Evaluation of the Impact of Scraping Operations during Winter Road Maintenance on Pavement Skid Resistance

Garance Liaboeuf, Mohamed Bouteldja, Antoine Martinet, Nicolas Grignard, Damien Pilet, Ali Daouadji, Alain Le Bot

***Abstract*—**A series of in-situ tests is set up to evaluate and quantify the long-term effects of scraping operations using steel plows on the skid resistance of pavements. Three pavements are tested, and a total number of 1.800 snowplow scrapings are applied. The skid resistance of the pavements is measured periodically using two indicators on two scales: an average profile depth (macrotexture) and a longitudinal friction coefficient (microtexture). The results of these tests show a reduction in the average profile depth between 4% and 10%, depending on the asphalt composition. This reduction of macrotexture is correlated with the reduction of high points on surfaces due to the removal of portions of the aggregate surfaces. The longitudinal friction coefficient of pavements decreases by 4% to 10%. This reduction in microtexture is related to the polishing of the surface of the aggregate used in the pavements. These variations of skid resistance are not linear. A phenomenon of regeneration of the friction coefficient is observed for pavements composed of sand-lime aggregates after several scraping operations.

***Keywords*—**GripTester, macrotexture, microtexture, pavement, skid resistance, snowplow, TM2, winter road maintenance.

I. Introduction

DURING the winter, meteorological events can lead to a deterioration in road serviceability. These bad weather conditions are responsible for driving difficulties such as increased travel time, inability to drive and reduced safety for road users [1]. In France, numerous winter maintenance operations are conducted on the roads to ensure a satisfactory level of safety for drivers. Winter maintenance operations can take different forms such as the removal of snow using snowplows (Fig. 1). The impact of snowplows in the short term is proven. It helps to reduce the number of accidents by improving the contact between the tires and the road: an increase in skid resistance is observed [2]. However, the long-term effects of these operations on the surface condition of pavements, and in particular on their skid resistance, have not been quantified. It has been assumed that damages appear by friction and abrasion of the surface when snowplows blades pass over it. This abrasion can be considered superficial and in a relationship between the nature of the pavement [3], [4].

It is necessary for all network managers to be able to assess the effects of winter maintenance operations over the long term. The objective of this study is to assess the impact of scraping operations. To quantify the effects of scraping with steel plows on the skid resistance of road surfaces, experimental *in-situ* tests are carried out. The results of these tests can be used to evaluate the impact of mechanical stresses associated with the passage of snowplows over the typical service life of a pavement.

Fig. 1 Winter maintenance operations – snowplows [5]

This article describes the main hypotheses concerning the effect of steel snowplows. Next, the protocol for the *in-situ* test campaign is described, along with the methodology for scraping and measuring skid resistance. Next, the measured skid resistance data and the methodology for processing them are discussed. Following this, the results of the tests are given. Finally, a discussion is drawn concerning the effect of steel snowplows on road surfaces.

A. Problem statement

Up to now, there have not been many studies on the impact of scraping operations during winter road maintenance. However, during operations using snowplows, the blades of snowplows (steel and/or rubber) come into contact with the surface of the road. Phenomena on different scales can occur on the surface of pavements and can be related to the evolution of pavement skid resistance. In fact, skid resistance is directly related to the texture of the road surface, which is considered in

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the range between 1 μm and 10 cm. Texture can be divided into two scales: the macrotexture (0.5 mm to 50 mm) and the microtexture (less than 0.5 mm) represented in Fig. 2 [6]- [10].

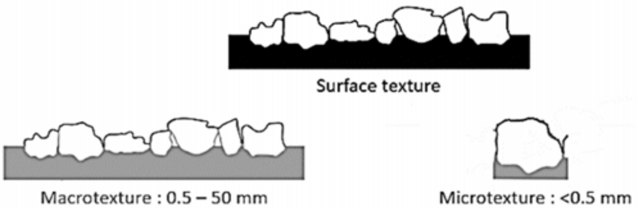

Fig. 2 Schematization of surface at macrotexture and microtexture scales

The first phenomenon (Fig. 3 (a)) is that snowplows can tear off parts of the aggregate due to their high application load. Changes in aggregate geometry and morphology can affect the macrotexture of the pavement. The second phenomenon (Fig. 3 (b)) is that snowplows can polish aggregate surfaces. The roughness of the aggregate is reduced in a microtexture scale.

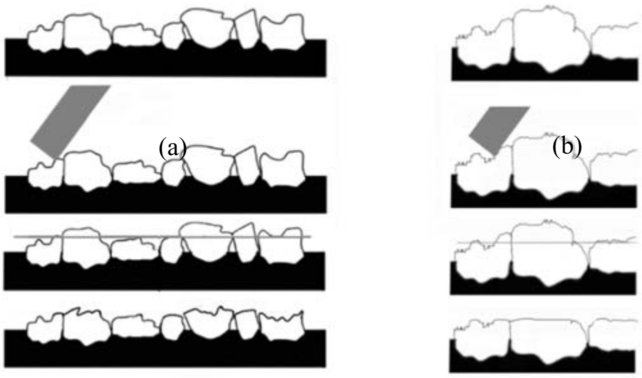

Fig. 3 Illustrations of tearing (a) and polishing (b) phenomena

These scraping operations can affect the skid resistance of pavements. They can reduce the skid resistance of the pavement by reducing the contact area between the tire and the pavement, or they can also increase the skid resistance by restoring the contact area. This article attempts to show how skid resistance evolves as a function of these phenomena.

II. Experimentation: In-Situ Tests

A. Approach and Methodology

The principle of *in-situ* measurement tests is to perform a representative number of winter maintenance operations (by passing snowplow blades) on different pavement surfaces and to periodically evaluate their surface condition using two indicators: the average profile depth and the longitudinal friction coefficient. The simplified protocol (Fig. 4) is as follows:

The *in-situ* measurement tests are conducted in winter, from November to March without the presence of road salt brine. Measurement takes place in the weather conditions of snow removal operations but without the presence of ice or snow. Prior to any scraping operations, the initial state of the pavements surfaces is characterized to establish the initial condition. The skid resistance of the pavements is assessed using two devices: the TM2 and the GripTester. The scraping operations are performed in one direction of the test section using snowplows. Each cycle consisted of 150 passages of the snowplow. The snowplow operated at speeds ranging from 30 to 50 km/h and applied typical loads. All scraping operations are conducted with steel blades. After each scraping session, the state of the pavements is re-evaluated using the TM2 and the GripTester after the pavements had been cleaned. This scraping/measurement alternation is repeated until 12 scraping cycles are completed for a total of 1.800 scraping operations.

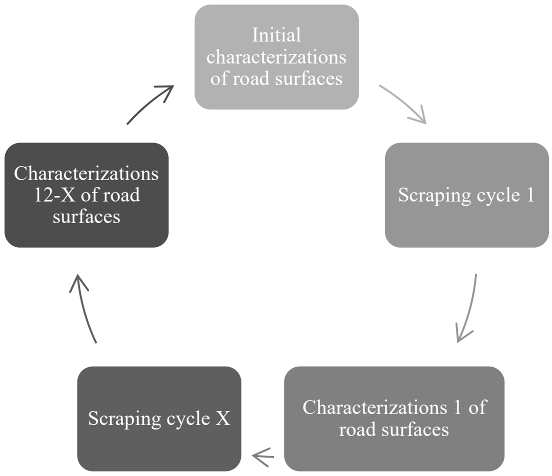

Fig. 4 Simplified in-situ test series protocol

B. Experimental Site

These tests are conducted on an experimental section of the Autoroutes et Tunnel du Mont-Blanc (ATMB) network, composed of four pavement zones with different composition. This section is not exposed to traffic. Its schematic representation is shown in Fig. 5. The asphalt mixes used on the section are as follows,

- Semi-Dense Asphalt Concrete (SDAC) composed of sand-lime aggregates.
- Semi-Dense Asphalt Concrete (SDAC) composed of diorite aggregates.
- Thin Asphalt Concrete (TAC) composed of steel slag aggregates.
- Thin Asphalt Concrete (TAC) composed of sand-lime aggregates.

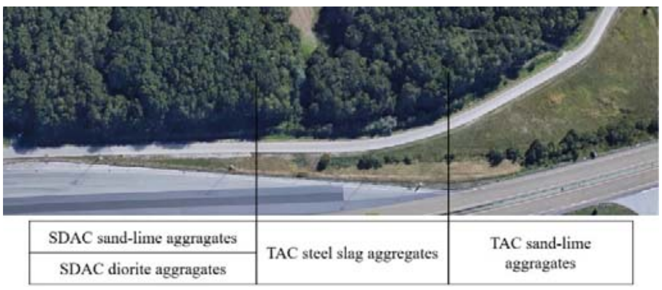

Fig. 5 In situ testing site

These tests consisted in applying snowplows to one direction only on the experimental board. It is leaving the other direction as a control not subjected to scraping to adjust the measurements. The surfaces studied during these tests are SDAC sand-lime, TAC steel slag and TAC sand-lime. This experimental site allows to evaluate the scraping resistance of two types of formulations and two petrographic types of aggregate. The intrinsic characteristics of aggregates are listed in

Table I.

TABLE I
INTRINSIC CHARACTERISTICS OF AGGREGATES OF THE IN SITU EXPERIMENTAL SITE

Petrographic composition of aggregate	Sand-lime	Steel slag
Los Angeles [11]	15	17
Micro Deval [12]	12	8
Polished Stone Value [13]	51	60

C. Scraping

The snowplow used for these tests comes from an ATMB operations center (Fig. 6). It is equipped with dual-scraper blades placed at the front of the vehicle. The name “bi-scraping” means that two types of blades are applicable to the road: one steel blade and the other rubber. The blades are placed on the ground by hydraulic control. This mode allows each blade applied to follow the profile of the road, but also to only apply its weight, without adding other loads [4], [14], [15]. In these test series, the steel scraping blade is only used.

Fig. 6 Snowplows using during the in-situ tests [16]

D. Measuring Devices

To measure and compare the evolution of the skid resistance and surface condition of the pavements during these tests, two devices are used. These are the TM2 and the GripTester. These two devices make possible to measure different parameters an average profile depth and a longitudinal friction coefficient. These indicators can describe respectively the macrotexture and the microtexture of a pavement surface [6]-[8].

The TM2 (Fig. 7) an optical device for continuous profilometric macrotexture measurement distributed by WDM company [17].The measurement is carried out via a laser beam transmitter and an optical potentiometer. The emitted ray hits the ground surface and is reflected on the optical potentiometer. Depending on the position of the illuminated point on this potentiometer, the height of the reflection point on the ground is deduced. It is pushed by an operator at a maximum speed of 5 km/h. The device returns average profile depth [mm] measures taken on a section of width 100 mm and in minimal steps of 1 mm. The average profile depth of a surface, expressed in millimeters, corresponds to the average of the height values between each profile of the surface and a horizontal line passing through the top of its highest asperity [10]. The resolution of the profile depth measurement is given as less than 0.05 mm. Measurements must be taken on dry, clean pavement. Repeatability of the device is estimated at 3% under the measurement conditions of these tests.

Fig. 7 TM2 device [18]

The GripTester (Fig. 8) is a device for continuous measurement of a coefficient of longitudinal friction measured at a slip rate of 14%, on a wet road surface with a smooth tire loaded to around 25 daN [19]- [21]. This device provides access to a coefficient of longitudinal friction under wheel-slide conditions, known as CFLG [8]. This dimensionless coefficient is generally between 0 and 1.20. Measurements are taken at test speeds ranging from 5 and 40 km/h. The equipment used during the *in-situ* tests operates in a towed version where measurements are taken at 35 km/h. The pavement is wetted using a tank inside the vehicle. The low wheel slip speed makes the measurement highly sensitive to the microtexture of the test surface. Repeatability of the device is estimated at 2% under the measurement conditions of these tests.

Fig. 8 GripTester device [22]

III. Data Collection and Processing

A. Data Collected

The TM2 measuring device allows access to two types of files. A file displays the average value at one-meter intervals of average profile depth. The average profile depth input data are measured in 1 mm increments and over a 100 mm section length. The other file displays the raw height measurement data of the points on the surface measured at 1 mm increments. The GripTester measuring device provides access to a file indicating for each position on the test site at intervals of 1 meter the calculated longitudinal friction coefficient values.

The condition of the road surfaces at each scraping state is evaluated with 3 times repetitions of the measurement from each device. The state of skid resistance of each measured pavements is the average of the values measured during the three passages.

B. Data Processing

Changes in skid resistance parameters are the result of a combination of factors linked to the scraping operations and the measurement conditions, such as pavement surface condition, the position of the measuring equipment or weather conditions. It is therefore crucial to eliminate the effects of these factors to isolate only the impact of snowplows on pavements. For each measurement cycle and each measured pavement, a correction is applied to the data.

The correction coefficients applied to the longitudinal friction coefficient and the average profile depth values take the following form (1):

$$C(x,t) = C^{-}(x,t) \times \frac{\overline{C^{+}(0)}}{C^{+}(t)} \quad (1)$$

where $C(x,t)$ is the corrected skid resistance value (average profile depth (mm) or longitudinal friction coefficient (-)) at each position x at a cycle of scraping t considered, $C^{-}(x,t)$ is the raw skid resistance value at each position x of the pavement during a cycle t studied, $C^{+}(0)$ is the skid resistance value of the pavement studied in the non-scraped part at initial cycle and $C^{+}(t)$ is the skid resistance value of the pavement studied in the non-scraped part at the cycle t studied. The correction coefficient values for each scraping cycle and each material are shown in TABLE II.

In this document, all the results presented correspond to values corrected using this correction coefficient.

IV. Results

A. Evolution of Average Profile Depth

Fig. 9 shows the evolution of the mean corrected average profile depth expressed in millimeters for the three pavements studied as a function of the number of steel blades applied to their surface. The three road surfaces studied have an initial average profile depth equal to 1.03 mm for sand-lime SDAC, 0.91 mm for steel slag TAC and 0.76 mm for sand-lime TAC. The average profile depth values of the coatings studied vary non-linearly with the number of scrapings applied to their surface. However, the final study shows that that the average profile depth indicator decreases for all materials as the number of scraping operations increases. After 12 scraping sessions, corresponding to 1.800 scrapings, the relative percentages of decrease observed are equal to 9.87 % for sand-lime SDAC, 5.40 % for steel slag TAC and 4.39 % for sand-lime TAC.

TABLE II
Correction Coefficients Applied to the Longitudinal Friction Coefficient and the Average Profile Depth Values in Function of the Number of Scrapings Applied and the Pavement Studied

Cumulative number of scrapes applied	SDAC diorite	TAC steel slag	TAC sand-lime
0	-	-	-
150	1,029	1,027	1,017
300	0,998	0,990	0,989
450	0,996	1,005	0,996
600	1,022	1,042	1,026
750	0,995	0,966	0,991
900	0,915	0,881	0,914
1050	0,975	0,959	1,017
1200	1,025	1,008	1,035
1350	1,112	1,068	1,135
1500	1,030	1,006	1,065
1650	1,133	1,078	1,147
1800	1,132	1,109	1,169

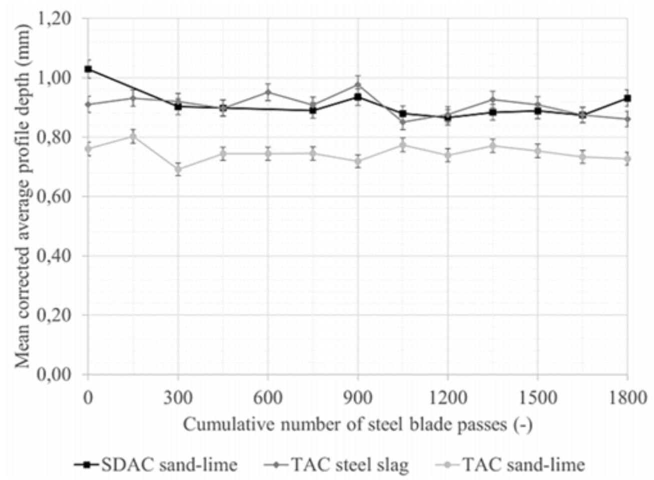

Fig. 9 Evolution of the mean corrected average profile depth (mm) in function of the cumulative number of steel blade passes for the three pavements on the experimental site

Studies using raw TM2 data are also carried out using MATLAB code. Fig. 10 shows the distribution histograms of height values, measured from TM2, for the three coatings for the initial (0 scraping) and final (1800 scrapings) cycles.

From these histograms we can see that the textures of the various coatings studied are positive, i.e. the surface has asperities that project above the average level of the surface. Initial histograms show that the distribution of height values in the initial state are extensive. The surface height values for sand-lime TAC are more clustered around an average value than for sand-lime SDAC or steel slag TAC. With the application of scraping operations corresponding to 12 years, the concentration of the number of surface points towards lower height values increases. This can be explained by the decrease in proportion of the highest height values shown in TABLE III. It can be quantified by the decrease in the percentage of height values in ranges above the average profile depth value for the cycle studied. The drop in concentration of the highest points is the most significant for the TAC sand-lime, with a quantified drop at 1.79%.

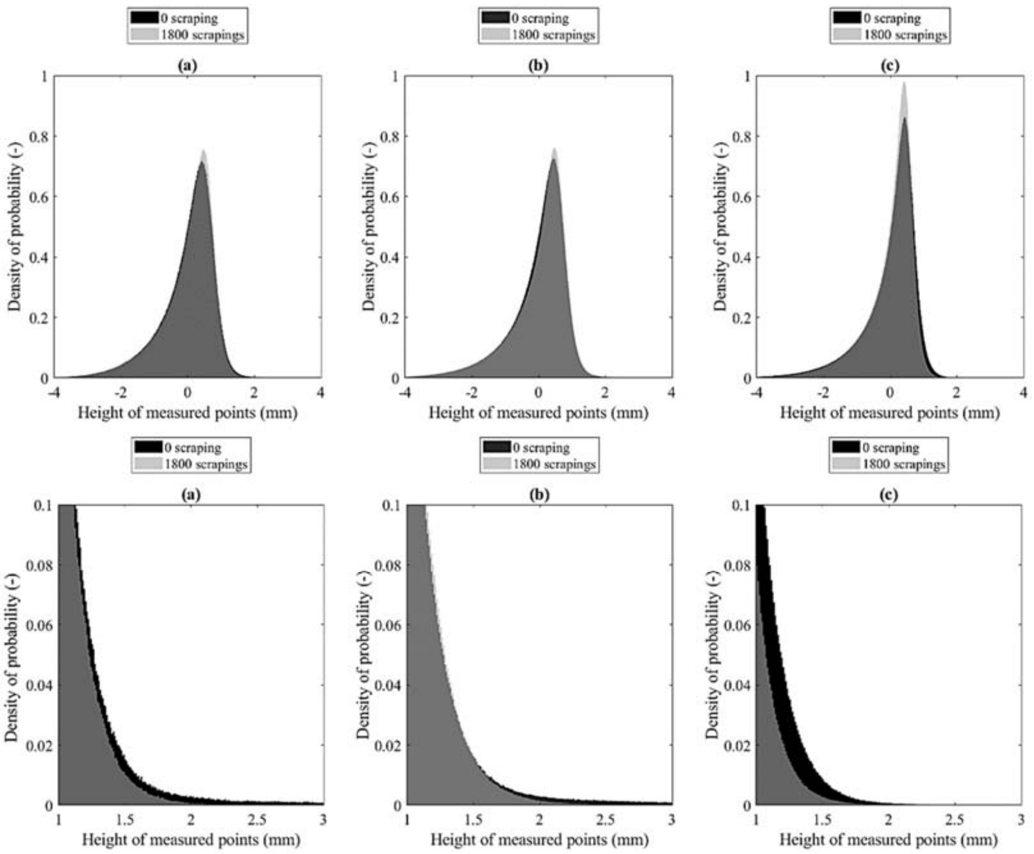

Fig. 10 Histograms of height values for the initial and final cycles of the in-situ test (a) STAC sand-lime (b) TAC steel slag (c) TAC sand-lime

TABLE III
PERCENTAGE (%) OF HEIGHT VALUES ABOVE THE INITIAL AVERAGE PROFILE DEPTH VALUE FOR THE INITIAL CYCLE (0) AND THE FINAL CYCLE (1800)

Percentage of height values above the initial average profile depth value	SDAC sand-lime	TAC steel slag	TAC sand-lime
Initial average profile depth value	1.20	1.17	0.93
0	1.68 %	1.98 %	3.70 %
1800	1.07 %	1.75 %	1.91%

B. *Evolution of Longitudinal Friction Coefficient*

The average corrected CFLG values for each test pavement after each scraping cycle are listed in Fig. 11.

Initial CFLG values are equal to 0.91 for steel slag TAC, 0.945 for sand-lime SDAC and 1.02 for sand-lime TAC. All materials show a reduction in their microtexture level after 12 years of snow removal operations. Sand-lime SDAC shows the smallest reduction, of around 4%, compared with 9% for TAC pavements. The microtexture of SDAC is less affected by the passage of blades than that of other materials. Steel slag TAC shows continuous wear, which appears to be linear after 600 blade passes.

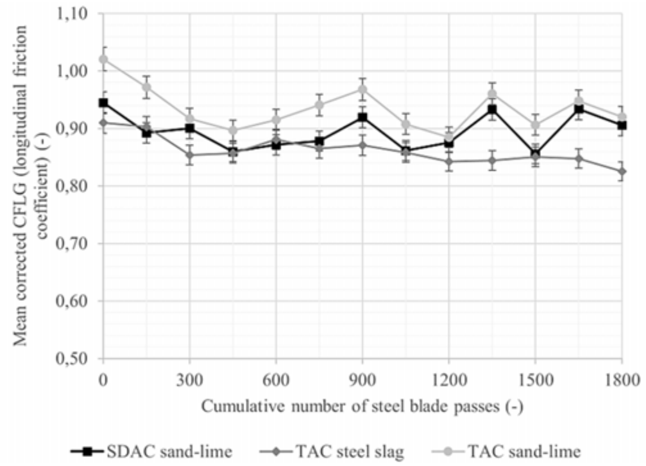

Fig. 11 Evolution of the mean CFLG of the three pavements on the experimental site in function of the cumulative number of steel blade passes

The various measurement sessions show that the average CFLG values of asphalt mixes composed of silico-limestone aggregates vary non-linearly. For SDAC sand-lime after 150 passes, there is a relative drop in longitudinal friction coefficient of around 6%, indicating an initial rapid degradation due to the first passes of the snowplows. This is also noticeable for TAC sand-lime, which tends to deteriorate in the same way up to 450 blade passes. The first significant drops in longitudinal friction show that pavement surfaces are rapidly affected by snowplows abrasion. TAC steel slag deteriorates only slightly during the first few blade passes, then by around 5% after the second cycle. For pavements composed of dans-lime aggregates, relative increases in longitudinal friction are observed. These regeneration phases show that coating degradation is not always linear. This is not particularly true of TAC made from steel slag aggregates.

The curves given in Fig. 12 show the evolution of the local longitudinal friction coefficient values for the three materials studied between the initial cycle and after 1800 steel blade passages.

The initial longitudinal friction coefficient curves as a function of position on the test section are relatively stable for SDAC and TAC sand-lime. This is representative of the homogeneous nature of their microtexture and their implementation. On the contrary, longitudinal friction coefficient values for TAC steel slag are not stable and tend to decrease with increasing position on the test section.

For all three surface layers, the longitudinal friction coefficient values measured in the final cycle follow the initial longitudinal friction coefficient variations. This proves that snowplows deteriorate all materials uniformly.

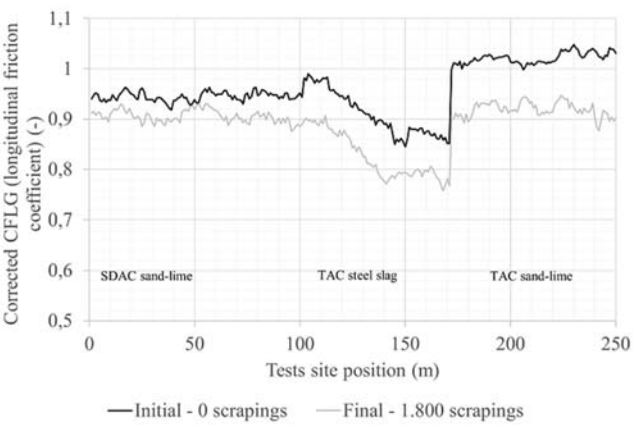

Fig. 12 Evolution of corrected CFLG of the experimental site in function of the localization on the site and for two cycles initial (0 scraping) and final (1.800 scrapings)

V. Discussions

This series of field tests allow to observe the evolution of pavement skid resistance, characterized in two scales, during the application of winter maintenance operations carried out using snowplows equipped of steel blades.

It is important to point out that the scraping operations carried out in this series of tests are more aggressive than those carried out during winter maintenance operations. This is because there is no layer of snow or ice between the snowplows and the road surface. Instead, the blades are applied directly to the surface of the aggregates, leading to greater damage.

In terms of macrotexture, the average profile depth of pavements has decreased with the increasing cumulative number of blades applied to pavement surfaces. This change is explained by the reduction in the height of the highest points of the surfaces. The use of snowplows tends to scrape off the highest points and homogenize pavement surface heights. Asperity heights are concentrated around lower values. These observations are valid in the case of these tests, as the textures of the coatings on the test site are positive.

In terms of microtexture, the average corrected longitudinal friction value is also impacted by these operations. Measured variations in the coefficient of longitudinal friction show that asphalt mixes react homogeneously to the passage of snowplows. Longitudinal friction variation between cycles reveals significant initial drops in longitudinal friction for SDAC and TAC sand-lime, whereas TAC steel slag shows a slower degradation. The fluctuations in longitudinal coefficient friction observed for sand-lime pavements could indicate temporary phases of surface regeneration. These fluctuations can be explained by temporary surface regeneration effects which can momentarily increasing roughness.

The evolution of skid resistance on two scales allows us to separate two types of pavement behavior when steel snowplows are used. Macrotexture degrades by lowering the height of the highest asperities, whereas microtexture degrades by scraping the roughness of the highest asperities in contact with the tire.

Surface degradation is attributed to the high mechanical pressure exerted by snowplows, leading to abrasion and fatigue of surface materials into two scales. The intrinsic characteristics of the aggregates used in the formulas are factors influencing the resistance of surfaces to snow removal operations.

When a coating is composed of aggregates with better polishing resistance (measured using the PSV test [13]), longitudinal friction coefficient values gradually decrease. No regeneration phase is observed during the period of application of steel scraper blades; contrary to aggregates with lower PSV characteristics, which tend to regenerate skid resistance during the test.

VI. Conclusions

These series of field tests enable us to measure the evolution of pavement surface properties and to quantify the degradation of skid resistance due to the mechanical action of snow removal over the entire service life of a surface course. Laboratory tests are planned to continue the research on the evaluation and quantification of the impact of snow removal operations on the skid resistance of steel snowplows. Samples of the three pavements were taken during these tests, at different cycles. Different scales need to be studied to explain the degradation of coatings using steel blades.

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