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The influence of mixture composition, adhesion promotor and compaction degree on the groove stability of grooved Marshall asphalt

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Abstract. After the first rehabilitation of runway 07R/25L in 2015, runway 01/19 was reconstructed in the summer of 2016, as part of a cycle where all runway pavements at Brussels airport are completely renovated each thirty years. The top layer is a Marshall asphalt with a polymer modified bitumen. To optimize the water drainage the central part of the runway (47 m wide) is grooved instead of applying an anti-skid layer. In this paper the focus is on the durability of the grooved top layer. Two different Marshall asphalt mixtures with a different maximum granulate size (10 mm or 14 mm) are compared, both in the laboratory and in a full-scale trial. In the laboratory the resistance against rutting and raveling are investigated for both mixtures with and without adhesion promotor, which did not show a positive effect. In the full-scale trial the compactability and impact of both a longer curing period and a variation in the degree of compaction on the groove stability is investigated for both mixtures using a heavy truck. No visual differences could be found except in areas which were undercompacted and showed more damage to the grooves.

1. Introduction
Grooving of the surface course for runways is used often as an alternative for so-called anti-skid layers. Both layers are used to improve the wet skidding resistance to prevent hydroplaning of the airplanes while landing or taking off. According to [1] there are four important factors that control the performance of runway surface grooves:

- Groove geometry (width and depth)
- Asphalt mixture properties
- Curing time before grooving
- Aircraft loading

As the groove geometry is fixed in the technical specifications and aircraft loading cannot be changed, this research focuses on the asphalt mixture properties and the curing time before grooving. A curing time of at least 30 days is still recommended by the Federal Aviation Administration (FAA)

[2, item P-621] and in Japan even up to two months [3], but for a commercial airport it is very difficult/expensive to wait such a long time. Grooving is performed mostly within one week of the laying of the asphalt. As shown in [3] the use of a polymer modified binder (PMB) can reduce the curing period and improve the groove stability drastically. This was both shown in laboratory test results as in a full-scale test, but it still remains unclear how long the curing period should remain. This was the inspiration for our full-scale tests.

The structure of the paper is the following: section two gives a description of the rehabilitation project for runway (RWY) 01/19 at Brussels airport and the different test tracks which were used for this research. In section three an overview is given of the laboratory results, including the resistance against rutting and raveling of the proposed mixtures with and without adhesion promotor (again to increase the groove stability). Next the results of a groove durability test on the full-scale test tracks are discussed in section four. The paper is finalized with some conclusions in section five.

2. Project description

In this section an overview is given of the actual runway and the full-scale test tracks that were constructed before the actual reconstruction to investigate the differences between the two Marshall asphalt types that were proposed by the contractor for the top layers. The focus of this research was on the top layers of the runway so no information will be provided about the foundation or base layers.

2.1. Runway 01/19

All runways at Brussels airport are being completely renovated as part of a 30 year cycle. Runway 07R/25L was rehabilitated as the first one in 2015, followed by runway 01/19 in the summer of 2016. The rehabilitation of the last runway 07L/25R is scheduled for 2018. An overview of the different runways and taxiways is shown in Figure 1.

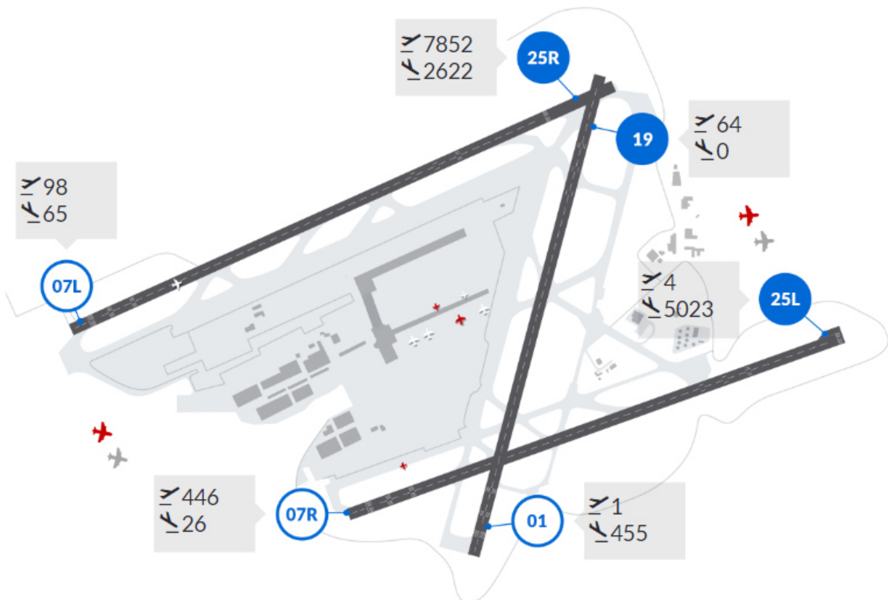


Figure 1. Overview of the different runways at Brussels airport.
[http://www.batc.be/en/statistics-runway-in-use]

The complete rehabilitation of runway 01/19 included:

- 239000 m² of asphalt on the runway and taxiways
- 62000 m² of asphalt on the shoulders (the area immediately beyond the lateral edges of the runway for aircraft running of the pavement)
- 373 kilometer of renewed cabling
- 5.6 kilometer of renewed runway drainage channels
- 3.2 kilometer of replaced sewage pipes
- replacement of 1850 lights by LED-lights

The current project had a total cost of approx. 21 million euro of which the asphalt pavements had a cost of approx. 5 million euro.

Originally the surface course of the runway consisted of a tar containing antiskid surface layer, but because of its high initial cost; environmental burden and its very strict installation instructions, it was decided to replace this antiskid surface layer by a grooved Marshall asphalt in the central part of the runway (47 m wide), as described in [4]. In [4] the binder type and content are described as between 5.0 and 7.0 % of a B70/100 or B100/150 paving grade bitumen (for easier compaction) and the aggregate size should be 0/14 mm when the thickness is between 40 and 50 mm for the surface course. A grading of 0/10 is used for regulating courses. To improve the groove stability and several mechanical properties such as fatigue and the resistance to rutting it was decided to use a polymer modified bitumen.

After the rehabilitation of RWY 07R/25L (2015) using a Marshall asphalt 0/14 (MA 0/14) some areas of the runway showed a surface texture which was too open, and could therefore lead to an early degradation, especially after the surface course was grooved. It was therefore decided to optimize the gradation of the mixture to obtain a more dense asphalt by including more fine material, while still maintaining the grading limits from [4]. As an alternative for this optimized MA 0/14 a Marshall asphalt 0/10 (MA 0/10) was proposed by the contractor Aswebo,

In order to be able to select the best mixture for RWY 01/19 an extensive laboratory study (see section 3) and tests on full-scale test tracks were performed (see section 2.2 and section 4).

2.2. Description of the full-scale test tracks

All test tracks have a length of 50 m and a width of 7.5 m as shown in Figure 2. The first goal of these test tracks was to assess the compactability of both asphalt mixtures in situ and to increase the thickness of the MA 0/14 from 4.2 cm (thickness of the surface course of RWY 07R/25L) to 5.0 cm (predetermined thickness for RWY 01/19) while still maintaining a good compaction degree. The second goal was to assess the influence on the groove stability due to a change in:

- Asphalt mixture grading: MA 0/10 vs. MA 0/14
- Compaction degree: normal compaction degree and instructions to roller operators to under- or overcompact
- Time of grooving: 3 days vs. 5 weeks after installation of the top layers

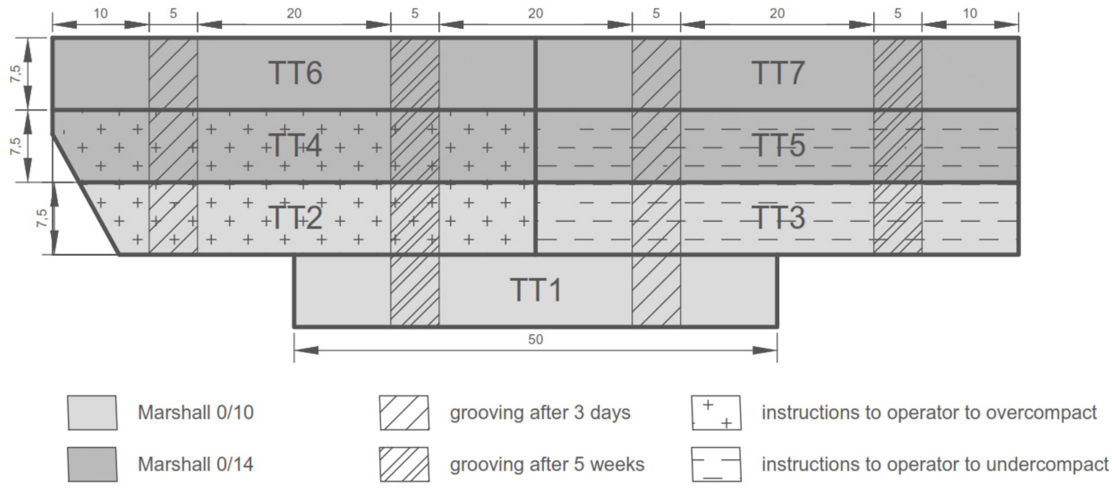


Figure 2. Overview of the full-scale test tracks.

The properties of all the different test tracks (TT) can be found in Table 1.

Table 1. Overview of the different test tracks

Test track ID	Grading	Compaction	Thickness [cm]
TT1	0/10	normal	4.2
TT2	0/10	instructions to overcompact	4.2
TT3	0/10	instructions to undercompact	4.2
TT4	0/14	instructions to overcompact	5.0
TT5	0/14	instructions to undercompact	5.0
TT6	0/14	normal	5.0
TT7	0/14	normal	4.2

The grooving dimensions are described in the tendering documents and are similar to the FAA grooving dimensions [2]. Transverse grooves saw-cut in the surface course must form a 6.0 ± 1.5 mm wide by 6.0 ± 1.5 mm deep by 38 ± 3 mm center-to-center configuration, as shown in Figure 3. To evaluate the possible effect of a longer curing period before grooving, as described in [3], two grooving areas of each 5 m wide were saw-cut in the asphalt, respectively one and three weeks after installation of the test tracks.

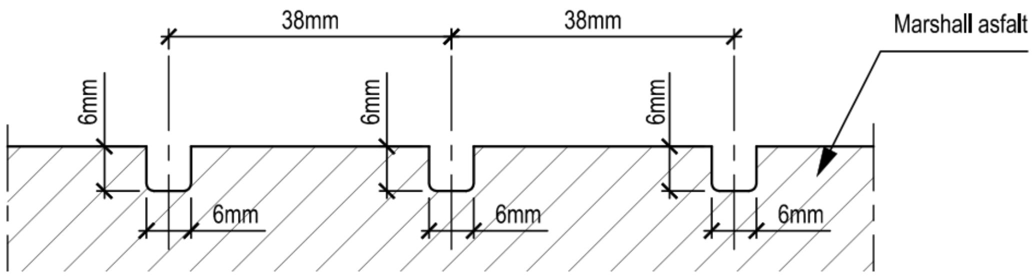


Figure 3. Detail of the grooving dimensions.

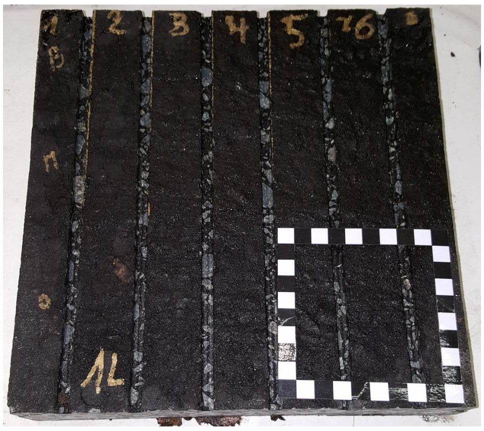
3. Laboratory results

The main goals of the laboratory tests were to determine the influence of the mixture grading (MA 0/10 vs. MA 0/14) and to evaluate the potential beneficial effect of an adhesion promotor (Wetfix AP17® by AkzoNobel at 0.3 % of the mass percentage of the binder). The purpose of an adhesion promotor is to enhance the bond between the binder and the aggregates which should lead to a better groove stability and resistance to raveling. If the adhesion promotor showed a beneficial impact on the laboratory results it would have been used as well in the full-scale test tracks.

The asphalt mixtures were mixed in the laboratory according to standard [5] and asphalt plates were compacted according to [6] using heavy compaction. Two types of plates were manufactured per mixture:

- Two plates of 50 x 18 x 5 cm which were not grooved and used for rutting tests
- Two plates of 60 x 40 x 5 cm which were then cut in two plates of 26 x 26 x 5 cm and grooved to be used for the raveling tests (4 tests per mixture), see Figure 4 (a)

The actual grooves were measured before performing the raveling tests. As mentioned in section 2.2 both the groove width and depth should be 6 ± 1.5 mm. The groove width ranges from 6.1 to 6.9 mm but the groove depth ranges from 4.5 up to 10.0 mm as the grooves were saw-cut manually. As all mixtures show a similar range of groove dimensions it was concluded that this was not an issue for comparing the different raveling results.



(a)

(b)

Figure 4. (a) Grooved plate of 26 x 26 x 5 cm used for raveling tests (b) Darmstadt Scuffing Device @ BRRC, adapted from [7].

3.1. *Resistance to rutting*

Two test samples of the same mixture are tested simultaneously with a load of 5000 N, a temperature of 50 °C and at a frequency of 1 Hz, according to [8]. The rutting is determined after 30000 cycles on both plates, averaged and expressed as a percentage of the sample height, as shown in Table 2.

The MA 0/14 outperforms the MA 0/10 in the rutting tests, although rutting isn't expected to be an issue on the runway itself. The influence of the adhesion promotor is unclear in these results as in one case the rutting is lowered and in the other case the rutting depth is higher.

Table 2. Results for the wheel tracking tests.

Mixture type	Average rutting depth [mm]	**Average rutting depth [%]**
MA 0/14	2.40	**4.90**
MA 0/14*	1.20	**2.30**
MA 0/10	2.55	**5.50**
MA 0/10*	2.90	**6.65**

* with adhesion promotor

3.2. Resistance to raveling

Four test samples of the same mixture are tested consecutively according to [9] with a tyre pressure of 3 bar, a vertical load of 1000 N, a test temperature of 25 ± 2 °C and a total of 10 cycles. The tests were performed by the Belgian Road Research Centre (BRRC) using a Darmstadt Scuffing Device (DSD), see Figure 4 (b).

The resistance against raveling is determined as the average weight loss in g/m² after 10 cycles, as shown in Table 3.

Table 3. Results for the raveling tests (measurements by BRRC).

Mixture type	Average weight loss [g/plate]	**Average weight loss [g/m²]**
MA 0/14	0.85	**21.4 ± 6.0**
MA 0/14*	2.67	**67.3 ± 11.5**
MA 0/10	0.97	**23.3 ± 4.8**
MA 0/10*	2.90	**51.0 ± 4.8**

* with adhesion promotor

The MA 0/14 and the MA 0/10 perform equally in the raveling tests. The influence of the adhesion promotor is surprisingly enough negative as the average weight loss increases. It was therefore decided not to use the adhesion promotor on the full-scale test tracks and on the actual runway.

More research is needed to verify if there might be a potential compatibility issue between the used PMB and the adhesion promotor.

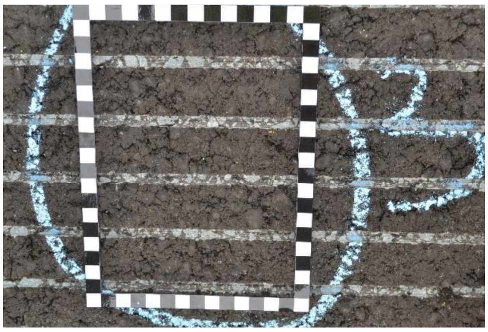
4. Durability test on the test tracks

During the installation of the test tracks different measurements were performed:

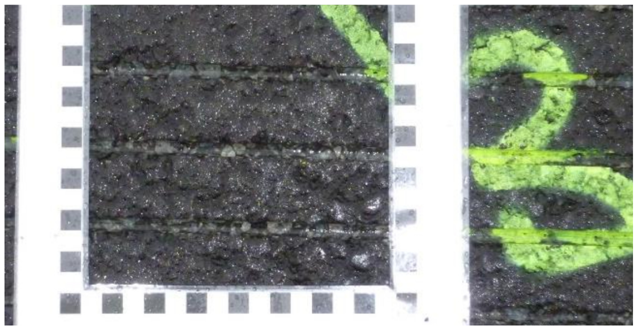
- Determination of the compaction degree using different methods, for more details see [10]:
  - drilled cores
  - a non-nuclear density gauge (TransTech PQI-380)
  - a gamma density measurement device (Troxler 3450), performed by the Belgian Road Research Centre
- IR thermography (FLIR T640)
- Taking of samples to be analysed in the laboratory for mixture grading and bitumen content

Five weeks after the installation of the test tracks a heavy loaded truck with 5 axles (43 ton total weight including 30 ton ballast) was used to investigate the groove durability. The truck makes 100 straight passes on each TT at a speed of 20 km/h followed by 2 full-stop emergency brakes at the location of the grooves. A speed of 45-50 km/h was obtained before executing a full stop in under two seconds. This was chosen to simulate an airplane performing an emergency landing and to check how much the grooves would be damaged by this manoeuver. Another series of 150 straight passes was performed three days later. The straight passes simulate an airplane taxying and can be considered as pre-loading which is considered as beneficial [11].

Pictures and measurements with a caliper were taken before and after each of the different series of passes. After the brake tests with a heavy loaded truck a significant amount of damage to the grooves became apparent. No visual differences could be found between the two types of Marshall asphalt or between the two different grooved sections (different curing time), but more damage was apparent in the sections which were undercompacted. This shows the importance for the groove stability to achieve the correct compaction degree. Figure 5 shows an example of the grooves before and after the brake test and the loose granulates which were recovered from the test tracks. As the loose granulates are completely covered with bitumen it is clear that the damage occurs in the mortar matrix and is not an adhesion problem.



(a)



(b)

(c)

Figure 5. (a) Measurement location before testing in an "undercompacted" MA 0/14 TT
(b) Same location after testing (c) Example of the loose granulates recuperated after testing.

5. Conclusions

In order to obtain a more closed surface of the top layer of the grooved runway a Marshall asphalt 0/10, prescribed in [4] for regulating courses, was proposed by the contractor as an alternative for a MA 0/14. In both laboratory and a full-scale test these two mixtures were compared. Furthermore the effect of an adhesion promotor was investigated in the laboratory study. The following conclusions can be made:

- The MA 0/14 outperforms the MA 0/10 in the rutting tests, although rutting isn't expected to be an issue on the runway itself. The influence of the adhesion promotor is unclear in these results as in one case the rutting is lowered and in the other case the rutting depth is higher.

- The MA 0/14 and the MA 0/10 perform equally in the raveling tests. The influence of the adhesion promotor is surprisingly enough negative as more ravelling occurs, but more research is needed to verify these results and check the compatibility between the used PMB and the adhesion promotor.
- After the brake tests with a heavy loaded truck a significant amount of damage to the grooves became apparent. No visual differences could be found between the two types of Marshall asphalt or between the two different grooved sections (different curing time), but more damage was apparent in the sections which were undercompacted. This shows the importance for the groove stability to achieve the correct compaction degree.

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