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A study on the development of Microsurfacing surface performance under laboratory-scale traffic simulation

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Abstract

In the field of preventative maintenance techniques, microsurfacing has gained scientific and practical interest, especially because of its effectiveness in restoring several distresses on structurally sound pavements; moreover, it provides social, economic, and environmental benefits since it is cold-applied in thin layers (less material and energy consumption), and it is fast-setting, allowing a quick reopening to traffic. Microsurfacing is also widely recognised for providing a regular and even surface texture with high skid resistance. Besides, assessing how the pavement surface performance changes over time under traffic conditions becomes essential in road pavement management. In light of the above and within the RILEM TC 280-CBE research activities framework, the work focused on optimising different bituminous cold microsurfacing mixtures: 'Basalt 0/6', 'Basalt 0/8', and 'Granite 0/8'. The optimised mixtures were fully characterised and subjected to a laboratory traffic simulator's action to study the development of the surface performance in terms of texture and skid resistance. A procedure has been implemented to model the relationship between the surface performance and the loading cycles, identifying the most representative phases (polishing and equilibrium) of the surface characteristics evolution. Notably, pertaining to skid resistance, the 'Granite 0/8' mixture achieves the same percentage decrease (about 18%) in a shorter conditioning period compared to the basalt ones. Regarding texture, the 'Basalt 0/8' mixture rapidly reaches the equilibrium phase but exhibits a lower drop (24.0%) compared to 'Basalt 0/6' and 'Granite 0/8' (38.0% and 39.6%, respectively).

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1. Introduction

The road network is strategic for all countries, representing the primary mean of transportation, with numerous kilometres being constructed or maintained worldwide each year. However, the combined effects of traffic loads, weather conditions, and the natural ageing of the paving materials lead to deterioration and, therefore, the need of managing the existing asset has now become crucial (Pan et al., 2021). Pavement preventive maintenance is a proactive and cost-effective approach for well-structured pavements, intending to postpone damage and maintain or enhance pavements' functional conditions for a longer period, increasing the project's overall sustainability (Giustozzi et al., 2011). Many surface treatments are widely used in flexible pavements maintenance; among others, Microsurfacing (MS) is a cold technique consisting of a mixture of polymer-modified emulsion, dense-graded mineral aggregate, mineral filler (cement or hydrated lime), and water, which is widely considered as a high-performance surface treatment. It is generally applied in very low thicknesses, from 6 to 10 mm in one layer, which firmly adhere to the laying surface in less than 15 minutes and turns into a dense-graded asphalt mixture usually within an hour, permitting a quick traffic reopening (Bhargava et al., 2020). MS is frequently mentioned to provide benefits for several distresses of road pavements with relatively low costs and environmental impact (De Rose et al., 2023). Nonetheless, MS provides superior skid resistance performance and an even and rough surface macrotexture (Vaiana et al., 2023) that restores friction to vehicles, improving road safety. In addition, surface texture changes over time, affecting the main functional characteristics of road pavements; researchers and road agencies must be aware of the development of surface performance under traffic conditions to perform appropriate pavement engineering and maintenance.

In the light of the above, and within the framework of the RILEM TC 280-CBE research activities, the overall objective of this paper is confined to the study and optimisation of the mix design for three different MS mixtures (following the EN 12274 standard series) in order to evaluate the deterioration rates of the surface performance when the mixtures are subjected to polishing action using an advanced laboratory-scale traffic simulator.

2. Materials and methods

2.1. Materials

In manufacturing the MS mixtures, two different aggregate sources were used, namely basalt and granite, whose mechanical properties are listed in Table 1. Two particle size distributions with different nominal maximum aggregate sizes were selected, a 0/6 mm and a 0/8 mm, specifically designed as part of the project of the TG2 working group within the technical committee 280-CBE RILEM. The particle size distributions are presented in Table 2. Specifically, three different mixtures were manufactured: 0/6 mm with basalt aggregate, and 0/8 mm with basalt and granite aggregates.

Table 1. Mechanical properties of the two sources of aggregates.

Mechanical Properties	Los Angeles (LA) [%]	MicroDeval (MD) [%]	Polished Stone Value (PSV) [-]
Basalt	20	10	50
Granite	30	15	50

Table 2. Particle size distributions used for MS mixtures.

Sieve Size [mm]	8	6.3	5.6	4	2	1	0.5	0.25	0.125	0.063
Basalt 0/6 [%]	100	98.1	95.4	85.8	57.3	39.4	28.9	20.4	14.5	10.0
Basalt and Granite 0/8 [%]	100	97.1	90.5	67.8	45.7	33.1	23.9	17.2	12.6	8.1

For this experiment, a quick-set cationic emulsion with a bitumen residue of 65% (EN 1428) and modified with SBR polymer was used. The bitumen characteristics are presented in Table 3. Portland cement (Type 42.5N) was

used as mineral filler; the water utilised is sourced from the local water supply network. No additional additives were employed to modify the breaking and setting times of the emulsion. All the experiments specified in the following paragraphs were conducted in the Road Laboratory of the University of Minho, Portugal.

Table 3. Properties of the asphalt emulsion's residue

Test on Bitumen Residue	Reference Standard	Unit	Min Value	Max Value	Class
Penetration@ 25°C	EN 1426	dmm	-	70	3
Softening Point	EN 1427	°C	60	-	3
Cohesion@ 5°C	EN 13589	J/cm ²	2	-	3
Elastic Recovery@ 25°C	EN 13396	%	50	-	3

2.2. Mix design process

For the mix design study, a preliminary procedure consisting of two tests, developed by the RILEM TC 280-CBE, was employed to estimate the initial quantity of water and cement required for the production of an MS mixture that was adequately workable and sufficiently durable (Moura et al., 2023).

Specifically, the first test, named the “Pizza test”, aims to determine the amount of water needed in the mixture. The procedure involves mixing a sample of approximately 200 grams of aggregates, adding the desired percentages of other materials, and pouring sufficient material onto a non-absorbent paper sheet, trying to form a disc approximately 1 cm thick, resembling a pizza. After 30 minutes, the disc's surface should be entirely black, and the inner part should be predominantly brown; after 60 minutes, the inner part should also turn black; otherwise, the amount of water used is probably too high and should be reduced to achieve the desired colour. Additionally, a small ball is formed from the same mixture, squeezing out excess water between the hands. Then, the ball is cured on a non-absorbent paper sheet for 60 minutes, and subsequently, it is dropped from a height of approximately 1.50 meters: if the ball breaks, the cement content in the mixture needs to be increased.

The preliminary procedure aimed at establishing initial formulations for testing, according to the EN standard series, to define the optimal job mix formula; in particular, the mix design process is detailed in Table 4.

Table 4. Recommended test for determining the optimal mix design formula of MS according to European (EN) standards.

Test	Standard	Brief description
Consistency	EN 12274-3	This test helps to understand the spreading behaviour of MS. A mixture with high consistency will be less workable, whereas a low consistency will determine segregation risks. Thus, the test is useful to establish the optimum water and mineral filler contents.
Cohesion	EN 12274-4	The test determines the development of mixture cohesion with time, and consequently, it provides the time required by the MS mixture to set and allow reopen to traffic without damage. The test's primary purpose is to determine the minimum mineral filler content.
Wearing Resistance	EN 12274-5	This test measures the wearing resistance of MS under wet abrasion conditions after favourable curing. Since the wearing resistance of a mixture depends on the asphalt coating on the aggregates, this test helps to determine the minimum asphalt emulsion content.
Shaking Abrasion	EN 12274-7	The test measures the abrasion resistance of MS mixtures, yielding information on the loss of adhesion caused by the water between the film of bitumen and the aggregate surface. It provides insights into the affinity between the asphalt emulsion and fine aggregates.

2.3. Traffic simulator

After the mix design process, the optimised MS mixtures were laid above the track of the laboratory-scale traffic simulator into three circular sectors of equivalent length, approximately 2.15 m in length each. Two sufficiently deformable plastic rods were placed on the pavement with steel nails to set the thickness at which the mixtures

should be levelled (10 mm); mixtures were spread by hand, using a wood sheet and following a continuously sawing motion, to replicate the mould-filling process used for the various tests defined by the EN 12274 standard series. Finally, the mixtures were allowed to cure for 72 hours before conducting surface characterisations and starting the pavement conditioning.

The laboratory scale traffic simulator (Figure 1) is a piece of equipment consisting of a central rotating shaft that holds the prototype in place and ensures system stability; two symmetrical arms, having a length of 1.25 m, extend from the shaft and are equipped with wheels at their ends. Each wheel represents a 700 N force, with an additional weight of 1000 N. An electric motor is coupled to one of the wheels (driving wheel), allowing the movement of the prototype, which is controlled by a specific software program created using LabVIEW (Araújo et al., 2019). A speed of rotation equal to 10 km/h was chosen. The tyres (195/50 R15 82V) are commonly available on the market, inflated with a pressure of 1.5 bar. Given the loads and the inflation pressure of the tyres, which results in a contact area of about 5700 mm², the contact pressure exerted on the pavement is equal to 0.3 MPa.

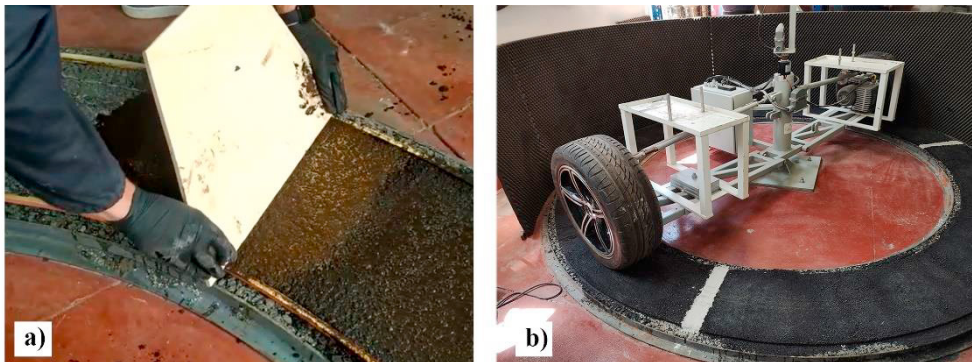


Fig. 1. Laboratory scale traffic simulator: a) laying operations; b) finalised surface.

2.4. Surface Performance Assessment

Five steps were selected for the pavement conditioning phase, starting from “T₀”, representing the pavement laying phase, to “T₅”; each step involves a different number of turns, and each turn corresponds to two-wheel passes or loading cycles, as shown in Figure 2. For each conditioning step, friction measurements were made to obtain the British Pendulum Number (BPN) and surface macrotexture measurements were collected using a laser profilometer. Specifically, the laser profilometer performed parallel surface readings spaced by 1 mm apart with a scanning step size (dx) equal to 0.5 mm. The laser profilometer was positioned to consistently read the same area affected by the passage of the selected tyre across all conditioning steps. The texture data returned from the laser profilometer were post-processed using the software U-PaveTex, developed by the University of Calabria, allowing the calculation of the Mean Profile Depth (MPD) according to the EN 13473-1 standard.

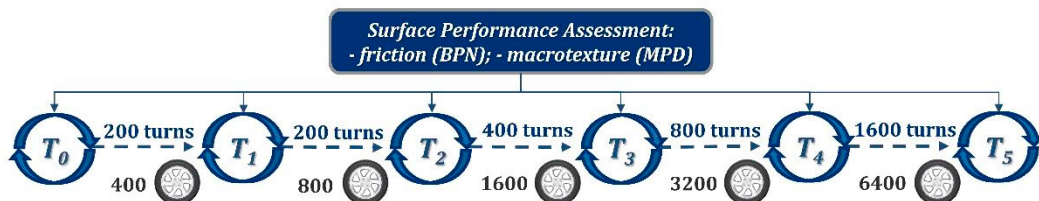


Fig. 2. Framework of the experimental plan.

A procedure for evaluating the surface characteristics' evolution process was established based on existing literature. It consists in modelling the relationships between BPN and MPD and the number of loading cycles; moreover, an algorithm has been implemented to identify the transition between the two phases governing the

surface deterioration process, respectively a polishing phase and an equilibrium phase (Wang et al., 2020). Table 5 shows the logical framework used for defining the procedure; a graphical explanation is provided in Figure 3.

The discrete points of BPN and MPD collected through each conditioning phase were approximated by two models (Shbeeb et al., 2018; Wang and Liang, 2014), illustrated in Equation (1) and (7), respectively. As for the BPN, the equilibrium phase is attained by finding the $f_{1a}(N)$ line (Eq. (2)), corresponding to the tangent line at the endpoint of conditioning ($N=6400$), with a slope ‘d’ equal to the first derivative of the BPN function (Eq. (3)) and intercept ‘e’ (Eq. (4)); hence, a 5% deviation between the BPN law and the latter allows for the identification of a notable point, NP, on the curve. Subsequently, the BPN law after the notable point is removed, and a linear model, $f_{1b}(N)$ (Eq. (5)), is applied to the remaining segment to find the polishing phase. The transition point between the two phases, T_{BPN} , identified on the BPN model, has coordinates as illustrated in Eq. (6). The process applies similarly to the MPD model, but the model for identifying the equilibrium phase is given by a regression line $f_{2a}(N)$ that minimises the difference with the MPD model (Eq. (8)). In this case as well, the 5% criterion is applied to identify the notable point, NP, and the linear model $f_{2b}(N)$ (Eq. (9)) is built on the remaining segment; the transition point, T_{MPD} , has coordinates as in Equation (10).

Table 5. Synthesis of the developed procedure for evaluating the evolution process of the surface characteristics.

BPN model	MPD model
$BPN = f_1(N) = c - \frac{N}{a+b \cdot N}$ (1)	$MPD = f_2(N) = MPD_0 \left(1 + \frac{N}{N_0}\right)^m$ (7)
$f_{1a}(N) = d \cdot N + e$ (2)	$f_{2a}(N) = p \cdot N + q$ (8)
$d = f'_1(N = 6400) = \frac{a}{(a+b \cdot N)^2}$ (3)	
$e = -d \cdot N(6400) + f_1(N = 6400)$ (4)	
$f_{1b}(N) = f \cdot N + g$ (5)	$f_{2b}(N) = r \cdot N + s$ (9)
$T_{BPN}(N_T; BPN) = \left(\frac{g-e}{d-f}; f_1(N_T)\right)$ (6)	$T_{MPD}(N_T; MPD) = \left(\frac{s-q}{p-r}; f_2(N_T)\right)$ (10)
N: number of loading cycles;	N: number of loading cycles;
a, b, c, d, e, f and g: fitting parameters of the proposed models;	MPD ₀ , m, p, q, r and s: fitting parameters of the proposed models;

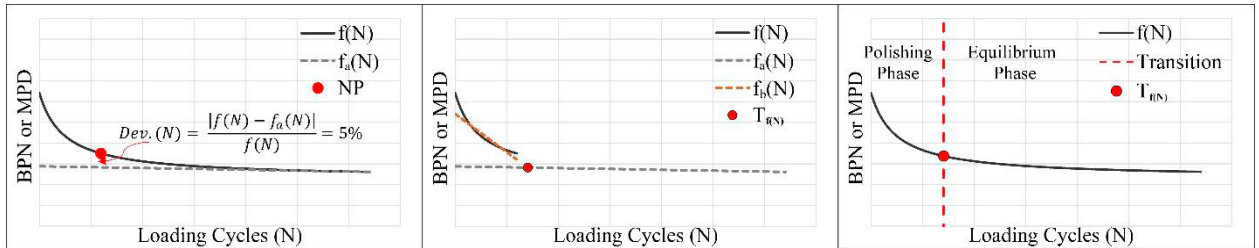


Fig. 3. Adopted approach to evaluate the surface characteristics development process.

3. Results and discussions

3.1. Mix design results

The use of the preliminary RILEM procedure has simplified the mix design process. Indeed, the two tests described allow for delineating the proportions of materials, resulting in a few trial mixtures, which are self-excluded if they do not meet the requirements of the tests envisaged by the mix design optimisation process. The final compositions of the studied mixtures are presented in Table 6, together with their test’s results. The consistency values fall within the standard range, albeit slightly on the lower limit, especially in the case of granite. Furthermore, it is noted that the cohesion values are significantly high already after 30 minutes, suggesting that the reopening to traffic could even be less than an hour. ‘Basalt 0/8’ reports higher values in the wearing resistance test compared to the others, although still below the allowable limit. Finally, the shaking abrasion test demonstrates that

the compatibility between granite and bituminous emulsion is poor compared to basalt aggregates; however, it was decided to proceed anyway with the traffic simulation process for this mixture.

Table 6. Final composition and mix design results of the investigated mixtures. Note: (*) suggested limits.

Test	Units	Requirements	Basalt 0/6	Basalt 0/8	Granite 0/8
Emulsion	[%]	9.0-15.0*	12.0	12.0	13.0
Water	[%]	as needed*	11.0	7.5	10.0
Cement	[%]	0.0-3.0*	2.0	2.0	2.0
Consistency	[cm]	2.5-3.5	2.87	2.70	2.55
Cohesion	[kNm]	> 12 @30 minutes	19.3	21.2	20.3
	[kNm]	> 20 @60 minutes	20.8	23.6	21.8
Wearing Resistance	[g/m ²]	< 538	272.5	401.6	234.5
Shaking Abrasion	[%]	-	1.3	1.3	17.6

3.2. Traffic simulation and surface performance assessment

After the optimisation phase of the mix design, the mixtures underwent the action of the traffic simulator. Table 7 presents the values of BPN and MPD recorded for each conditioning step of the MS pavement. It is noteworthy that at time “T₀”, following the laying, the MS exhibits very high friction values and pronounced macrotexture, especially in the case of the 0/8 gradation; furthermore, these values remain high even during the conditioning phases.

Table 7. Results of BPN and MPD for each mixture at each conditioning step.

BPN	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Basalt 0/6	82	70	69	68	67	63
Basalt 0/8	88	79	72	71	67	67
Granite 0/8	81	71	72	64	65	64
MPD	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Basalt 0/6	1.042	0.706	0.670	0.658	0.608	0.606
Basalt 0/8	1.241	0.966	0.981	0.944	0.886	0.864
Granite 0/8	1.366	0.848	0.879	0.877	0.880	0.735

Subsequently, using the algorithm described in Section 2.3, it was possible to model the obtained points and identify each mixture’s polishing and equilibrium phases. Table 8 summarises the fitting parameters obtained for each model, interpolating the BPN and MPD data.

Table 8. Synthesis of the fitting parameters calculated for the BPN and MPD models applied to each mixture.

BPN	a	b	c	d	e	f	g	T _{BPN} (N _T , BPN)
Basalt 0/6	23.700	0.049	82.050	-2.1 10 ⁻⁴	64.41	-0.009	77.003	(1404.901; 66.868)
Basalt 0/8	18.984	0.044	88.040	-2.1 10 ⁻⁴	67.89	-0.010	81.747	(1384.700; 70.561)
Granite 0/8	15.956	0.054	81.042	-1.2 10 ⁻⁴	64.23	-0.012	75.922	(991.157; 66.851)
MPD	MPD ₀	m	p	q	r	s	T _{MPD} (N _T , MPD)	
Basalt 0/6		1.096	-0.073	-1.5 10 ⁻⁵	0.664	-2.1 10 ⁻⁴	0.793	(665.776; 0.682)
Basalt 0/8		1.280	-0.045	-1.4 10 ⁻⁵	0.942	-3.0 10 ⁻⁴	1.074	(464.621; 0.972)
Granite 0/8		1.437	-0.074	-2.0 10 ⁻⁵	0.868	-2.7 10 ⁻⁴	1.036	(672.511; 0.890)

Regarding the BPN, it is necessary to highlight that both ‘Basalt 0/6’ and ‘Basalt 0/8’ mixtures behave similarly, transitioning between the two phases at a similar number of cycles and showing comparable drops (18.5% and 19.8%, respectively). This is despite having different initial BPN values due to the difference in gradation. In contrast, although the drop in BPN is almost comparable (17.5%), ‘Granite 0/8’ exhibits a significant earlier phase transition compared to basalt (991 N vs 1400 N): despite the same PSV value of the aggregates, this may be attributed, on the one hand, to the different mechanical resistances (higher LA and MD values), and on the other hand, to the lower aggregate-bitumen compatibility recorded during the mix design process. Furthermore, concerning the MPD, the phase transition is nearly comparable for all mixtures, and the values correlate well with the difference in gradation, given that the 0/8 mixtures have a greater texture in the equilibrium phase in comparison to the 0/6 one. Interestingly, ‘Granite 0/8’ and ‘Basalt 0/6’ show a more pronounced MPD drop (around 39.6% and 38.0%, respectively), despite experiencing the same number of cycles during the transition from the polishing to the equilibrium phase. In contrast, ‘Basalt 0/8’ exhibits a lower MPD loss (24.0%), and reaches the equilibrium phase earlier than the other mixtures. This translates to maintaining higher MPD values throughout.

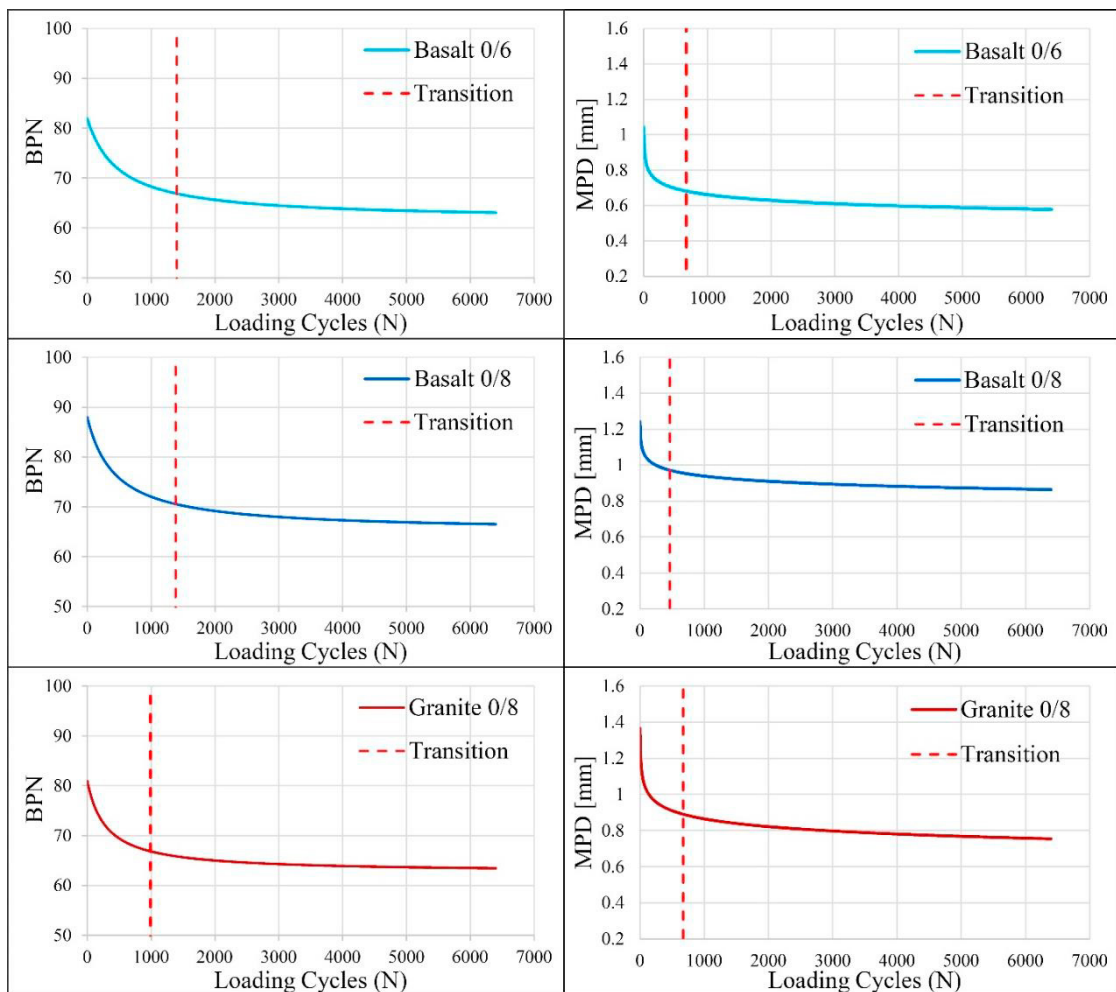


Fig. 4. Models for the evolution of surface characteristics (BPN and MPD) under laboratory traffic simulation.

4. Conclusions

This work presents a comprehensive research on MS, from optimising three MS mixtures to studying their surface characteristics and development over time when subjected to simulated traffic action in the laboratory.

In the mix design phase, the RILEM approach efficiently streamlined the process, allowing to focus on a few promising formulations for further testing according to EN 12274 standards. The analysed mixtures meet the specification limits required by the standards, except for the granite mixture, which exhibited poor bitumen-aggregate compatibility. However, it was decided to test the granite mixture under traffic simulator conditions to comprehend any possible impact of that weakness.

The laboratory-scale traffic simulator was essential to gather significant data for studying the development of the MS surface performance, especially regarding micro and macrotexture. Notably, even after the conditioning process, the MS pavements maintained high friction and surface texture values. Moreover, the algorithm developed to model the trends of BPN and MPD during successive conditioning phases under the influence of the traffic simulator, along with identifying the polishing and equilibrium phase, enables a clear description of the differences among the studied mixtures.

Particularly, with reference to BPN, both basalt mixtures exhibited similar behaviour, experiencing comparable reductions (around 19%) during the transition phase, despite having different gradations. In contrast, the ‘Granite 0/8’ undergoes the same drop earlier in the conditioning process. With respect to MPD, ‘Basalt 0/8’ reached the equilibrium phase faster and maintained higher final values, with a lower drop (24.0%) at the transition point compared to ‘Basalt 0/6’ (38.0%) and ‘Granite 0/8’ (39.6%).

Finally, this research represents an optimal starting point for understanding the deterioration behaviour and predicting future performance during the MS lifespan.

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