LIFE E-VIA

“Electric Vehicle noIse control by Assessment and optimisation of tyre/road interaction”

LIFE18 ENV/IT/000201

Deliverable	D6 – B1 Report
Content	Technical Report on Action B1
Action/Sub-action	Action B1
Status - date	Final Version- 31-03-2021

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List of keywords and abbreviations

AC	Asphalt Concrete
ACFC	Asphalt Concrete Friction Course
AR	Asphalt Rubber
ARFC	Asphalt Rubber Friction Course
AV	Air-void Content
b	Binder Percentage
BPN	British Pendulum Number
BWC	Bonded Wearing Course
CB	Controlled Pass-By Method
CPX	Close Proximity Index
CR	Crumb Rubber
CRMB	Crumb Rubber Bitumen Modified
DAC	Dense Asphalt Concrete
DGAC	Dense Graded Asphalt Concrete
DPAC	Double-layer Porous Asphalt Concrete
E	Dynamic Modulus
ELT	End Life Tires
ENDt	Estimated Noise Difference Due to Texture
ERNL	Estimated Road Noise Level
FC	Friction Course (PA)
GAP	Gap Graded
GAR	GAP with crumb rubber
GG	Gap Graded
HMA	Hot Mix Asphalt OGAC Open Graded Asphalt Concrete
HRA	Hot Rolled Asphalt
ISO	ISO 10844 reference surface
k	In-lab permeability
LOA 5D	Lärmoptimierter Asphalt (noise reducing asphalt for surface layer)
MPD	Mean Profile Depth
MF	Marshall Flow
MQ	Marshall Quotient
MS	Marshall Stability
$NMAS_{90}$	Nominal Maximum Aggregate Size
OG	Open Graded
OGAR	Open Graded Asphalt Rubber
OGFC-AR	OGFC+ Asphalt Rubber
OGFC-SBS	OGFC+ Styrene-Butadiene-Styrene
OGR	OG with crumb rubber
PA	Porous Asphalt
PAC	Porous Asphalt Concrete
P-ACFC	Porous- Asphalt Concrete Friction Course
PEM	Porous European Mic
PERS	Poro-elastic Road Surface
PLSD	Paver-Laid Surfacing Dressing
PMB	Polymer-Modified Bitumen
PMFC	Polymer Modified Friction Course
RAC	Rubberized Asphalt Concrete
RAC(G)	Rubberized Asphalt Concrete, Gap Graded
RAC(O)	Rubberized Asphalt Concrete, Open
RAC-O	Rubber Asphalt Concrete-Open

Ref.	Reference
SLPA	Single Layer Porous Asphalt
SM	Stone Mastic Asphalt
SMA	Stone Mastic Asphalt
SMA-LA	Split Mastic Asphalt
SPB	Statistical Pass-By Method
SUP	Superpave
TAL	Thin Asphalt Layer
TL	Thin Layer
TLPA	Twin Layer Porous Asphalt
TPA	Two-layers Porous Asphalt
UTLAC	Ultra-Thin Layer Asphalt Concrete
VTAC	Very Thin Asphalt Concrete

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Executive Summary

Tracks design (B1) makes a contribution to the majority of project objectives. This action aims at targeting a durable reduction of noise (objectives 1 and 7). Importantly, because material and technology choices imply different environmental impact, this action greatly impacts the sustainability and, consequently, it affects objective 6. Furthermore, the design of the bituminous mixtures is going to affect how much the pavement will affect noise reduction compared to tyre and vehicle influence (objectives 2 and 3).

Results, including the actual composition of the mixes, are going to be used to contribute to regional policies and to the editing of the guidelines as per objective 3. Importantly, the track design is going to affect how dwellers are going to perceive the new quiet environment (objective 5). Ultimately, the quieter streets will give the population the emerging importance to human health of time spent in quiet environments.

The action B1:

i) benefits from actions A1, A2, A3;
ii) gives the instructions for B2 prototype;
iii) uses B2 results;
iv) gives the instructions for the pilot area in Florence (B3). Consequently, it basically starts after the actions Ai and ends before B3.

UNIRC delivers two internal reports (B12- and B15-related, cf. Table on page 9), whose contents are below detailed.

The main sub-actions consist in:

- B1.1 Data gathering (from A1, A2, A3 and B2.1).
- B1.2 Preliminary design of the mixtures (Before B2). At the end of B1.2, UNIRC delivers the first internal report. B1.2 gives the required pieces of information for B2. By means of B1.1 and B1.2, B2.2 to B2.4 are carried out and led by IFSTTAR.
- B1.3 Data gathering from IFSTTAR that refer to Nantes prototype (during and after B2).
- B.1.4 Data gathering from IFSTTAR that refer to IPOOL tests (during and after B2).
- B1.5 Final design and support to track construction (during and after B2, and before B3). At the end of B1.5, the second internal report is delivered. By means of B1.5, B3 is carried out and led by FI.

For details about the sub-actions and what has been done by UNIRC, c.f. Table 1 'Action B1: project versus activities'.

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B1's PROJECT DELIVERABLE PRODUCTS

Deliverable name	Deadline
B1 Report	03/2021

1 Action B1: scheduled versus done

1.1 Scheduled activities and sub-actions.

Main sub actions/milestones/deliverables	Main internal actions carried out and main draft Documents edited
Sub-action B1.1 - Data gathering	Carried out.
Sub-action B1.2 - Preliminary design of the mixture	Report_B1_LIFE_UNIRC_excerpt draft July 28; for Julien August 27 2020 B1 life
Sub-action B1.3 - Data gathering from IFSTTAR that refer to Nantes prototype	D44.20.REZE.056 - Université EIFFEL - piste référence 2020 09 08 - suivi BBTM6 poudrette; D44.20.REZE.056 - Université EIFFEL - piste référence 2020 09 08 - suivi BBTM6; LIFE E-VIA_202103151_B2_action_UGE_Cesbron_OneDrive_internal_version
Sub-action B1.4 - Data gathering from IFSTTAR that refer to IPOOL tests	Data were received. Data are located on a google drive folder "Per Julien".
Sub-action B1.5 - Final design and support to track construction	Report_B1_LIFE_UNIRC_26_11_2020_F; Life E-Via B1 for B3 27 04 2021
Milestone name B1 Tracks design. Deadline: [01/2021]	Life E-ViaB1forB3 -2nd internal report B15 16.11.2020
Deliverable name: B1 Report. Deadline [03/2021]	Draft Based on Report_B1_LIFE_UNIRC_26_11_2020_F +Life E-Via B1 for B3 27 04 2021 +for Julien August 27 2020 B1 life

1.2 Compliance of B1 activities with project submission

ACTION B1: Tracks design. B1 aims at selecting mixtures (volumetrics, materials, and surface texture), for the tracks to be constructed in France and Italy, in order to minimize noise from EV, taking into account the synergy with actions B2 [UNIRC].

Deliverables: UNIRC delivers two internal reports, whose contents are below detailed

Scheduling: This action i) benefits from actions A1, A2, A3; ii) gives the instructions for B2 prototype; iii) uses B2 results; iv) gives the instructions for the pilot area in Florence (B3). Consequently, it basically starts after the actions Ai and ends before B3.

B1 Scheduled	**B1 Done**
B1.1 Data gathering (from A1, A2, A3 and B2.1). **Sub-action B1.1**. B1.1 deals with data gathering. UNIRC needs data and observations and benefits from the technical reports of the actions A1 (IFSTTAR), A2 (same UNIRC), A3 (CRD=CONTI). In more details, IFSTTAR provides UNIRC with B2 data: road surface properties and layer thickness of the existing test sections in Nantes, acoustical properties of EVs on existing tracks (cf. B2.1) and details about tyre-related data (cf. B2.4).	B.1 aims at selecting mixtures (materials, and surface texture), for the tracks to be constructed in France and Italy, in order to minimize noise from EV, taking into account the synergy with actions B.2. This action i) benefits from actions A.1, A.2, A.3; ii) gives the instructions for B.2 prototype; iii) uses B.2 results; iv) gives the instructions for the pilot area in Florence (B.3). Consequently, it basically starts after the actions Ai and ends before B.3. **B1.1 Data gathering** was carried out but there are delays due to the pandemic (tests on Nantes proving ground).
B1.2 Preliminary design of the mixtures (Before B2). At the end of B1.2, UNIRC delivers the first internal report. B1.2 gives the required pieces of information for B2. By means of B1.1 and B1.2, B2.2 to B2.4 are carried out and led by IFSTTAR. **Sub-action B1.2** refers to the preliminary design of the mixtures. At the end of B1.2, UNIRC delivers the first internal report and IFSTTAR/IPOOL carry out the tests in B2. As above-mentioned, overall, B1 aims at selecting mixtures (volumetrics, materials, and surface texture), for France (small-scale test-track) and Italy, in order to minimize noise from EV, taking into account the synergy with actions B2/3. It is important to highlight that this action focuses on pavement and friction course design. Apart from the issues above, the primary goal is to comply with LCPX targets (87 and 90 dBA at 50km/h). The idea is to start from the existing/ongoing projects (e.g., Nereide), from the literature, and from the considerations above. In more detail, the tentative pillars of the two new mixtures (friction courses) are the following: 1) Increase the percentage of the crumb rubber used to modify the bitumen (from 20%, by weight of bitumen, to about 25%), enhancing its mechanistic and rheological properties. 2) Increase the percentage of the crumb rubber used to substitute aggregates (from 1-3% to 4%), therefore reducing its mechanical	See Preliminary design Based on data gathering (B1.1 - data gathering initially from A1, A2, and A3), **in B1.2**, two types of mixtures (with and without crumb rubber, nominal maximum size of about 6mm) were designed and partly validated through experiments. At the end of B1.2, **UNIRC delivered the first internal report (July-August, 2020),** used by IFSTTAR (B2), now University of G. Eiffel, UGE, to construct the proving ground in Nantes, France.

B1 Scheduled	**B1 Done**
impedance and noise generation; 3) Don't use viscosity-reducing additives. 4) Face CR swelling-related issues through the green pre-treatment of CRs (Astolfi et al, 2019). 5) Reduce the nominal maximum aggregate size in order to better pursue structural and acoustic benefits (from about 8mm to ISO 7.1 mm). As abovementioned, this process entails delivering a report in which, for the selected mixtures and tracks, the following pieces of information are included: Mixtures. gradations and types of aggregates (including the filler), types and quantities of crumb rubber, types and quantities of asphalt binder, types and quantities of further components, process-related recommendations (temperatures, times, and prescriptions, pre-treatment), including, if needed, recommendations about laydown, compaction and curing. Tentative design of the pavement (based on data provided by IFSTTAR and FI). Overall organisation and scheduling of mixture production and lay down. This report is produced by UNIRC, and uses data preliminarily provided by FI (layers behind the new friction course, geometry of tracks, updated information about traffic (AADT, traffic spectrum), by CRD (through IFSTTAR and CRD Report A3), and by IFSTTAR (layers in the full-scale proving ground). Based on this report, IFSTTAR is going to carry out action B2 (on the new tests).	
B1.3 Data gathering from IFSTTAR that refer to Nantes prototype (during and after B2). **The Sub-action B1.3** deals with data gathering from IFSTTAR (during and after B2): response (also acoustic) of the mixtures designed by UNIRC in B1.2 (feedback). As a consequence of the sub-actions B1.3 and B1.4, UNIRC has the needed "response" data and is able to carry out the final design of the mixtures.	B1.3 refers to data gathering from IFSTTAR/UGE that refer to Nantes prototype (during and after B2).
B.1.4 Data gathering from IFSTTAR that refer to IPOOL tests (during and after B2). **The Sub-action B.1.4** deals with data gathering from IPOOL (during and after B4). These data will be useful in the pursuit of better carrying out the final design of the mixtures to be used in Florence-Via Paisiello.	B.1.4 refers to data gathering from IFSTTAR that refer to IPOOL tests (during and after B2).

B1 Scheduled	B1 Done
B1.5 Final design and support to track construction (during and after B2, and before B3). At the end of B1.5, the second internal report is delivered. By means of B1.5, B3 is carried out and led by FI. **The Sub-action B1.5** addresses the final design and support in the pursuit of track construction (B3). At the end of this activity, the second internal report is delivered to FI. As a result, in B3, Fi is going to take care of bid-related documents (technical and administrative), work management, and related managers and procedures according to the Italian laws. it is noted that UNIRC, besides the data gathered B.3 and B1.4, needs also updated data from FI. To this end, FI provides UNIRC with the updated characteristics of the selected road (Via Paisiello, Firenze): traffic data for the selected road, geometric data, lane and shoulder widths, etc.). To this end, it is noted that the selection of the tracks in Florence has been carried out in order to better achieve the primary objectives of the project. To this end, note that the following factors are going to affect the final results in terms of performance and perceived noise: 1) modification of the traffic spectrum and loads due to the increase in EVs. An increase of 15-35% of weight is expected; 2) changes in terms of driving force-to-speed diagram, accelerations and, probably, speeds due to the same reasons above (an increase of accelerations is expected); 3) changes in terms of shear stresses, tyre wear, pavement wear (an increase of surface texture wear and tyre wear is expected); 4) consequent change of pavement (and particularly, friction course) expected life.	**B1.5 refers** to the final design and support to track construction (during and after B2, and before B3). By means of B1.5, B3 is carried out and led by FI. As a part of B1.5 (Final design and support to track construction -during and after B2, and before B3), UNIRC started to draft the second internal report (B15 for B3), where it was expected to receive the pertaining information from the other partners including the ones that were supposed to test the proving ground in Nantes. Due to the pandemic, this news is still to come, but in the meanwhile, the exchange of information between UNIRC and FI, aiming at B3 construction, received a great impulse. **<u>In October-November, 2020, the first draft of the second internal report has been sent by UNIRC to FI</u>**, in order to start the bid process. The level of details was modified due to the fact that the tests from Nantes were delayed by the pandemic. In March-April 2021, the file "Life E-Via B1 for B3 27 04 2021" was sent to Florence municipality.

B1 Scheduled	B1 Done
Final Note. Tracks design (B1) makes a contribution to the majority of project objectives stated above. Track design aims at targeting a durable reduction of noise (objectives 1 and 7). Importantly, because material and technology choices imply different environmental impact, this action greatly impacts the sustainability and, consequently, it affects objective 6. Furthermore, the design of the bituminous mixtures is going to affect how much the pavement will affect noise reduction compared to tyre and vehicle influence (objectives 2 and 3). Results, including the actual composition of the mixes, are going to be used to contribute to regional policies and to the editing of the guidelines as per objective 3. Importantly, the track design is going to affect how dwellers are going to perceive the new quiet environment (objective 5). Ultimately, the quieter streets will give the population the emerging importance to human health of time spent in quiet environments.	The first impressions are quite positive especially from an acoustic standpoint. The transition from Nantes tests to Florence implementation should be better supported by more results coming from Nantes, hopefully in the next months. It may be observed that the same design (UNIRC) and construction (UGE) of the test track in Nantes are a good starting point especially when considering that in the meanwhile Europe underwent the first and the second wave of the Covid 19 pandemic.

Table 1. Action B1: project versus activities

2 Activities carried out

2.1 B11 Data gathering

This action i) benefits from actions A.1, A.2, A.3; ii) gives the instructions for B.2 prototype; iii) uses B.2 results; iv) gives the instructions for the pilot area in Florence (B.3). Consequently, it basically starts after the actions Ai and ends before B.3.

2.2 B12 Preliminary design of the mixture

2.2.1 In-lab plan of experiments

Figure 1 summarises the plan of experiments carried out during the preliminary design of the mixture. These involved:

- Experiment on a given mixture without crumb rubber - Solution 1
- Experiments on a crumb rubber-added mixture - Solution 2

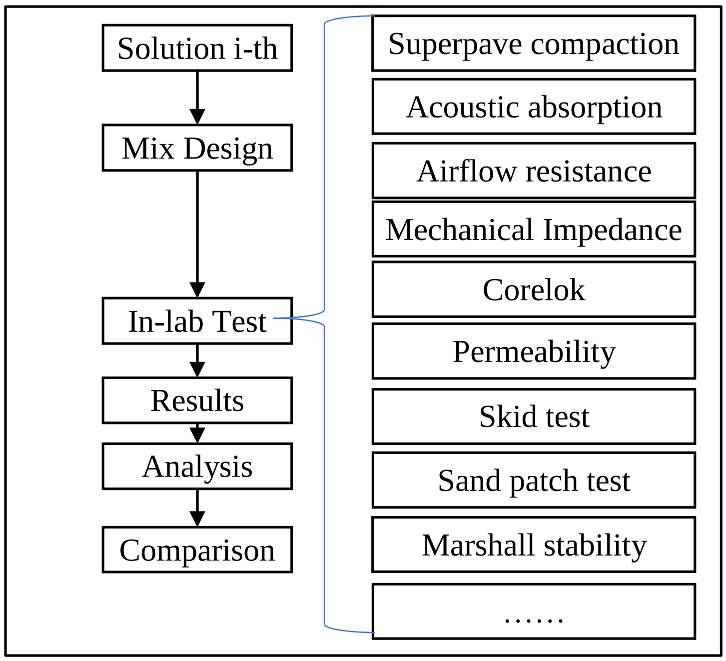


Figure 1. Plan of experiments

2.2.2 Experiments carried out in B12

In practise in B12 UNIRC focused on two solutions, namely, **AC6d_1_0%_PFU** (without crumb rubber) and **AC6d_2_5%_PFU** (with crumb rubber).

In Figure 2 the gradation of the crumb rubber used for the Solution 2 is illustrated. In Figures 3 and 4 the aggregate gradation of the Mix AC6d (0% PFU) and Mix AC6d (5% PFU) are illustrated, respectively.

Figure 5 summarises the main components used for the production of the mixtures, as follows:

a. Aggregates;
b. Filler;
c. Bitumen;
d. Crumb rubber.

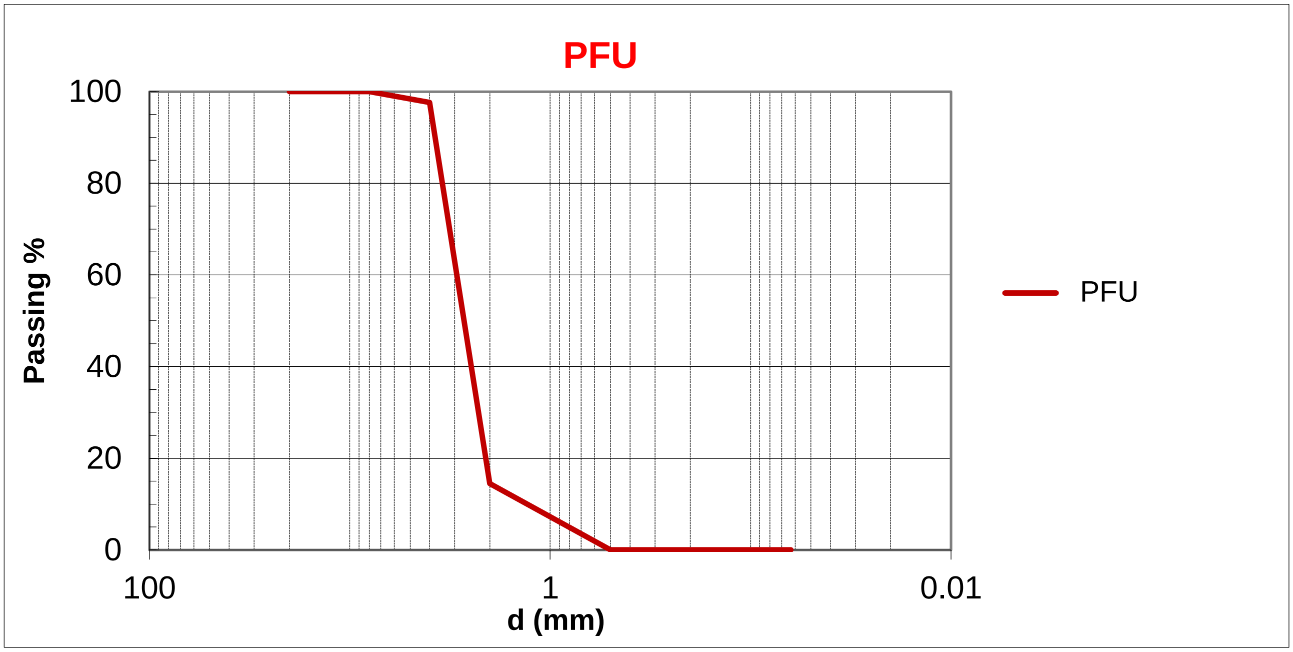


Figure 2. Example of CR gradation

Note. PFU=CR=crumb rubber

2.2.2.1 Solution 1: AC6d

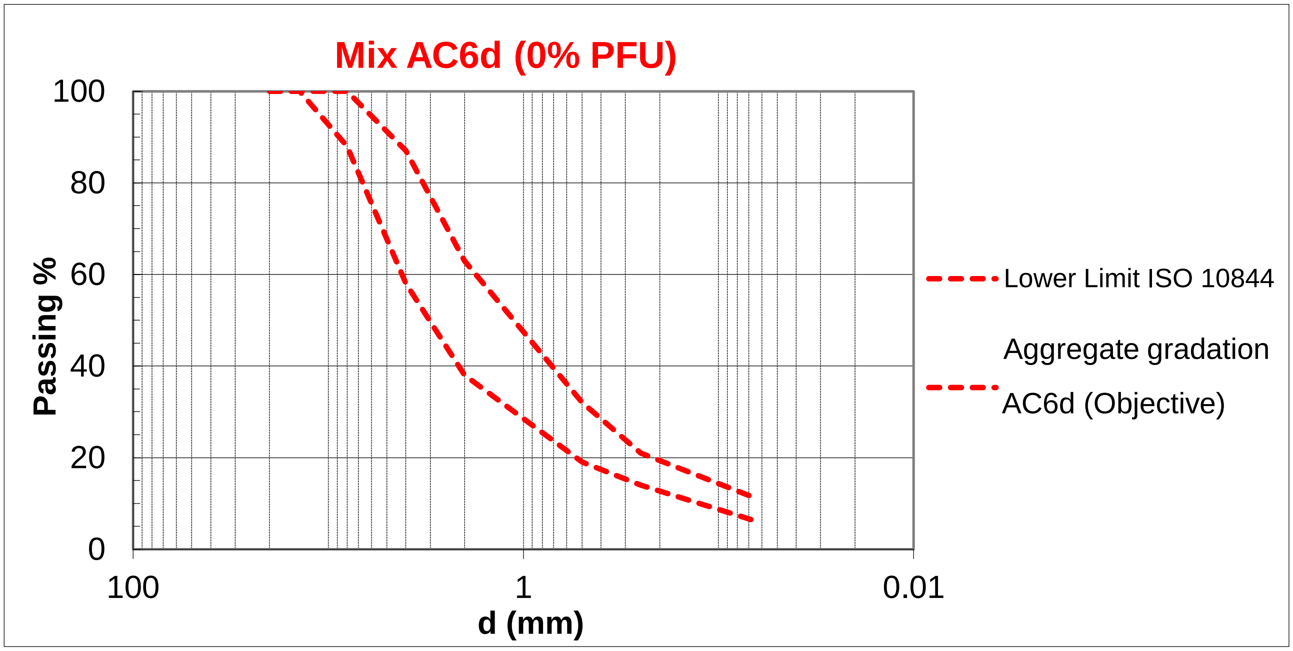


Figure 3. Overall aggregate gradation (experiments with CR=0%)

2.2.2.2 Solution 2: AC6d+5% PFU

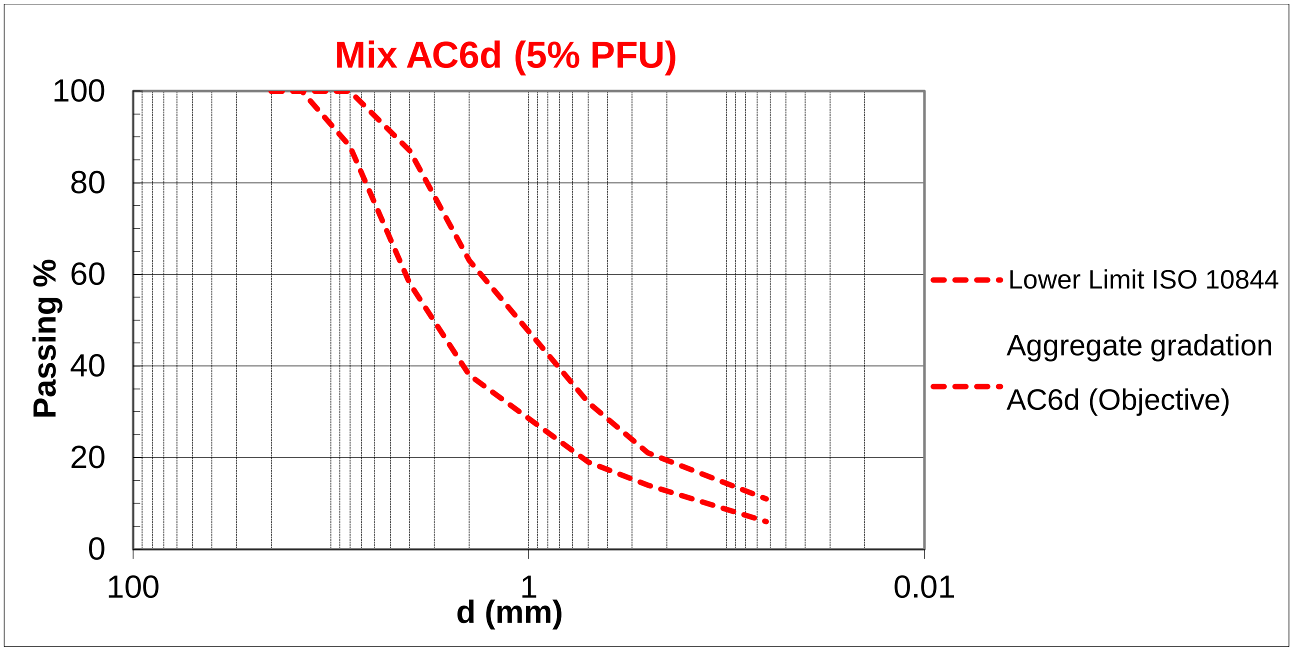


Figure 4. Overall aggregate gradation (experiments with CR=5%)

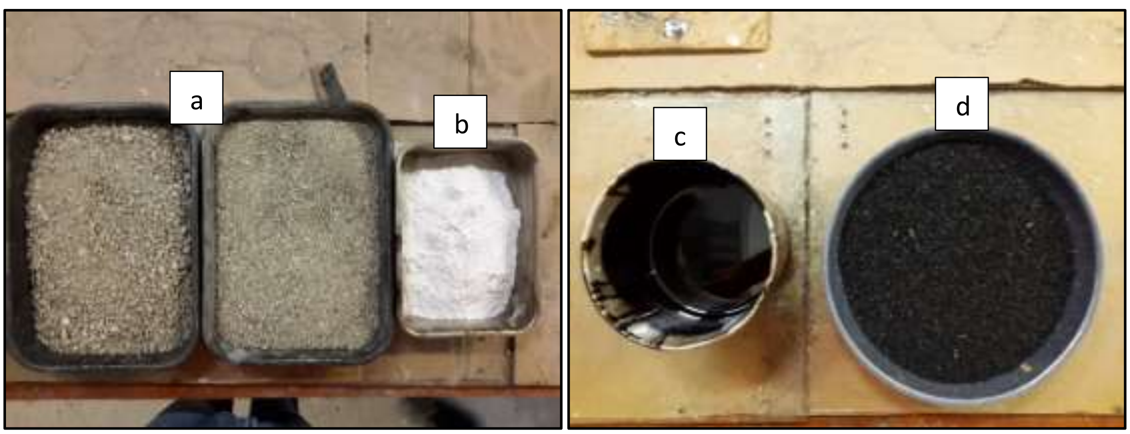
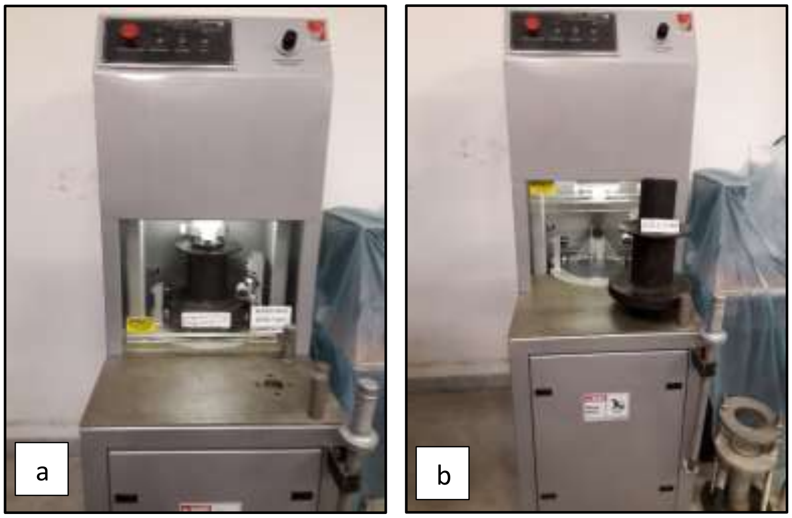
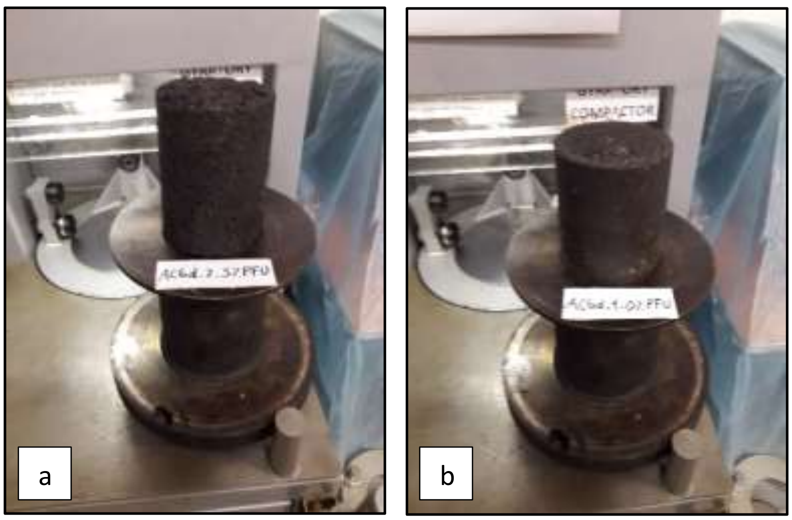


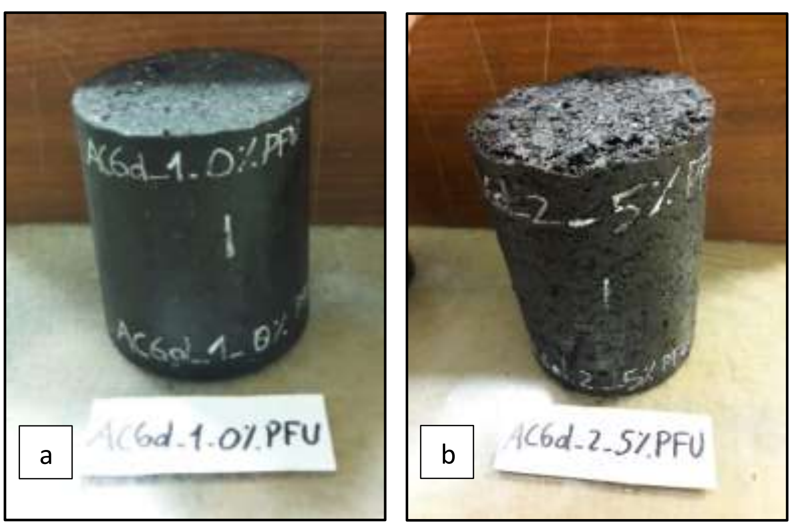
Figure 5. Main components used for the production of mixtures

2.2.3 Superpave gyratory

A gyratory compactor 'Rainhart' (EN 12697-31:2019) has been used for the samples production, as illustrated in Figure 6. The characteristics of the gyratory-compacted samples are reported in Table 2.


a
b


AC6d_2.5%PFU
COMPACTOR
AC6d_1.0%PFU
a
b


AC6d_1.0%PFU
AC6d_2.5%PFU
a
b

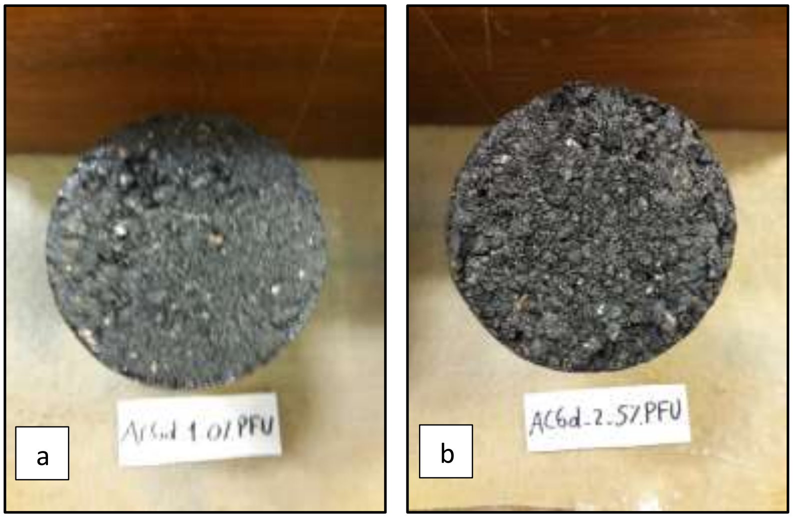


Figure 6. Gyratory-compacted samples: (a) solution without PFU and (b) solution with 5% of PFU

Specimen	**AC6d_1_0%_PFU**	**AC6d_2_5% PFU**
Weight [g]	2046.23	1906.39
Thickness 1 [cm]	11.47	13.2
Thickness 2 [cm]	11.48	13.27
Thickness 3 [cm]	11.48	13.34
Thickness 4 [cm]	11.48	13.45
Thickness [cm]	**11.48**	**13.32**
Diameter 1 [cm]	9.75	9.77
Diameter 2 [cm]	9.75	9.75
Diameter [cm]	**9.75**	**9.76**
$G_{mb,dim}$ [g/cm^3]	**2.39**	**1.91**

Table 2. Specimens characteristics.

Note. Weight, thickness, diameter, and $G_{mb,dim}$ (bulk specific gravity calculated considering the dimensions and weight of the sample).

In Figure 7 and in Table 3 the characteristics obtained during the compaction process are illustrated. In particular, in Table 3 the following parameters are reported: the number of gyrations, the thickness of the specimen during the compaction, the angle and the pressure applied on the specimen, the bulk specific gravity calculated considering the dimensions and weight of the sample ($G_{mb,dim}$), the air void content (AV), and the maximum specific gravity (G_{mm}).

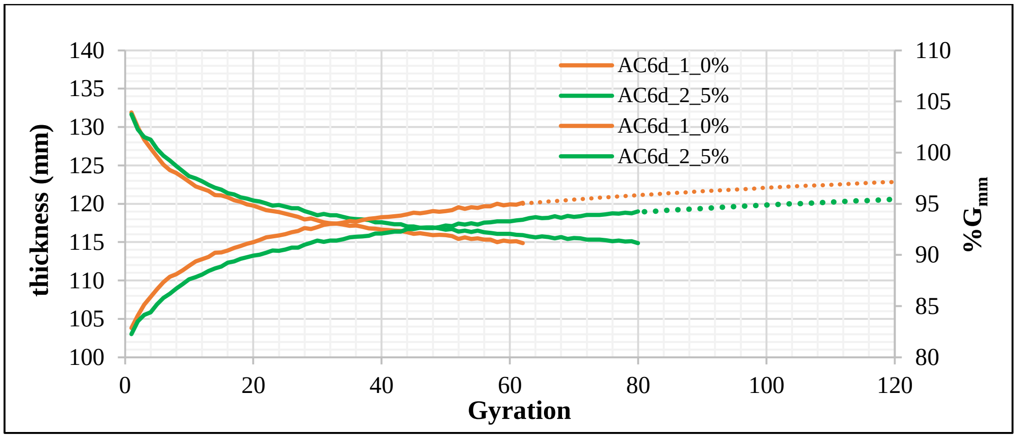


Figure 7. Compaction curves (experiments)

Sample	Gyration	Thickness(mm)	Angle	Pressure (KPa)	$G_{mb,dim}$	AV	$\%G_{mm}$
AC6d_1_0%_PFU	1	131.9	1.15	596.1	2.07	17%	82.84
	10	129.98	1.13	599.57	2.10	16%	84.06
	20	128.35	1.13	599.57	2.13	15%	85.13
	30	127.21	1.12	600.15	2.15	14%	85.89
	40	126.13	1.11	598.71	2.16	13%	86.63
	50	125.11	1.11	600.73	2.18	13%	87.34
	62	124.38	1.11	600.44	2.20	12%	87.85

Sample	Gyration	Thickness(mm)	Angle	Pressure (KPa)	$G_{mb,dim}$	AV	$\%G_{mm}$
AC6d_2_5%_PFU	1	131.66	1.05	596.68	1.94	18%	82.26
	10	123.61	1.03	601.31	2.06	12%	87.62
	20	120.42	1.02	602.47	2.12	10%	89.94
	30	118.49	1.02	602.18	2.15	9%	91.40
	40	117.59	1.02	602.47	2.17	8%	92.10
	50	116.63	1.02	602.76	2.19	7%	92.86
	60	116.09	1.02	601.31	2.20	7%	93.29
	70	115.55	1.03	601.31	2.21	6%	93.73
	80	114.89	1.03	601.89	2.22	6%	94.27

Table 3. Compaction parameters

2.2.4 Airflow resistance

The airflow resistance was measured using the apparatus Norsonic Nor 1517 A, by applying the alternating airflow method (Method B) in accordance with UNI EN ISO 9053-1 "Acoustics - Determination of airflow resistance - Part 1: Static airflow method" [1]. This latter specifies the measurements to carry out for the determination of the static airflow resistance, in a laminar flow regime, of porous materials for acoustical applications. The results of the tests carried out on specimens with and without the presence of crumb rubber are reported in Table 4. In particular, five measurements on the lower surface and five measurements on the upper surface were made for each specimen, and the average values were calculated. The values obtained for the Equivalent Continuous Sound Pressure Level (Leq) in decibels (dB) and in the Engineering Unit (EU), the specific airflow resistance (Rs), the airflow resistance (R), and the airflow resistivity (r) are illustrated in Table 4.

Figure 8. Airflow resistance test

AC6d_1_0%_PFU_Bottom					
Measure	**Leq(dB)**	**Leq(EU)**	**Rs (Pa*s/m)**	**R (Pa*s/m³)**	**r (Pa*s/m²)**
1	194.3	103760.0	103760.0	13897314.4	904029.7
2	194.4	104961.5	104961.5	14058237.7	914497.9
3	194.4	104961.5	104961.5	14058237.7	914497.9
4	194.4	104961.5	104961.5	14058237.7	914497.9
5	194.3	103760.0	103760.0	13897314.4	904029.7
Average	**194.4**	**104480.9**	**104480.9**	**13993868.4**	**910310.6**

AC6d_1_0%_PFU_Top					
Measure	**Leq(dB)**	**Leq(EU)**	**Rs (Pa*s/m)**	**R (Pa*s/m³)**	**r (Pa*s/m²)**
1	194.2	102572.3	102572.3	13738233.2	893681.3
2	194.3	103760.0	103760.0	13897314.4	904029.7
3	194.3	103760.0	103760.0	13897314.4	904029.7
4	194.2	102572.3	102572.3	13738233.2	893681.3
5	194.3	103760.0	103760.0	13897314.4	904029.7
Average	**194.3**	**103284.9**	**103284.9**	**13833681.9**	**899890.4**

AC6d_2_5%_PFU_Bottom					
Measure	**Leq(dB)**	**Leq(EU)**	**Rs (Pa*s/m)**	**R (Pa*s/m³)**	**r (Pa*s/m²)**
1	180.4	20942.6	20942.6	2799242.2	157285.5
2	180.5	21185.1	21185.1	2831655.9	159106.8
3	180.6	21430.4	21430.4	2864444.9	160949.2
4	180.5	21185.1	21185.1	2831655.9	159106.8
5	180.6	21430.4	21430.4	2864444.9	160949.2
Average	**180.5**	**21234.7**	**21234.7**	**2838288.8**	**159479.5**

AC6d_2_5%_PFU_Top					
Measure	**Leq(dB)**	**Leq(EU)**	**Rs (Pa*s/m)**	**R (Pa*s/m^3)**	**r (Pa*s/m^2)**
1	163.0	2825.1	2825.1	377607.4	21217.2
2	163.2	2890.9	2890.9	386403.0	21711.4
3	163	2825.1	2825.1	377607.4	21217.2
4	163.1	2857.8	2857.8	381979.9	21462.9
5	163.1	2857.8	2857.8	381979.9	21462.9
Average	**163.1**	**2851.3**	**2851.3**	**381115.5**	**21414.4**

Table 4. Airflow resistance (results)

Where:

EU=Pa*s/m (EU is the engineering unit; for this application is Pa·s/m)

Rs=specific airflow resistance (R_s is the observed resistance normalised to an area for the specimen of 1 m^2)

R=airflow resistance (R is the non-normalized value of R_s. It may be computed by division with the area for testing A)

r=airflow resistivity (r is the specific airflow resistance per unit length $r=R_s/d$)

2.2.5 Acoustic absorption

In this section, the determination of the sound absorption coefficient according to ISO 10534-2 “Acoustics - Determination of sound absorption coefficient and impedance in impedances tubes - Transfer-function method” [2] is described. This test method covers the use of an impedance tube, two microphone locations and a digital frequency analysis system for the determination of the sound absorption coefficient of sound absorbers for normal sound incidence (see Figure 9). In this test method, plane waves are generated in a tube by a noise source, and the decomposition of the interference field is achieved by the measurement of acoustic pressures at two fixed locations using wall-mounted microphones or an in-tube traversing microphone, and subsequent calculation of the complex acoustic transfer function, the normal incidence absorption, and the impedance ratios of the acoustic material [2].

Figure 9. Kundt tube

In Figure 10 the acoustic absorption of the specimens with and without crumb rubber is illustrated. It is noted that the acoustic absorption for mixtures with CR is higher than the ones for mixtures without CR. Note that this could depend on many variables.

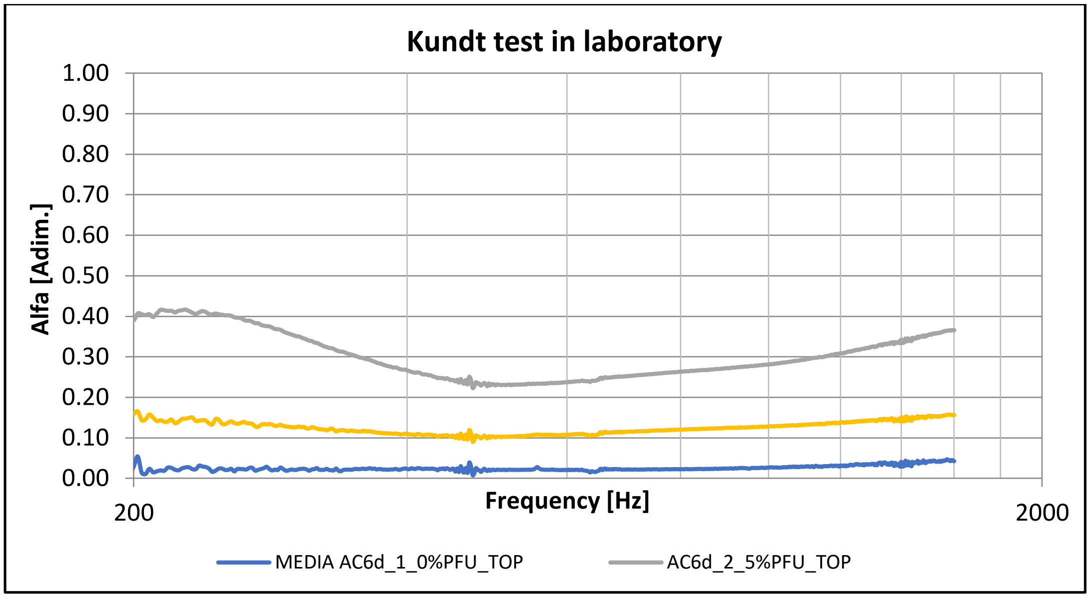


Figure 10. Acoustic absorption for specimens without CR (blue curve) and with CR (grey and yellow curves)

Note. CR=crumb rubber=PFU

2.2.5.1 Inverse Problem

This section refers to the values of resistivity that were measured and to the corresponding data obtained based on the inverse problem solution (c.f. [3]). Note that for porosity, the Corelok data were used. The Corelok machine is a system for sealing asphalt samples so that the sample densities may be measured by water displacement methods (cf. ASTM and AASHTO standards).

Sample	**Airflow Resistivity**	**Inverse Problem**				
	r (Pa*s/m2)	**S (cm)**	**Ω (%)**	**q^2**	**r(Pa*s/m2)**	**err.**
AC6d_1_0 % PFU_ Bottom	910,311	11.48	4.44%	5.00	910,310	1.61E-08
AC6d_1_0 % PFU_ Top	899,890	11.48	4.44%	5.00	899,890	1.64E-08
AC6d_2_5 % PFU_ Bottom	159,480	13.32	18.26%	9.99	199,380	7.20E-05
AC6d_2_5 % PFU_ Top	21,414	13.32	18.26%	3.89	43,100	8.13E-07

Sample	**Airflow Resistivity**	**Inverse Problem**				
	r (Pa*s/m2)	**S (cm)**	**Ω (%)**	**q^2**	**r(Pa*s/m2)**	**err.**
AC6d_1_0 % PFU_ Bottom	910,311	11.48	1.28%	5.00	910,310	3.58E-12
AC6d_1_0 % PFU_ Top	899,890	11.48	1.28%	5.00	899,890	3.64E-12

AC6d_2_5 % PFU_ Bottom	159,480	13.32	13.86%	9.76	190,090	2.43E-06
AC6d_2_5 % PFU_ Top	21,414	13.32	13.86%	2.88	46,010	2.19E-04

Table 5. Inverse problem

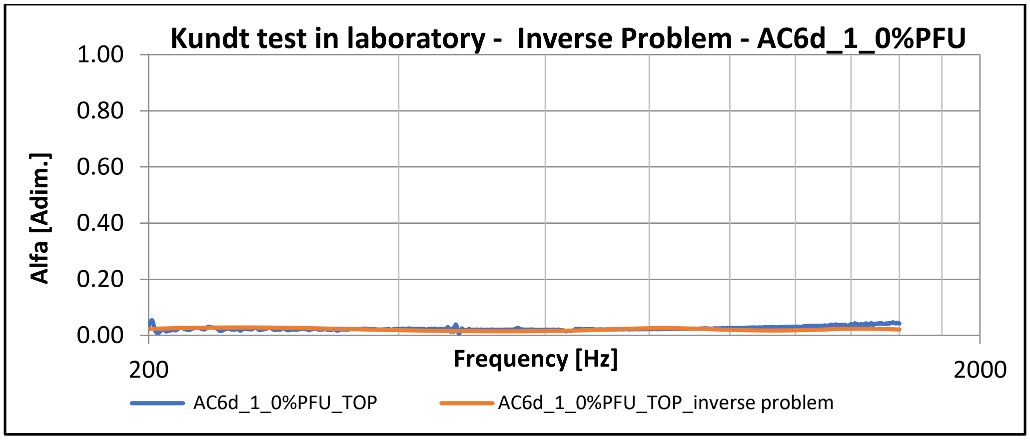


Figure 11. Acoustic absorption spectra on specimen AC6d_1_0%PFU

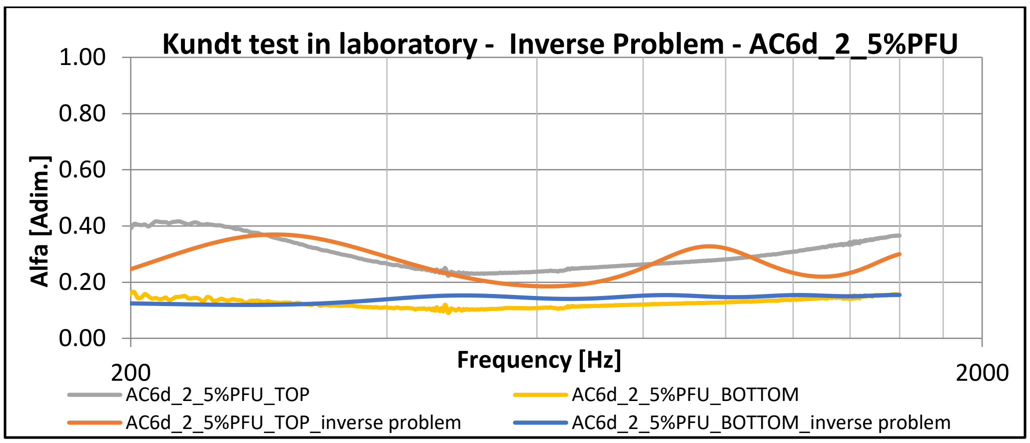


Figure 12. Acoustic absorption spectra on specimen AC6d_2_5%PFU

2.2.6 Mechanical Impedance

The mechanical impedance (MI) is a measure of how much a structure resists motion (e.g., speed) when subjected to a unit force. The most direct technique to determine the mechanical impedance is to utilize force and motion measuring transducers [4]. According to the literature [5], MI has been supposed to be a sound indicator to evaluate the road acoustic response for frequencies in the range of 400–3200 Hz. In Figure 13 the set-up used for the laboratory tests according to EN29052-1 [6] is illustrated while in Figure 14 the results for the mixtures with and without the presence of crumb rubber are shown. The specimen with crumb rubber (AC6d_2_5%PFU, orange curve in Figure 14) has lower values of MI than the specimen without crumb rubber (AC6d_1_0%PFU, blue curve in Figure 14) in the range 40-3200 Hz.

Figure 13. Set up used to derive the mechanical impedance in laboratory

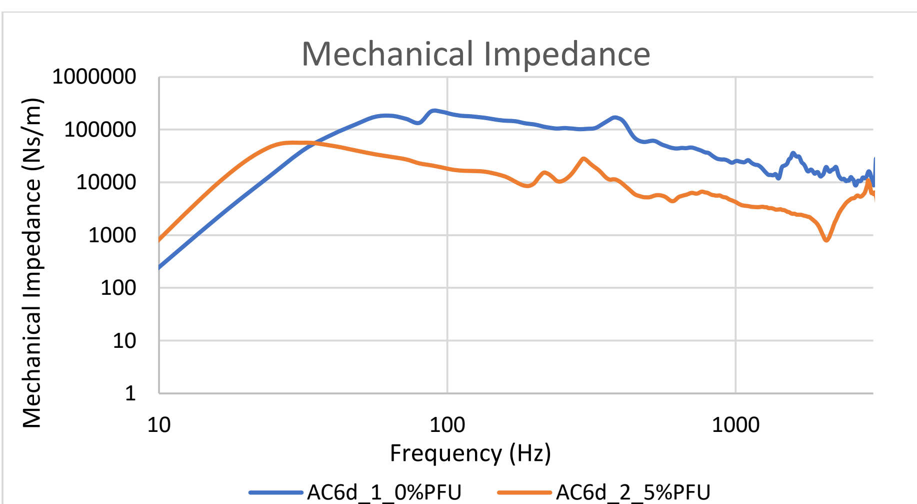


Figure 14. Mechanical Impedance derived for mixtures with and without the crumb rubber

2.2.7 Corelok machine

This section refers to the determination of maximum specific gravity (Gmm), bulk specific gravity (Gmb), and effective porosity (n_{eff}) of bituminous mixtures by the vacuum sealing method (Corelok machine, see Figure 15), according to the ASTM D6752 - 02 “Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method” [7]. The bulk specific gravity of the compacted bituminous mixtures can be used in calculating the unit weight of the mixture. Based on the tests carried out, the results obtained are summarised in Table 6:

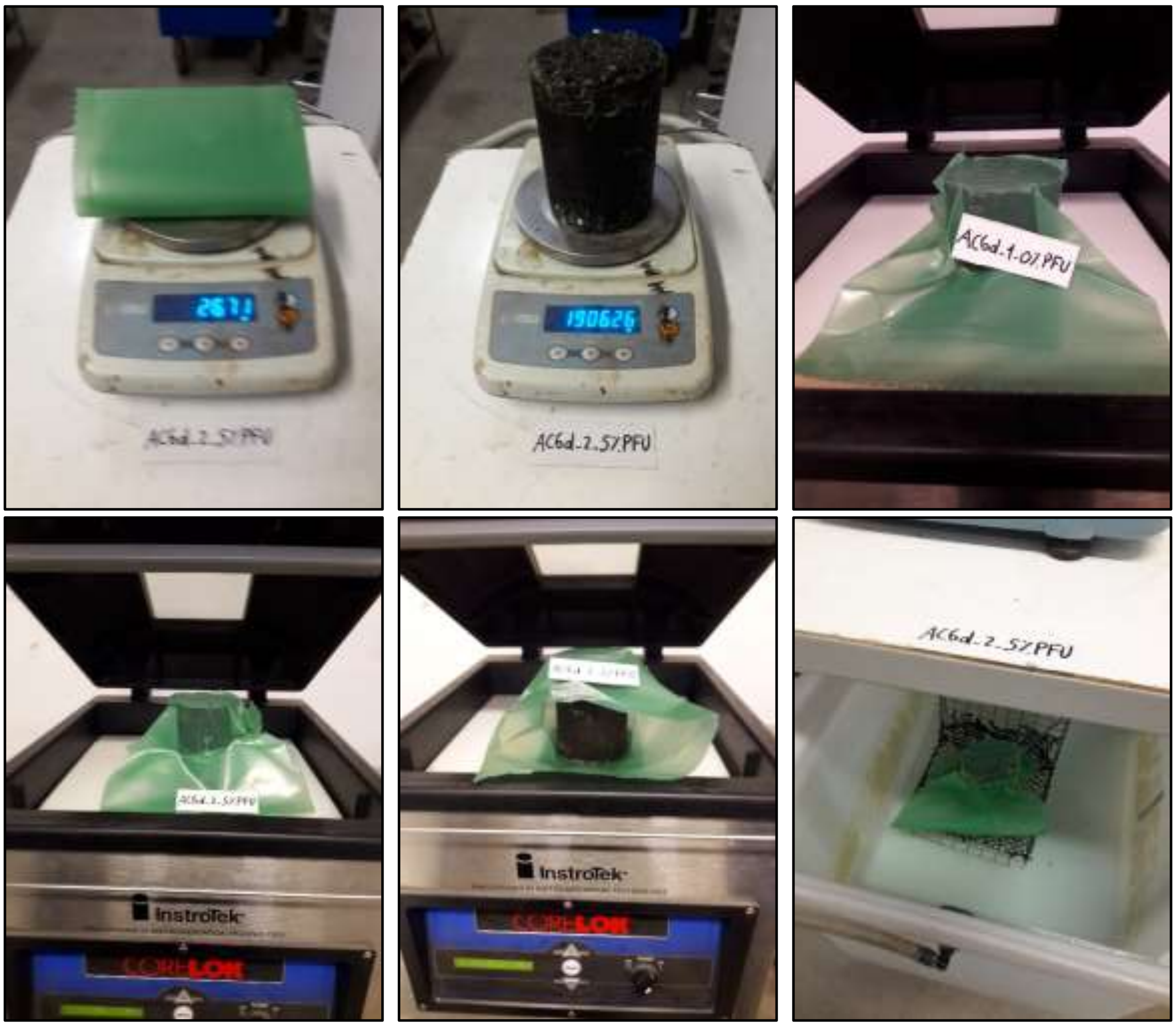


Figure 15. Corelok measurements

Sample ID	Gmm [dim.less]	Gmb [dim.less]	N_{eff} [dim.less] (%)
AC6d_1_0% PFU	2.484	2.384	2.01
AC6d_2_5% PFU	2.310	2.287	1.73

Table 6. Corelok results

2.2.8 Pendulum Test Value (PTV) or Skid Test

This section refers to the measurement of slip/skid resistance of a road surface through the use of the pendulum test, according to the EN 13036-4 “Road and airfield surface characteristics - Test methods - Part 4: Method for measurement of slip/skid resistance of a surface: The pendulum test” [8]. The Pendulum Test is an established and reliable method for friction. This latter is measured by means of a slider mounted at the end of a pendulum arm which imitates the action of slipping and determines the dynamic friction of the surface (see Figure 16). The results are measured on a scale under a “Pendulum Test Value” (PTV) and summarised in Table 7.

Figure 16. Pendulum test

Sample	Slide length [mm]	Measured values					Average of the last 3 measurements	T (°C)	Temperature correction (CNR) [9]	Average values	**Average values reported to the slide length: 125 mm**
AC6d_1_0% PFU	62.5	30	29	30	30	29	30	18.7	1	31	**66**
AC6d_2_5% PFU	62.5	26	25	30	30	30	30	18.4	1	31	**66**

Table 7. PTV results

Note that the skid test was conducted on cylindrical specimens. The value of PTV obtained when using a length of 62.5 mm is tentatively related to in-situ tests [10].

2.2.9 Permeability Test

This section refers to the measurement of permeability of the bituminous mixtures, according to the ASTM PS 129 “Standard Provisional Test Method for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter” (see also “Florida method of test for measurement of water permeability of compacted asphalt paving mixtures” [11]). This test method covers the procedures for determining the relative permeability of water saturated laboratory compacted specimens or field cores of compacted bituminous paving mixtures using a flexible wall permeameter (see Figure 17). Based on the tests carried out, the results obtained are summarised in Table 8:

Figure 17. Permeability test

Sample ID	Test	T (°C)	R_T	k (cm/sec)	K_{20} (cm/sec)
AC6d_1_0% PFU	1	17.1	1.074	0.006	0.007
	2	17.1	1.074	0.006	0.007
	3	17.1	1.074	0.006	0.007
	4	17.1	1.074	0.006	0.007
	5	17.1	1.074	0.006	**0.007**
AC6d_2_5% PFU	1	16.1	1.103	0.007	0.008
	2	16.1	1.103	0.007	0.008
	3	16.1	1.103	0.007	0.008
	4	16.1	1.103	0.007	0.008
	5	16.1	1.103	0.007	**0.008**

Table 8. Permeability test results

2.2.10 MTD sand patch Test

This section refers to the determination of the average depth of pavement surface macrotexture by the application of a known volume of material (sand) on the surface and subsequent measurement of the total area covered (see Figure 18). The reference standard is the EN 13036-1 “Road and airfield surface characteristics - Test methods - Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique”. Estimates are carried out based on Praticò and Astolfi, 2017 [12], based on tests carried out on cylindrical specimens. Results are summarised in Table 9.

Figure 18. MTD sand patch test

Sample	Volume (mm^3)	Sand excess (g)	Effective volume (mm^3)	MTD (mm)
AC6d_1_0% PFU	4500	3.96	1784	0.24
AC6d_2_5% PFU	4500	1.36	3567	0.48

Table 9. MTD sand patch results

2.2.11 Marshal Stability

This section refers to the determination of Marshall Stability (MS), Marshall Flow (MF), and Marshall Quotient (MQ), according to the EN 12697-34 “Bituminous mixtures - Test methods - Part 34: Marshall test”[13]. Results are summarised in Table 10:

Figure 19. Marshall stability

Sample	MS (kg)	MF (mm)	MQ (kg/mm)
AC6d_1_0% PFU	1005.09	4.65	215.92
AC6d_2_5% PFU	2188.85	4.11	531.79

Table 10. Marshall stability results

2.2.12 B1.2 Preliminary design results

Two types of mixtures were designed and partly validated through experiments. Details are given in annex B1-Annex.

2.2.13 B2: lesson learned to date and how they impact track design

This section refers to the outputs deriving from action B2. Note that B2 and A2 overlap for 9 months.

2.2.14 Other emerged issues and perspectives

It seems important here to highlight that other suggestions derived from partners (e.g., IPOOL and UGE, formerly IFSTAR). Indeed, in the early phase of the E-VIA project, the contribution of IFSTTAR included experimental tests with electric vehicles on several road surfaces already available on our test facility in Nantes (Sub-action B.2.1). In Nantes, many types of road surfaces were investigated (including - PA 0/6, VTAC 0/6, DAC 0/10, SMA 0/8 and ISO 10844 road surfaces)and many types of measurements were carried out, including 1) Standard controlled (all surfaces) and microphone array (only ISO 10844) **pass-by** measurements (- Vehicles planned: - 1 ICE vehicle-Kangoo Diesel- and several EVs -Kangoo ZE, Zoe, C-Zero, Nissan Leaf, BMW i3, Tesla Model S; - Pass-by conditions: - Constant speed: from 20 to 110 km/h in 5 km/h steps. 2) **Full-throttle** acceleration from several start speeds at the entrance of the test zone (in order to get various speeds in front of the microphones): start speeds 0 to 50 km/h, in 10 km/h steps; 3) Braking from several start speeds at the entrance of the test zone (in order to get various speeds in front of the microphones): start speeds 40 km/h to 70 km/h, in 10 km/h steps; -The start speeds range may be adapted to each vehicle, according to its technical specificities.

2.3 B13 Data gathering from IFSTTAR that refer to Nantes prototype

B1.3 refers to data gathering from IFSTTAR/UGE that refer to Nantes prototype (during and after B2).

2.4 B14 Data gathering from IFSTTAR that refer to IPOOL tests

B.1.4 refers to data gathering from IFSTTAR that refer to IPOOL tests (during and after B2).

2.5 B15 Final design and support to track construction

2.5.1 Conclusions (scientific and practical bases to design the tracks)

The file “Life E-Via B1 for B3 27 04 2021” that was sent by UNIRC to Florence municipality includes the conclusions of B1: two mixes are going to be laid down in Florence. The first is the one that is traditionally used as a friction course in Florence. The second is the result of this project and contains about 2% of crumb rubber (pre-treated composite). The nominal maximum aggregate size is around 6mm.

2.6 B1 Annex-Preliminary design (first internal report)-B12-based

This part is the output of B12.

2.6.1 Mixture type 1

2.6.1.1 Bitumen

An asphalt binder type 50/70 is foreseen (different types could be selected based on Nantes weather).

Parameter	*Standard*	*Unit of measure*	*Type* A
Penetration at 25°C	EN1426, CNR24/71	dmm	50-70
Softening point	EN1427, CNR35/73	°C	≥ 65
Breaking point (Fraass)	EN 12593 CNR43 /74	°C	≤ - 15
Dynamic viscosity at 160°C, γ =10s^{-1}	PrEN 13072-2	Pa•s	≥ 0,4
Elastic recovery at 25 °C	EN 13398	%	≥ 75%
Storage stability 3days at 180°C- softening point variation	EN 13399	°C	≤ 0,5
After RTFOT	EN12607-1		
Volatility	CNR54/77 or equivalent	%	≤ 0,8
Residual Penetration at 25°C	EN1426, CNR24/71	%	≥ 60
Increase in softening	EN1427, CNR35/73	°C	≤ 5

Table 11. Bitumen quality

Additives. In case of addition of additives (including fibres), please note that the performance specified below remain as a requirement.

2.6.1.2 Aggregates

Coarse aggregate (retained to 5mm sieve) must comply with the requirements below.

Retained at 5mm round sieve (UNI n. 5)			
Parameter	*Standard*	*Unit of measure*	*Threshold*
Los Angeles	CNR 34/73- UNI EN 1097-2	*%*	≤ 20
Micro Deval	CNR 109/85- UNI EN 1097-1	*%*	≤ 15
Crushed and broken surfaces	UNI EN 933-5	*%*	100
Maximum size of aggregates	CNR 23/71 - UNI EN 933-1	*mm*	20
Freezing and thawing cycles.	CNR 80/80 – UNI EN 1367-1	*%*	≤ 30
Boiling water stripping test	CNR 138/92 - UNI EN 12697-11:	*%*	0
Passing to 0.075mm	CNR 75/80 - UNI EN 933-1	*%*	≤ 1
Shap coefficient	CNR 95/84-		≤ 3

	UNI EN 933-4		
Aggregate flakiness	CNR 95/84- UNI EN 933-3		≤ 1,58
Flakiness index	CNR 95/84 - UNI EN 933-3	%	≤ 20
Porosity	CNR 65/78 - UNI EN 12697-8	%	≤ 1,5
Polishing stone value	CNR 140/92- EN 1097-8	%	≥ 45

Table 12. Coarse aggregate

Fine aggregate (passing to the 5mm sieve) must comply with the requirements below.

Fine aggregates (passing to the round sieve n.5mm, UNI n. 5)			
Quality indicators			
Parameter	*Standard*	*Unit of measure*	*Threshold*
Sand equivalent	CNR 27/72 - EN 933-8	%	≥ 80
Passing percentage at 0.075mm	CNR 75/80 - UNI EN 933-1	%	≤ 2
Percentage of crushed and broken surfaces in coarse aggregate particles	CNR 109/85 – UNI EN 933-5	%	100

Table 13. Fine aggregate

Filler (passing to 0.075mm sieve) must comply with the requirements below.

Filler (lower than 0.075mm)			
Parameter	*Standard*	*Unit of measure*	*Threshold*
Boiling water stripping test	CNR 138/92 – UNI EN 12697-11	%	≤ 5
Passing percentage at 0.18 mm	CNR 23/71- UNI EN 933-1	%	100
Passing percentage at 0.075 mm	CNR 75/80 – UNI EN 933-1	%	≥ 80
Plasticity index	CNR-UNI 10014- ASTM D4318		N.P.
Rigden voids - voids of dry compacted filler	CNR 123/88- EN 1097-4	%	30-45
Stiffening Power (filler/bitumen = 1.5)	CNR 122/88- EN 13179-1	ΔPA	≥ 5

Table 14. Filler

Before on-site construction works, the contractor must produce aggregate qualification certificates complying with requirements.

Aggregate gradation must comply with the requirements below. The expected air void percentage is **about 5%.**

Sieve	%
Mm	%
2-8	42
0.063-2	48
0.063	10

Table 15. Aggregate gradation

Nota Bene. This solution does not include crumb rubber (CR=0%).

2.6.1.3 Bituminous mixture

Bitumen percentage is going to be assessed based on the study of bituminous mixture. Volumetric method or Marshall method may be used. The thickness of the compacted mixture will be about 0.025m. Requirements are given in the table below. The selected mixture should be tested (at 98% of D_G) foe modulus or similar properties foe better on-site quality control and assurance.

Test parameters	*Unit of measure*	*Thresholds*
Rotation Angle		1.25° ± 0.02
Rotation speed	r/min	30
Vertical pressure	KPa	600
Sample diameter	mm	150
Voids at 10 gyrations	**%**	**9-18**
Voids at 120 gyrations	**%**	**4-9**
Voids at 210 gyrations	**%**	**≥ 2**
Indirect tensile strength at 25°C (@120 gyrations)[1] (EN 12697-23)	N/mm^2	> 0,4
Coefficient of indirect tensile strength[2] at 25 °C (@120 gyrations)	N/mm^2	> 30
Loss of indirect tensile strength at 25°C after 15 days of water immersion	%	≤ 25

Table 16. Gyratory compaction and design

Test parameters	*Unit of measure*	*Thresholds*
Compaction	75 drops per face	
Marshall stability	KN	>5
Marshall stiffness	KN/mm	> 2,0
Residual voids (∗)	**%**	**3-6**
Loss of Marshall stability after 15 days of water immersion	%	≤25

1

Coefficient if indirect tensile strength, CTI

CTI = $\pi/2$ DRt/Dc

where

D = sample diameter, mm

Dc = deformation at the breaking point

Rt = resistance

Indirect tensile strength at 25°C (EN 12697-23)	N/mm^2	>0,4
Coefficient of indirect tensile strength[2] at 25 °C	N/mm^2	>30

Table 17. Marshall compaction and design

Sample density (or specific gravity, Gmb) must be determined according to Corelok method or according to paraffin-coated method.

2.6.1.4 Bituminous mixture type 2

This mixture is going to comply with the above with the following differences.

This mixture is going to include mineral aggregates, crumb rubber (dry method) and bitumen.

The gradation must comply with the one mentioned above (i.e., without rubber).

mm	%	±
8	See table above	
5.6		
4		
2		
1		
0.5		
0.25		
0.063		

Table 18. Gradation

Crumb rubber type: RARX

Note. The percentage of RARX (with respect to total, w/w) will be 1.9%.

2.6.2 Bituminous mixture acceptance

The contractor is going to submit to the client the final mixture composition based on the studies carried out (for approval).

2.6.3 Mixture production and on-site procedures

Mixture production will be carried out according to procedures and in plants approved by the client [2]. Mixture on-site construction will be carried out according to procedures and through machines and devices approved by

[2] The following tentative values and procedures are given.
Order of introduction (carried out in the lab): mineral aggregates (hot) - RARX (ambient temperature) - bitumen (hot) – filler.
Temperature during mixing (in the lab): about 175°C.
Temperature during compaction (in the lab): about 160°C.
Admissible time between mixture production and on-site laying: approximately less than two hours under given assumptions and conditions (insulated truck beds, tarps covering the load, and many other boundary conditions).
Minimal temperature during laying process: about 125-140°C.
Compactor suggested: <10 tons, static mode.

the client. In more detail, also the characteristics of the emulsified bitumen will be proposed by the contractor for client approval.

2.6.4 Mixture laydown and controls

On-site construction, including machines (and their characteristics), joints, procedures, materials, timing, temperatures, will be detailed by the contractor and submitted to the client for approval. The client will carry out controls and will apply pay adjustments based on acceptance procedures. On site density, in 95 cases our of 100, must be higher than the 95% of in-lab density (DG or DM).

2.6.5 Controls

Controls will include also:

Layer thickness

Skid Tester (CNR 105/85) BPN (British Pendulum Number) ≥ 60.

Macrotexture (HS) CNR 94/83 ≥ tba

CPX, as per project and as per client requirements

Sampling frequency for controls will be submitted by the contractor to the client for approval.

2.7 B1 Annex second internal report (see B1 for B3) – B15-based

This part is the output of B15.

2.7.1 Project requirements

The main characteristics stated in the project are as follows.

- *ACTION B.1:* Tracks design. **Deliverable**s: **UNIRC delivers two internal reports**, whose contents are below detailed. **Scheduling**: This action i) benefits from actions A1, A2, A3; ii) gives the instructions for B2 prototype; iii) uses B2 results; iv) gives the instructions for the pilot area in Florence (B3). Consequently, it basically starts after the actions Ai and ends before B3.
    - **B1.1 Data gathering** (from A1, A2, A3 and B2.1).
    - **B1.2 Preliminary design of the mixtures** (Before B2). At the end of B1.2, UNIRC delivers the **first internal report**.[3] B1.2 gives the required pieces of information for B2. By means of B1.1 and B1.2, B2.2 to B2.4 are carried out and led by IFSTTAR.
    - **B1.3 Data gathering from IFSTTAR that refer to Nantes prototype** (during and after B2).
    - **B.1.4 Data gathering from IFSTTAR that refer to IPOOL tests** (during and after B2). The **Sub-action B.1.4 deals with data gathering from IPOOL** (during and after B4). **These data will be useful in the pursuit of better carrying out the final design of the mixtures to be used in Florence-Via Paisiello**.

[3] This report has been delivered in July, 2020 to IFSTTAR-Eiffel.

  - **B1.5 Final design and support to track construction** (during and after B2, and before B3). At the end of B1.5, the **second internal report**[4] is delivered. By means of B1.5, B3 is carried out and led by FI. As a consequence of the sub-actions B1.3 and B1.4, UNIRC has the needed "response" data and is able to carry out the final design of the mixtures. **The Sub-action B1.5 addresses the final design and support in the pursuit of track construction** (B3). At the end of this activity, the **second internal report is delivered** to FI. As a result, in B3, Fi is going to take care of bid-related documents (technical and administrative), work management, and related managers and procedures according to the Italian laws. it is noted that UNIRC, besides the data gathered B.3 and B1.4, needs also updated data from FI. To this end, **FI provides UNIRC with the updated characteristics of the selected road** (Via Paisiello, Firenze): traffic data for the selected road, geometric data, lane and shoulder widths, etc.). To this end, it is noted that the selection of the tracks in Florence has been carried out in order to better achieve the primary objectives of the project. To this end, note that the following factors are going to affect the final results in terms of performance and perceived noise: 1) modification of the traffic spectrum and loads due to the increase in EVs. An increase of 15-35% of weight is expected; 2) changes in terms of driving force-to-speed diagram, accelerations and, probably, speeds due to the same reasons above (an increase of accelerations is expected); 3) changes in terms of shear stresses, tyre wear, pavement wear (an increase of surface texture wear and tyre wear is expected); 4) consequent change of pavement (and particularly, friction course) expected life.
- **B3: Pilot area: Implementation. Replication and transferability** (B1 based). Tracks: 1) REFERENCE TRACK, about 150 m long, complying with the "core" criterion for low-noise pavement of the EU GPP Criteria for Road Design, Construction and Maintenance, 2016 (EUGPPC), i.e., LCPX<90 dB(A) at 50 kph; 2) surface-OPTIMIZED track, about 150 m long, crumb rubber added, complying with the "comprehensive" criterion of the EUGPPC above, i.e., LCPX<87 dB(A) at 50 kph. B3 focuses on implementation area, based on actual noise pollution, the number of vehicles, speed and other parameters to maximize mitigation efficiency. Tracks will be constructed one next to the other to improve testing efficiency. B3 targets obj.1 of Reducing noise in populated urban areas. [FI].

In other terms, the following schematic is foreseen.

[4] This report is the object of this document.

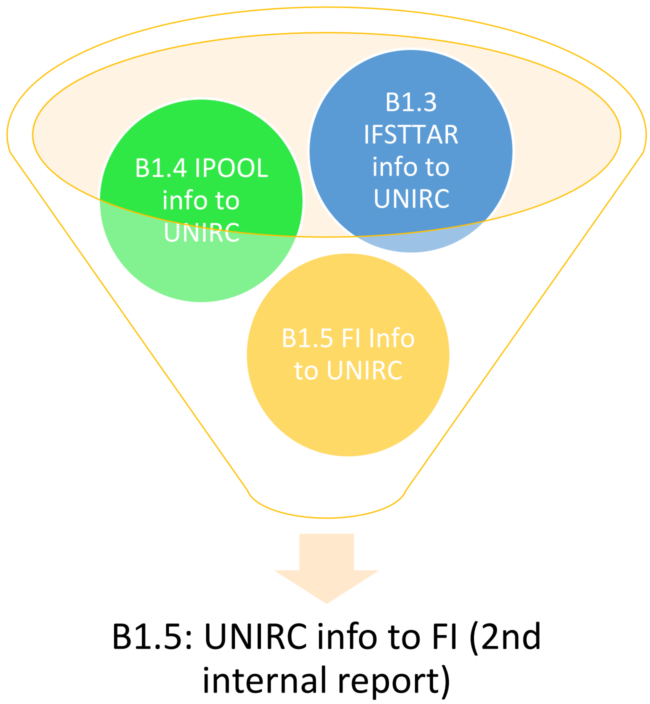


Figure 20. External sources of information of UNIRC B1.5 second internal report

2.7.1.1 Introduction

IFSTTAR- Universitè de Gustave Eiffel provided UNIRC with the results of the construction phase held in Nantes for CR-added mixtures[5] and for mixtures without CR[6]. The results would appear quite encouraging especially in terms of noise reduction.

IPOOL and FI information related to their activities was not received at the moment (November 2020-April 2021).

This notwithstanding, FI has requested to start the bid process in the pursuit of speed up the overall process (Action B3).

Mixtures were designed at UNIRC and they were partly validated through in-lab experiments (Action B1). Furthermore, they were partly validated in Nantes (Action B2).

Based on results, two bituminous mixtures will be used in Florence, Via Paisiello.

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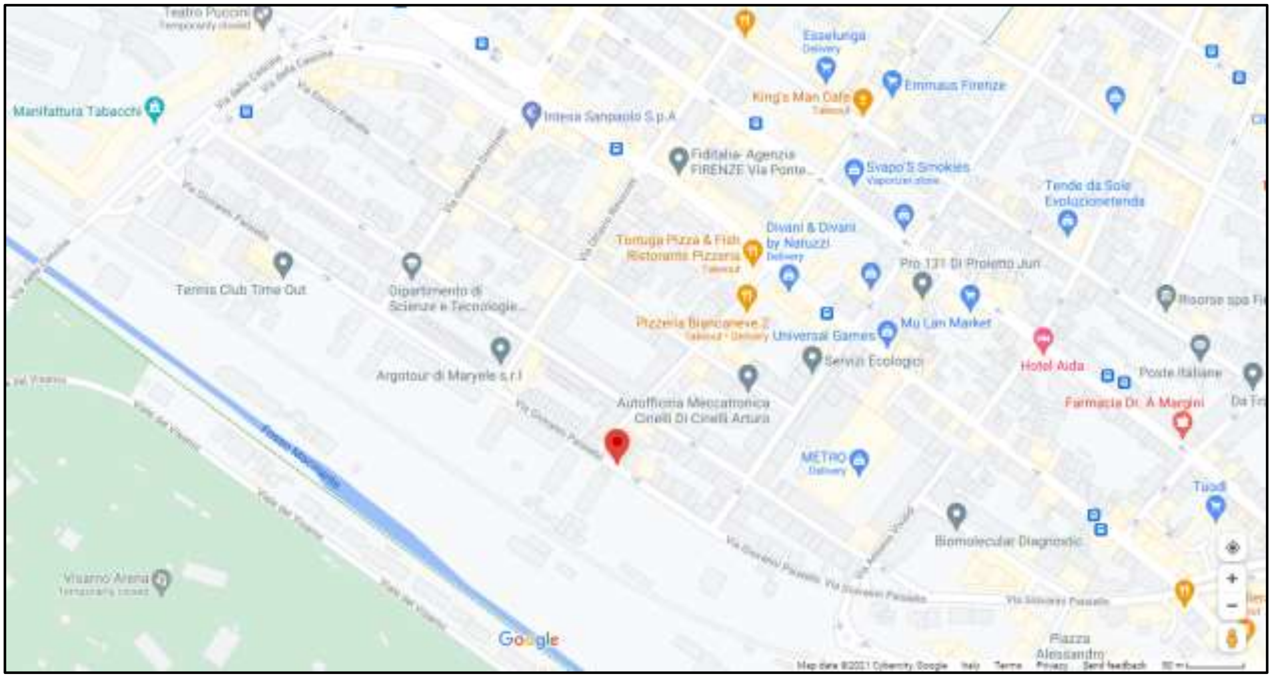
[5] Rapport de prestation- D44.20.REZE.056- Prototype piste - Université EIFFEL - 08/09/2020 – Bouguenais. Macrotexture: PMT moyenne : 0,42mm. P6.3mm=99%. 0.063/2:41%. Bitume d'apport 50/70: 6,10%. Bitume total: 6,40% RARX: 1,9%. Mesures SRT – Feuilles de notes Date: 18/09/2020 - Opérateur: PA / MTD: PTV=82,47. Valeurs issues des manips EASE (PA – AG) PMT: 0.30-0.32mm.

[6] Rapport de prestation - D44.20. REZE.056-Prototype piste - Université EIFFEL-08/09/2020. P6.3mm=99%. 0.063/2= 42%. Bitume total=Bitume d'apport: 6,40%. RARX=0%. PMT moyenne : 0,51mm. Mesures SRT – Feuilles de notes Date: 18/09/2020 - Opérateur : PA / MTD: PTV= 70,37. Valeurs issues des manips EASE (PA – AG) PMT: 0.39-0.42mm



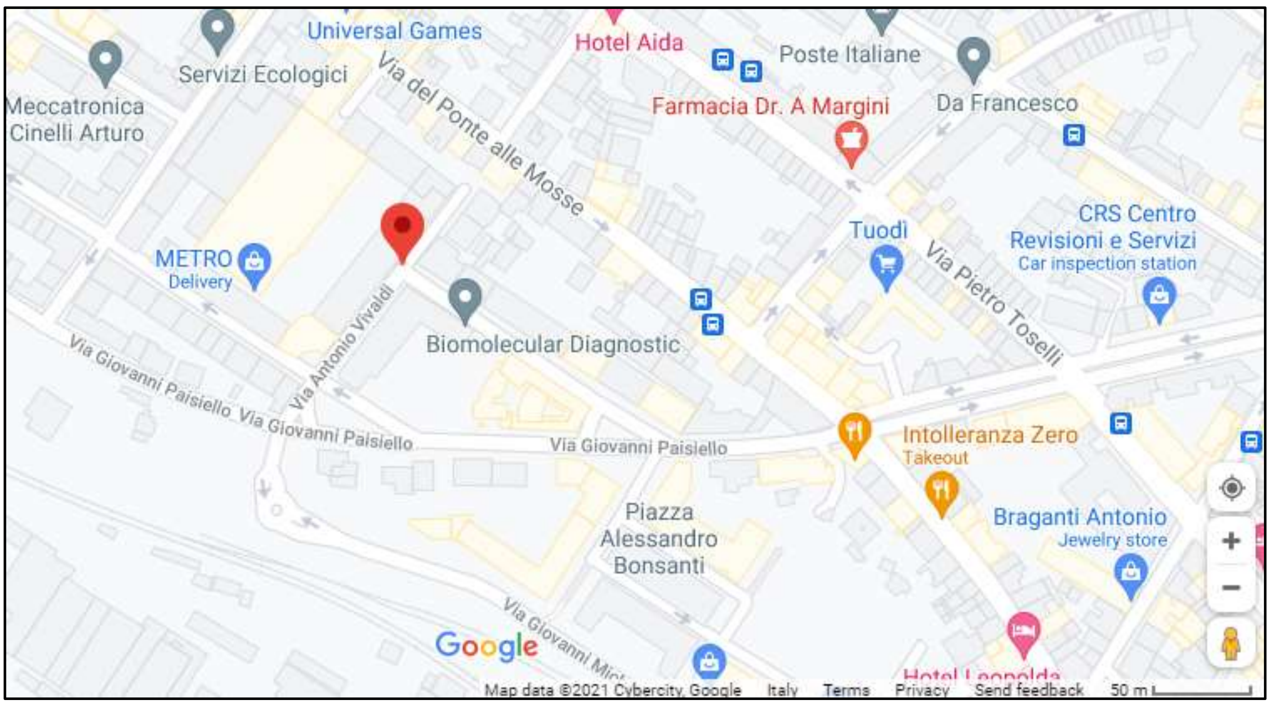


Figure 21. Via Paisiello - Florence

The main characteristics of the mixtures to use are summarised in Table 19:

	Where: Florence, Via Paisello. Width of about 11m.	
	Section 1(L=150m)	Section 2 (L=150m)
Type of treatment (friction course):	REF (Reference mixture for Florence streets)	PCR*
Thickness of the treatment once compacted	0.03m=3cm	0.025m=2.5cm.

Notes	The following document was received: Global Service della Rete Stradale del Comune di Firenze Norme Tecniche di Esecuzione	Scheduled type of crumb rubber: RARX Possible strategy in terms of construction (upon FI decision): milling: 0.085m+ tack coat + binder course laydown (0.06m, modified bitumen) + tack coat + PCR laydown (gradation close to 0/6mm, modified bitumen).
Reference	Annex 1 - Global Service della Rete Stradale del Comune di Firenze Norme Tecniche di Esecuzione. Livello di traffico: P (tbp[7])	Annex 2

Table 19. Mixtures for Via Paisiello- Florence

Nota Bene. Gradation and bitumen percentage shown below could undergo variations based on Florence municipality decisions and based on further results expected.

Further details are provided in the annexes.

2.7.2 Annex 1 - Bituminous mixture type 1 (without crumb rubber, REF)

See Global Service della Rete Stradale del Comune di Firenze Norme Tecniche di Esecuzione.

2.7.3 Annex 2 - Bituminous mixture type 2 (with crumb rubber, PCR*)

For the type of bitumen, coarse aggregate, fine aggregate, filler, c.f. Tables 11-14.

Before on-site construction works, the contractor must produce aggregate qualification certificates complying with requirements.

This mixture is going to include mineral aggregates, crumb rubber (dry method) and bitumen.

The specifications for the gradation (mineral aggregates) are given below.

Sieve openings, mm	
14	
8	
5.6	
4	
2	
1	
0.5	
0.25	
0.063	SEE TABLE 15
[redacted]	
RARX percentage, %, (w/w)	1.8-2.0

Table 20. Aggregate gradation and bitumen percentage

[7] Tbp= to be provided.

Nota Bene. Gradation and bitumen percentage shown could undergo variations based on Florence municipality decisions and based on further results that are expected.

Bitumen percentage is given below as a function of **total mixture weight (i.e., mineral aggregates + bitumen + CR)**.

Crumb rubber type: RARX

Note. The percentage of RARX (with respect to total, w/w) will be 1.9%.[8]

2.7.3.1 Bituminous mixture

Bitumen percentage is going to be assessed based on the study of bituminous mixture. Volumetric method or Marshall method may be used.

The thickness of the compacted mixture will be about 0.025m. Requirements are given in the table below.

The selected mixture should be tested (at 98% of D_G) foe modulus or similar properties for better on-site quality control and assurance.

Test parameters	*Unit of measure*	*Thresholds*
Rotation Angle		1.25° ± 0.02
Rotation speed	r/min	30
Vertical pressure	KPa	600
Sample diameter	mm	Tbp
To be Provided (tbp)	**%**	**Tbp**
To be Provided	**%**	**Tbp**
To be Provided	**%**	**Tbp**
Indirect tensile strength at 25°C (@120 gyrations)[9] (*EN 12697-23*)	N/mm^2	> 0,4
Coefficient of indirect tensile strength[2] at 25 °C (@120 gyrations)	N/mm^2	> 30
Loss of indirect tensile strength at 25°C after 15 days of water immersion	%	≤ 25

Table 21. Gyratory compaction and design

[8] For example, if the mixture weights about 2086 kg, then the bitumen added could weight about 91kg, the RARX could weight about 40Kg, and the mineral aggregates added about 1955kg. Note that the "bitumen added" above does not include the bitumen contained into the RARX and that the mineral aggregates added above do not include the filler contained into the RARX.

[9] Coefficient if indirect tensile strength, CTI Coefficient if indirect tensile strength, CTI. CTI = $\pi/2$ DRt/Dc where D = sample diameter, mm Dc = deformation at the breaking point Rt = resistance.

Test parameters	*Unit of measure*	*Thresholds*
Compaction	50-75 drops per face (tbp)	
Marshall stability	KN	>5
Marshall stiffness	KN/mm	> 2,0
Residual voids	%	tbp
Loss of Marshall stability after 15 days of water immersion	%	≤ 25
Indirect tensile strength at 25°C (*EN 12697-23*)	N/mm^2	> 0,4
Coefficient of indirect tensile strength[2] at 25 °C	N/mm^2	> 30

Table 22. Marshall compaction and design

Sample density (or specific gravity, Gmb) must be determined according to Corelok method or according to paraffin-coated method.

2.7.3.2 Bituminous mixture acceptance

The contractor is going to submit to the client the final mixture composition based on the studies carried out (for approval).

2.7.3.3 Mixture production and on-site procedures

Mixture production will be carried out according to procedures and in plants approved by the client. Mixture on-site construction will be carried out according to procedures and through machines and devices approved by the client. In more detail, also the characteristics of the emulsified bitumen will be proposed by the contractor for client approval.

2.7.3.4 Mixture laydown and controls

On-site construction, including machines (and their characteristics), joints, procedures, materials, timing, temperatures, will be detailed by the contractor and submitted to the client for approval. The client will carry out controls and will apply pay adjustments based on acceptance procedures. On site density, in 95 cases out of 100, must be higher than the 95% of in-lab density (DG or DM).

2.7.3.5 Controls

Controls will include also:

Layer thickness

Skid Tester (CNR 105/85) BPN (British Pendulum Number) ≥ 60.

Macrotexture (HS) CNR 94/83 ≥ tbp

CPX, as per project and as per client requirements

Sampling frequency for controls will be submitted by the contractor to the client for approval.

2.8 Final notes

This document illustrates the guidelines to follow to produce and laydown the mixtures. FI highlights that due to the need for receiving the needed information above (tests still to perform) revisions could be needed.

For the prediction of the noise impact deriving from using the selected mixtures, it is observed that:

- In the proposal, the following objectives were stated: REFERENCE TRACK, about 150 m long, complying with the "core" criterion for low-noise pavement of the EU GPP Criteria for Road Design, Construction and Maintenance, 2016 (EUGPPC), i.e., LCPX<**90**dB(A) at 50 kph; 2) surface-OPTIMIZED track, about 150 m long, crumb rubber added, complying with the "comprehensive" criterion of the EUGPPC above, i.e., LCPX<**87** dB(A) at 50 kph.
- The derivation of the acoustic impact at the design stage is very difficult and such a well-established method does not exist, even if many studies were carried out in the past (e.g., [14–25]).
- This notwithstanding, based on the literature and based on the studies carried out, it is expected to fit the requested thresholds as follows: 1) REFERENCE TRACK, LCPX<**90±2**dB(A) at 50 kph; 2) surface-OPTIMIZED track, crumb rubber added, LCPX<**87±2** dB(A) at 50 kph.

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