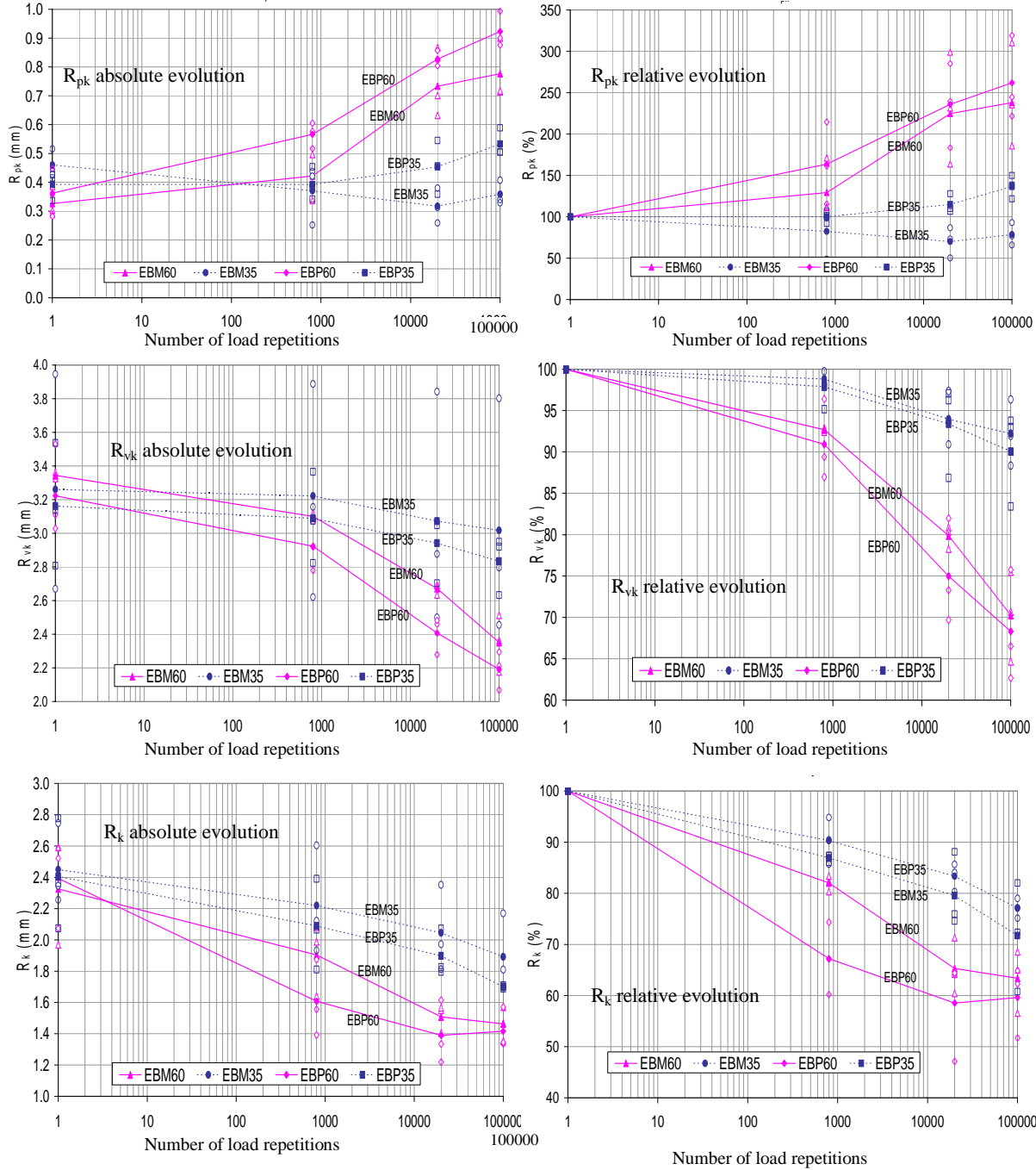


Figure 4 – Evolution of Abbott curve parameters

By examining the evolution of the parameter R_{vk} , it was observed from Figure 4 that R_{vk} decreases with the load repetition. This decrease is also influenced by the temperature and binder nature. The decrease of R_{vk} can be explained by the decrement of valleys depth. This may reduce the volume of pores on the surface and may reduce the surface drainage. Similarly to R_{pk} evolution, the R_{vk} decrease is more significant at 60°C than that at 35°C. The binder influence is also visible, especially at 60°C. To reach a decrease of 20 % at 60°C (for R_{vk}), 8000 cycles are required for specimens with pure bitumen and 20000 repetitions for those with modified bitumen. For a 25 % decrease, 20000 cycles are required for specimen with pure bitumen and near 48000 cycles are required for specimens with modified bitumen.

Similarly to R_{vk} , R_k decreases with the number of cycles (Figure 4). The binder influence is more apparent in case of R_k . We note that for a 20 % decrease at 60°C, only 60 repetitions are required in the case of the specimen with pure bitumen but more than 1000 repetitions in the case of specimens made with modified bitumen. For a decrease of 30 % the numbers of load repetitions needed become 450 and 8000 respectively. The decrease of R_k means that pavement-tyre contact surface becomes thinner; a phenomenon resulting from granulates rearrangement.

The evolution of other parameters is also studied in the experiment, exhaustive data are analyzed in (Ech, 2007).

5. Conclusion and prospects

The experimental procedure developed during this study makes it possible to evaluate the durability of macrotexture in the laboratory. This procedure is composed of a mechanical test and a laser cartography method. The laboratory mechanical test simulates the aggregate indentation under controlled conditions. The laser cartography offers an accurate description of the surface. Numerical data provided by the laser profiler are analysed using the bearing ratio curve. Abbott curve parameters constitute a comprehensive set of information about the studied surface including fraction of peaks and valleys in the surface, magnitude of peaks, depth of valleys, height of plateau, etc..

The experimental procedure was used to test different specimens of asphalt concrete. Results showed that the developed test is able to quantify the effects of temperature and binder nature. The series of experiments show that the macrotexture evolution increases significantly with the test temperature. The use of bitumen modified with polymers improves significantly the durability of the surface, since more cycles (at least 2.5 times more) are required to obtain the same degradation with pure binder. In this work, we have focused on the experimental procedure development which can be used later on for testing specimens with several types of bitumen, which seems to be very necessary in order to confirm the binder influence.

The application of an analysis method based on the bearing ratio curve to the pavement surfaces characterization seems to be original. The construction of 3D bearing ratio curve allows studying the "in-depth" evolution of the surface. This may open the way to the study of surface drainage and may improve the modelling of pavement/tyre contact.

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