



Actions 3.3.1, 3.3.2, 3.4 and 3.5

Technical guidelines for the field implementation of the “dry” technology

POLITECNICO DI TORINO

Project partners



**Patrimonio
s.r.l.**



With the contribution of



Introduction

These technical guidelines were prepared as a result of the activities carried out in Actions 3.3.1, 3.3.2, 3.4 and 3.5, focused on the development of a prototype device for the implementation of the “dry” production process and on the subsequent construction of reduced-scale pavement sections. They may be used as a reference for future applications and as a starting point of further improvements.

1. Mix design

Mix design of bituminous mixtures containing crumb rubber from end-of-life tyres to be produced by means of the “dry” technology should be carried out by following a volumetric and mechanical approach. In particular, dense-graded formulations may be sought by referring to standard Technical Specifications with minor modifications to their content, provided that the volume occupied by crumb rubber particles is adequately taken into account.

This engineering activity is illustrated in the following paragraphs by referring to the results of the investigation which was carried out as part of Action 3.3.1 of the TYREC4LIFE project. Experimental data and results, which were obtained for wearing course and base course mixtures, should be considered as examples which have the purpose of clarifying the rationale followed throughout the mix design exercise (which may also be applied to binder course mixtures). Nevertheless, it should be considered that the use of component materials different from those considered in this investigation may lead to different results and conclusions.

1.1 Materials

Aggregates employed for the production of dense-graded bituminous mixtures with the “dry” technology should satisfy all requirements indicated by standard Technical Specifications (for coarse aggregates, fine aggregates and filler). The same rationale applies to bitumen, the characteristics of which should satisfy standard requirements and should possibly be selected by taking into account the predicted traffic and environmental conditions of the corresponding pavement in service (e.g. according to SUPERPAVE guidelines).

Crumb rubber products should be characterized in terms of their particle size distribution and unit weight. Additional tests for the assessment of particle morphology and surface area may be useful for the comparative selection of products of similar products.

Considered crumb rubber products will be associated to d/D codes, where d and D are the openings (in mm) of the bottom and top sieve, respectively, which correspond to 10% and 90% passing, respectively. Options admitted within the “dry” technology include coarse, standard and fine crumb rubber products, which are typically characterized by D values greater than 1 mm, between 0.5 and 1 mm, and smaller than 0.5 mm, respectively.



Viscosity-reduction additives added to the bitumen may be employed in the design and production of “dry” mixtures in order to reduce production temperatures and costs, reduce compaction temperature, and improve workability in adverse conditions. Their dosage and mixing temperature will be established based on trial tests and/or on the indications of the producer. The corresponding bituminous mixtures, compacted at the temperature indicated by the supplier, will satisfy the volumetric and mechanical requirements set for all other mixtures.

1.2 Mixtures

The combination of aggregates and crumb rubber adopted for production of “dry” dense-graded bituminous mixtures shall have a particle size distribution contained in the acceptance ranges defined by standard Technical Specifications. However, the percent passages shall be considered in volume, so to take into account the different unit weight of aggregates and crumb rubber.

Percentages of the different aggregates fractions shall be defined by means of an adequate optimization process, for example by minimizing deviations from the central grading (e.g. mean squares method). Crumb rubber dosage shall be defined by considering 1% (by weight of dry aggregates) as a reference and by possibly increasing such a percentage if this is compatible with the volumetric and mechanical properties of the corresponding bituminous mixtures.

Binder content will be comprised in the acceptance ranges indicated by standard Technical Specifications. However, it should be considered that optimal binder content may have to be increased with respect to standard mixtures (containing no crumb rubber), due to the time-dependent absorption of lighter bitumen fractions which takes place at the rubber-bitumen interface after mixing.

Composition of the design mixtures, expressed in terms of percentages of aggregate fractions, filler, crumb rubber and bitumen, shall be established on the basis of a preliminary laboratory study. In such a study, conditioning temperatures of all components during mixing shall be closely controlled in order to simulate full-scale production operations.

In particular, care should be taken in replicating the conditions in which crumb rubber is added to the mixtures. This may occur directly in the mixer with no preliminary heating (according to the so-called “cold” production process) or by pre-heating crumb rubber in the plant dryer (according to the so-called “hot” production process).

In the laboratory study the volumetric and mechanical properties of Marshall-or gyratory-compacted specimens will be compared to requirements set by standard Technical Specifications. It is recommended that laboratory studies of “dry” mixtures include, for comparison purposes, standard mixtures of similar composition with no crumb rubber.

Results obtained on the “dry” bituminous mixtures considered in Action 3.3.1 of the TYREC4LIFE project are provided, as an example, in the following. They were obtained for the following mixtures:

- Standard/reference wearing course mixture (no crumb rubber);
- “Dry” wearing course mixture - fine crumb rubber - “hot” production process;
- “Dry” wearing course mixture - fine crumb rubber - “cold” production process;



- “Dry” wearing course mixture - coarse crumb rubber - “hot” production process;
- “Dry” wearing course mixture - coarse crumb rubber - “cold” production process;
- Standard/reference base course mixture (no crumb rubber);
- “Dry” base course mixture - fine crumb rubber - “hot” production process;
- “Dry” base course mixture - fine crumb rubber - “cold” production process;
- “Dry” base course mixture - coarse crumb rubber - “hot” production process;
- “Dry” base course mixture - coarse crumb rubber - “cold” production process;

In all cases crumb rubber was employed in partial substitution of standard aggregates, considering a constant dosage of 1% in volume.

	0-5	3-8	5-18	15-30	filler	CR(0-0,4)	CR(1-4)
Reference	43%	27%	26%	-	4%	-	-
With fine CR	37%	33%	25%	-	4%	1%	-
With coarse CR	43%	25%	27%	-	4%	-	1%

Table 3 – Job mix formulae of wearing course mixtures

	0-5	3-8	5-18	15-30	filler	CR(0-0,4)	CR(1-4)
Reference	43%	-	8%	47%	2%	-	-
With fine CR	39%	-	11%	46%	3%	1%	-
With coarse CR	41%	-	7%	48%	3%	-	1%

Table 4 – Job mix formulae of base course mixtures

The mixtures prepared as part of Action 3.3.1 of the TYREC4LIFE project were compacted at 100 gyrations by means of a gyratory shear compactor (as per UNI EN 12697-31). Target void content was set at 4%. Thus, the following optimal binder contents were identified:

- Standard/reference wearing course mixture (no crumb rubber): 4.9%;
- “Dry” wearing course mixture - fine crumb rubber - “hot” production process: 4.9%;
- “Dry” wearing course mixture - fine crumb rubber - “cold” production process: 5.3%;
- “Dry” wearing course mixture - coarse crumb rubber - “hot” production process: 4.9%;
- “Dry” wearing course mixture - coarse crumb rubber - “cold” production process: 4.9%;
- Standard/reference base course mixture (no crumb rubber): 4.2%;
- “Dry” base course mixture - fine crumb rubber - “hot” production process: 4.4%;
- “Dry” base course mixture - fine crumb rubber - “cold” production process: 5.0%;
- “Dry” base course mixture - coarse crumb rubber - “hot” production process: 4.3%;
- “Dry” base course mixture - coarse crumb rubber - “cold” production process: 4.3%;



It should be pointed out that while the identification of optimal binder content corresponding to 4% voids is usually quite straightforward in the case of mixtures containing fine crumb rubber, this may not be the case of those containing coarse rubber particles. This is due to the fact that such mixtures may exhibit a non-negligible volumetric expansion after gyratory compaction due to the rebound of rubber particles subjected to compression.

Mechanical properties of design mixtures may be assessed by means of repeated load indirect tensile tests for the determination of stiffness at 20°C.

The optimum mixtures prepared as part of Action 3.3.1 of the TYREC4LIFE project yielded the average stiffness values listed in **Table 5**.

	Wearing	Base
Reference	6,070	12,540
Fine-cold	5,930	6,070
Fine-hot	4,440	5,400
Coarse-cold	1,760	2,490
Coarse-hot	1,860	2,530

Table 5 – Stiffness (in MPa) of optimal « dry » mixtures

1.3 Comments and conclusions

Experimental results indicate that the introduction of crumb rubber in bituminous mixtures by means of the “dry” technology may cause the following effects:

- volumetric expansion of mixtures after compaction, which is negligible when fine rubber particles are employed and is significant in the case of coarser products (with the consequent need of changing the optimization process);
- increase of the optimal binder content, which is greater when fine rubber particles are used and in the case of rubber use in “cold” conditions (with no pre-heating);
- reduction of workability, which is greater in the case of employment of smaller rubber particles;
- reduction of stiffness, which is greater in the case of use of coarser rubber particles.

In synthesis:

- mixtures prepared according to the “hot” protocol were superior to the others, thus suggesting that premixing of crumb rubber with aggregates is absolutely necessary to minimize segregation phenomena;
- for all considered crumb rubber types the reference dosage (equal to 1% by weight on dry aggregates) should be recommended, at least in the preliminary phases of full-scale implementation of the technology.



2. Production process

According to the results achieved in Action 3.3.1 of the TYREC4LIFE project, the solution adopted for production of “dry” mixtures was that of employing a double cylinder drum capable of simultaneously processing aggregates and crumb rubber with differential temperature histories. Technical details of this prototype device, together with the final layout of the hot mix plant, are given in the following. Pictures of actual installation operations performed as part of Action 3.3.2 of the TYREC4LIFE project are also shown.

As shown in Figure 1, the double cylinder drum (furnace) is capable of directly receiving crumb rubber (CR), thus processing it at high temperatures and ensuring its partial fusion with a maximization of its interaction with the other components of the bituminous mixture. The drum also acts as a heater for virgin aggregates (VA), which are dried out as they flow in the longitudinal direction.

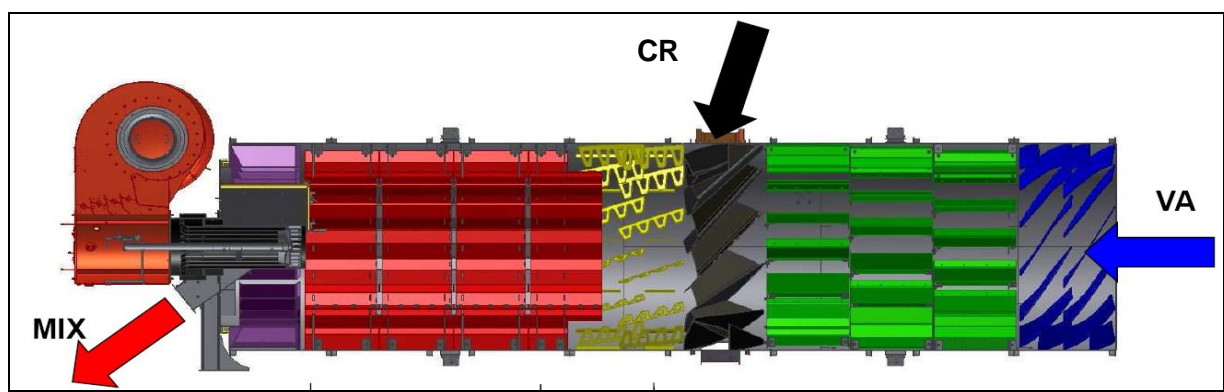
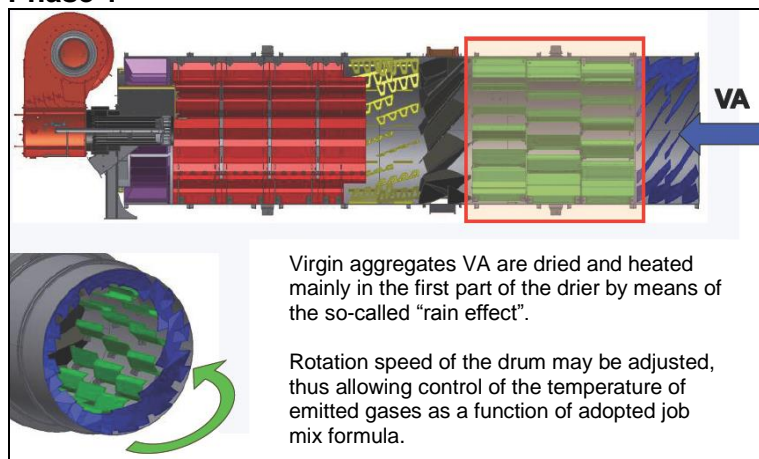


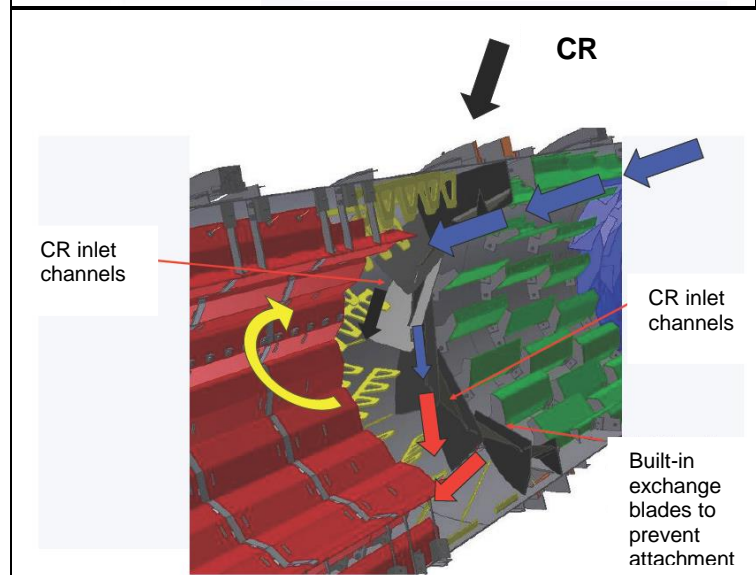
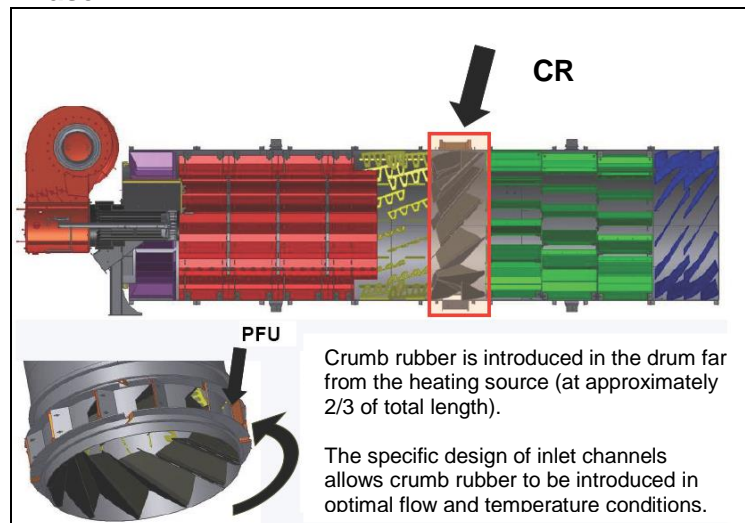
Figure 1. Double cylinder drum diagram

The “hot” version of production, selected on the basis of preliminary laboratory investigations (Action 3.3.1), is structured as shown in the following.

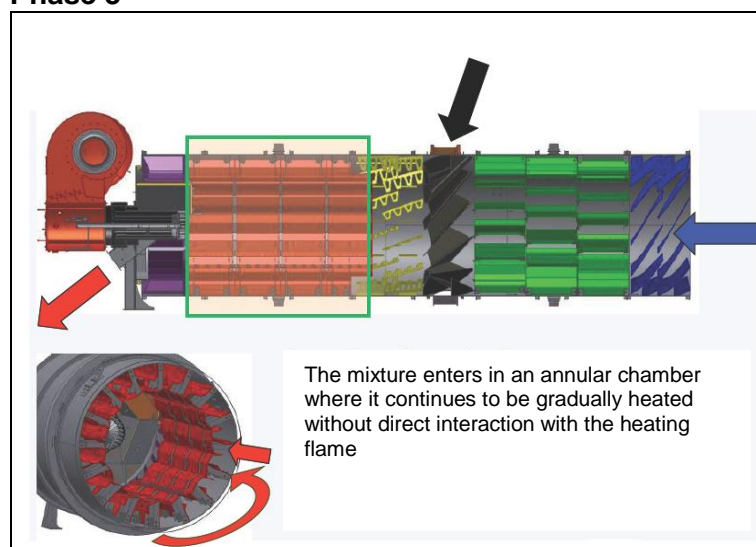
Phase 1



Phase 2



Phase 3



It should be noted that according to such a technological solution crumb rubber undergoes premixing with other aggregates (such as sand). This is to avoid the possibility of crumb rubber to be pulled, as a consequence of convection currents and of its low specific weight, to areas where the flame would cause combustion of the material, with the risk of fire inside the drum.

The adopted solution for “dry” production finally requires an adequate system of hoppers connected to conveyor belts that directly feed crumb rubber to the double drum.

The final layout of the prototype device, is given in Figure 2.

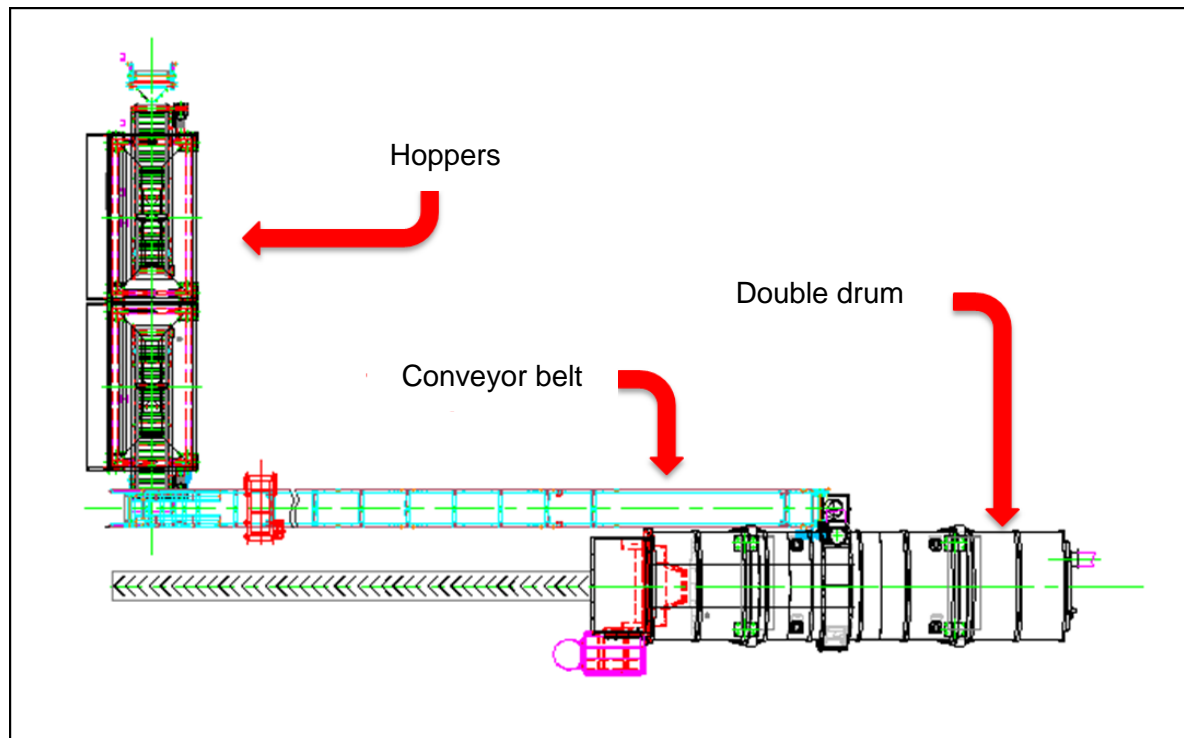


Figure 2. Final layout of the prototype device.

Installation and construction operations carried out in the premises of Brillada Vittorio & C. are given in the following.





3. Field implementation

Laying of bituminous mixtures produced by adopting the technological solution described in the previous section (based on the use of the selected prototype device) may be carried out by employing standard paving equipment and procedures.

It is recommended that analyses carried out in support of paving works should include:

- Assessment of composition (binder content and aggregate size distribution);
- Volumetric properties of Marshall- and gyratory compacted specimens;
- Determination of Marshall parameters (stability, flow, stiffness);
- Assessment of resistance to crack propagation (SCB test);
- Evaluation of complex modulus master curves (AMPT tests);
- Assessment of resistance to permanent strain accumulation (Flow Number tests);
- Determination of volumetric properties of cores taken from compacted layers.

Whenever deemed necessary, investigations should also include the sampling and subsequent analysis of fumes generated during paving operations.

The system describe above was validated in the TYREC4LIFE project as part of Actions 3.4 and 3.5, which consisted in the construction of reduced-scale pavement sections built in the premises of Brillada Vittorio & C.

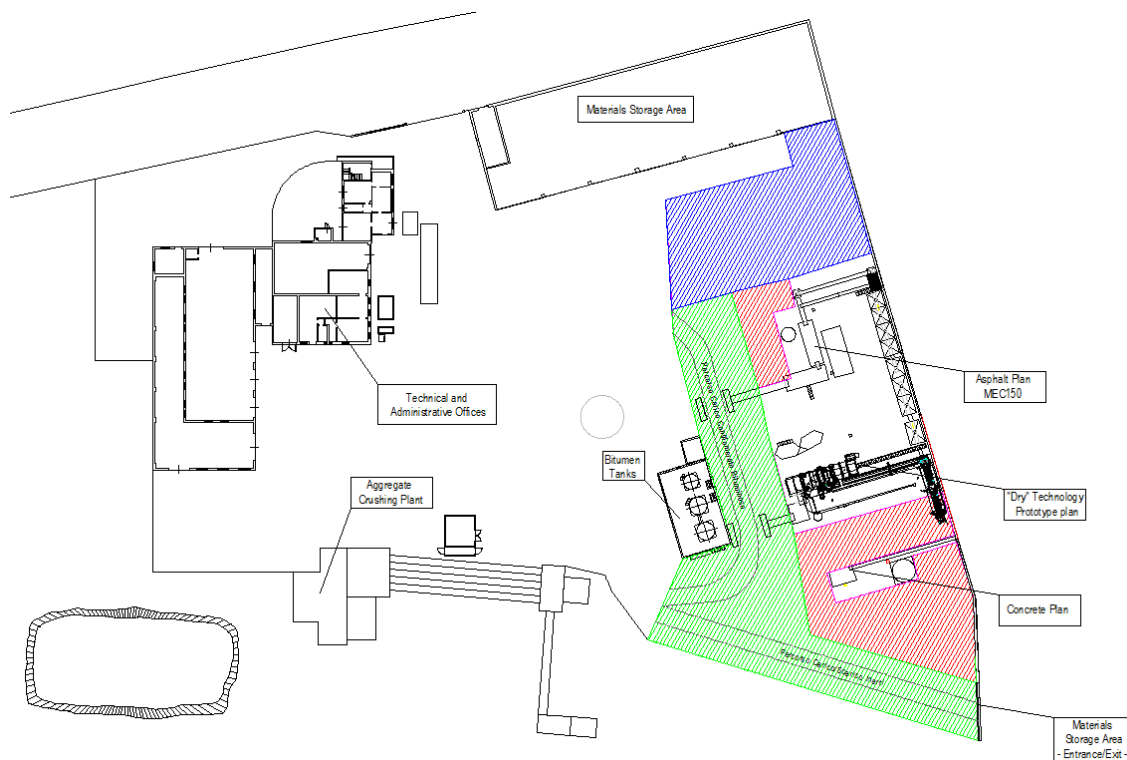
Mixtures produced and laid on site included the four “dry” ones derived from the factorial combination of layer type (wearing course and base course) and crumb rubber size (coarse and ultrafine, characterized by particle size ranges equal to 1-4 mm and 0-0.4 mm, respectively), plus two additional reference mixtures (for wearing and base courses) included in the activities for comparative purposes. Finally, the investigation also considered a base course mixture containing ultrafine crumb rubber and by using a

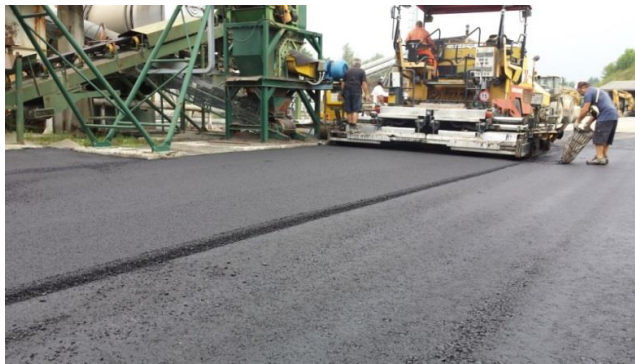
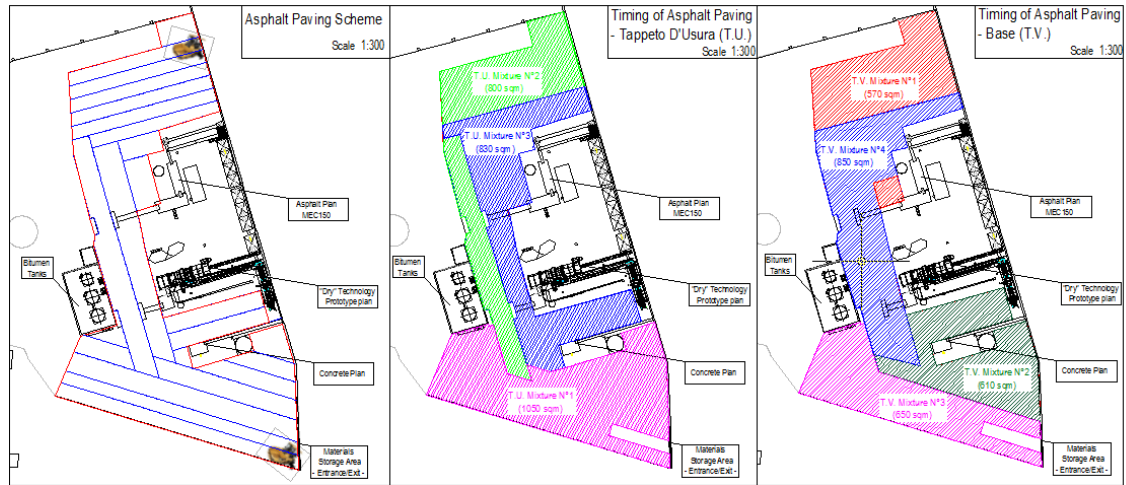
commercial viscosity-reduction additive (with 1% dosage on the weight of the neat bitumen).

Recipes of the mixtures were those defined in the mix design phase of the investigation (see paragraph 1), with a fixed crumb rubber dosage of 1%. Future implementations may be carried out with higher dosages, provided that adequate mix design activities are carried out.

As shown in the layouts provided in the following, the total surface covered by paving trials was equal to 2,680 m², with the laying of base courses with 5 cm thickness and wearing courses with 3 cm thickness. In particular, the following mixtures were produced and laid on site:

- The base course mixture containing coarse crumb rubber on 850 m²;
- The base course mixture containing ultrafine crumb rubber on 650 m²;
- The base course mixture containing ultrafine crumb rubber and viscosity-reduction additive on 610 m²;
- The reference base course mixture on 570 m²;
- The wearing course mixture containing coarse crumb rubber on 830 m²;
- The wearing course mixture containing ultrafine crumb rubber on 1050 m²;
- The reference wearing course mixture on 800 m².





Laying of bituminous mixtures was performed with the application between the two layers of an emulsion tack coat. Laying was carried out by employing a standard paver, while compaction was thereafter performed by making use of a tandem vibrating roller (Dynapac CC232HF).

During laying operations samples of the bituminous mixtures were taken from the paver and thereafter employed in the laboratory for the assessment of their composition and for the evaluation of their volumetric and mechanical properties (following Marshall or gyratory compaction). Results were compared to those obtained in the mix design studies (Action 3.3.1).



Paving works were also monitored with respect to gaseous emissions produced by the mixtures at the paver. In particular, by adopting a set of techniques and procedures developed and validated by the Politecnico di Torino in previous investigations, fumes were characterized in terms of their content of Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs).

Finally, an assessment of the efficiency of compaction was performed by taking cores from the individual paving areas and by determining in the laboratory their volumetric properties (density, voids content and percent compaction).

Results obtained in this investigation are provided in the following.

	%B _{mixture}	%B _{aggregates}	%B _{aggregates-target}
	[%]	[%]	[%]
Reference	3.9	4.0	4.1
Coarse CR	3.5	3.6	4.2
Ultrafine CR	3.6	3.8	4.3
Ultrafine CR + additive	3.3	3.4	4.3

Table 1 – Binder content of base course mixtures

	%B _{mixture}	%B _{aggregates}	%B _{aggregates-target}
	[%]	[%]	[%]
Reference	4.6	4.9	4.8
Coarse CR	4.6	4.8	4.9
Ultrafine CR	4.1	4.3	5.0

Table 2 – Binder content of wearing course mixtures

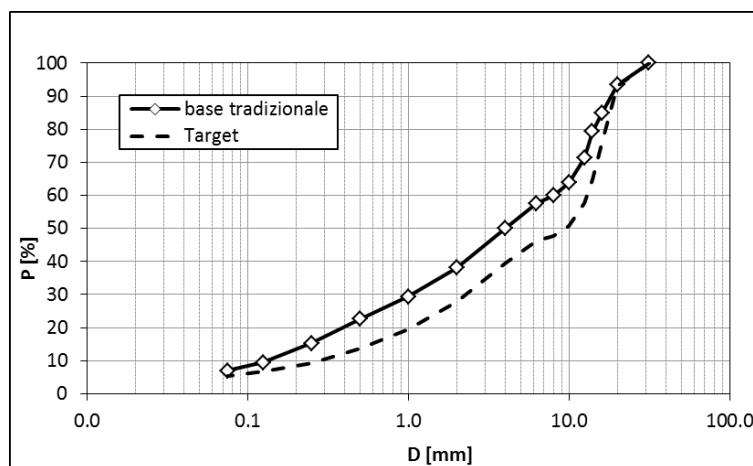


Figure 3 – Reference base course



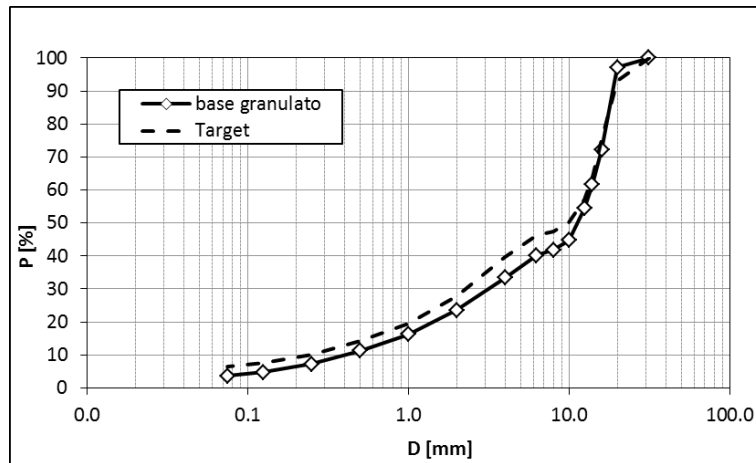


Figure 4 – Base course with coarse CR

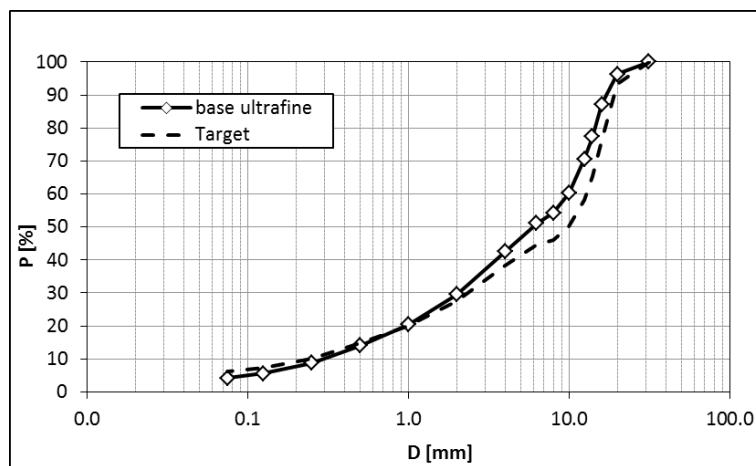


Figure 5 – Base course with ultrafine CR

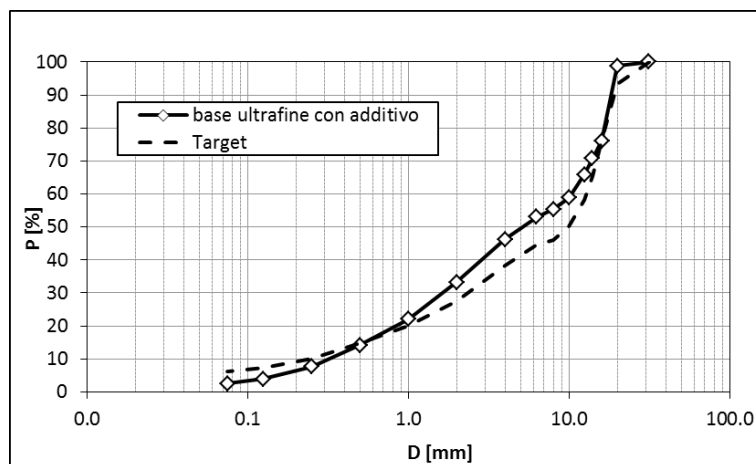


Figure 6 – Base course with ultrafine CR + additive



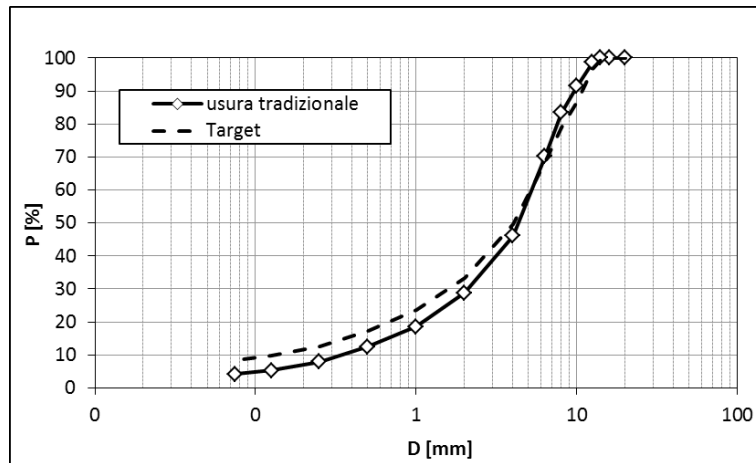


Figure 7 – Reference wearing course

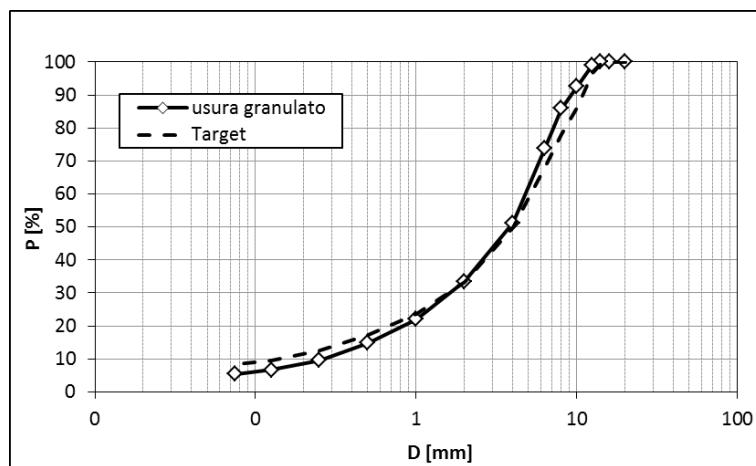


Figure 8 – Wearing course with coarse CR

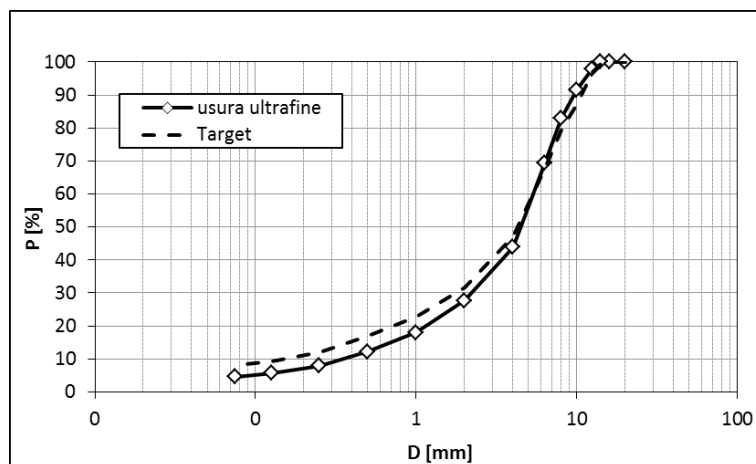


Figure 9 – Wearing course with ultrafine CR



	ρ_{ssd}	ρ_{mw}	vuoti
	[kg/m ³]	[kg/m ³]	[%]
Reference	2356	2653	11.2
Coarse CR	2326	2612	10.9
Ultrafine CR	2355	2595	9.3
Ultrafine CR + additive	2340	2598	9.9

Table 3 – Volumetric properties of cores taken from base course layers

	ρ_{ssd}	ρ_{mw}	vuoti
	[kg/m ³]	[kg/m ³]	[%]
Reference	2233	2542	12.1
Coarse CR	2182	2520	13.4
Ultrafine CR	2215	2535	12.6

Table 4 – Volumetric properties of cores taken from wearing course layers

	d=150 mm		
	k	C ₁	%v
	[-]	[%]	[%]
Reference	5.5	81.3	7.9
Coarse CR	6.5	74.7	12.6
Ultrafine CR	6.5	81.5	5.7
Ultrafine CR + additive	7.2	80.6	5.2

Table 5 – Workability parameters of base course mixtures

	d=100 mm			d=150 mm		
	k	C ₁	%v	k	C ₁	%v
	[-]	[%]	[%]	[-]	[%]	[%]
Reference	8.1	74.0	9.9	8.2	73.1	8.9
Coarse CR	7.1	72.1	14.0	6.9	72.7	12.4
Ultrafine CR	8.3	74.5	9.1	8.1	74.6	9.4

Table 6 – Workability parameters of wearing course mixtures

	%v	S	F _T	F	F _t	R	R _{CNR}
	[%]	[kN]	[mm]	[mm]	[mm]	[kN/mm]	[kN/mm]
Reference	9.1	19.8	2.5	2.3	1.2	8.8	7.8
Coarse CR	10.1	12.3	7.2	7.0	2.2	1.7	1.7
Ultrafine CR	7.1	13.7	2.1	2.0	1.1	6.9	6.4
Ultrafine CR + additive	6.7	11.3	2.5	2.4	1.0	4.9	4.8

Table 7 – Marshall parameters of base course mixtures



	%v	S	F _T	F	F _t	R	R _{CNR}
	[%]	[kN]	[mm]	[mm]	[mm]	[kN/mm]	[kN/mm]
Reference	9.1	10.9	2.4	2.1	1.2	5.2	4.6
Coarse CR	12.4	9.9	3.7	3.5	2.1	2.8	2.7
Ultrafine CR	8.6	11.1	2.6	2.2	1.3	5.1	4.4

Table 8 – Marshall parameters of wearing course mixtures

	%v	F _{max}	ΔW	□ _{max}	□ _{max}	K _{1,c}	U _{Fmax}
	[%]	[N]	[mm]	[%]	[N/mm ²]	[N/mm ^{3/2}]	[N·mm]
Reference	8.0	2322	0.75	1.02	1.30	7.8	1001
Coarse CR	13.1	1209	1.14	1.53	0.67	4.0	963
Ultrafine CR	5.7	3687	0.84	1.15	2.09	12.4	1908
Ultrafine CR + additive	5.0	3289	1.15	1.58	1.84	11.0	1901

Table 9 – SCB parameters of base course mixtures

	%v	F _{max}	ΔW	□ _{max}	□ _{max}	K _{1,c}	U _{Fmax}
	[%]	[N]	[mm]	[%]	[N/mm ²]	[N/mm ^{3/2}]	[N·mm]
Reference	8.8	2751	1.06	1.45	1.55	9.2	1812
Coarse CR	13.7	1093	1.32	1.79	0.60	3.6	896
Ultrafine CR	9.1	2138	1.42	1.93	1.20	7.2	1775

Table 10 – SCB parameters of wearing course mixtures

	E* _{min}	E* _{10Hz}	E* _{max}
	[MPa]	[MPa]	[MPa]
Reference	3.9	8609	31901
Coarse CR	0.1	2515	11880
Ultrafine CR	4.8	7644	28068
Ultrafine CR + additive	10.3	8336	30937

Table 11 – Master curve parameters of base course mixtures

	E* _{min}	E* _{10Hz}	E* _{max}
	[MPa]	[MPa]	[MPa]
Reference	3.3	7188	25283
Coarse CR	0.4	2057	9047
Ultrafine CR	2.9	6225	27317

Table 12 – Master curve parameters of wearing course mixtures



	ID	%v [%]	Flow number	Flow number (average)
Reference	1	8.4	266	446
	8	7.7	626	
Coarse CR	2	12.2	54	63
	9	12.9	71	
Ultrafine CR	3	6.1	640	864
	10	5.8	1087	
Ultrafine CR + additive	4	5.7	459	529
	11	5.5	599	

Table 13 – Flow number values of base course mixtures

	ID	%v [%]	Flow number	Flow number (average)
Reference	5	8.8	173	142
	12	9.9	110	
Coarse CR	6	14.1	33	35
	13	13.5	37	
Ultrafine CR	7	10.5	82	116
	14	9.3	150	

Table 14 – Flow number values of wearing course mixtures

	Reference		Coarse		Ultrafine		Ultrafine + additive	
	D	S	D	S	D	S	D	S
Benzene	6.6	5.2	6.4	9.8	11.4	5.3	24.0	5.9
Toluene	3.9	2.8	0.0	0.0	8.7	0.0	15.8	
ethylbenzene	4.6	4.8	11.1	29.4	41.3	10.3	56.4	8.8
p-Xylene	8.1	7.1	16.4	43.1	60.4	15.1	82.6	12.9
Styrene	0.9							
Benzene, bromo-	<0,05							
Benzene, 1,3,5-trimethyl-	36.2	17.2	15.2	26.6	27.1	22.1	18.3	36.1
Benzene, 1,2,4-trimethyl-	34.6	14.8	22.3	22.0	11.8	9.5	15.9	15.0
p-isopropiltoluene	<0,05	4.6	6.2	11.9	7.8	5.2	13.7	7.0
Benzene, butyl-	<0,05						4.9	
Benzene, 1,3,5-trichloro-	<0,05		1.3	1.5	1.3		1.4	1.4
Benzene, 1,2,4-trichloro-	<0,05	3.3		2.2			2.6	
total VOCs	95.0	59.6	79.0	146.3	169.7	67.6	235.8	87.1
T laying (°C)	173	188	163	150	195	163	178	130
wind speed (km/h)	1.5	2.3	1.7	3.5	1.9	3.1	2.2	2.9

Table 15 – VOC values of emissions sampled during laying of base course mixtures (values in $\mu\text{g}/\text{m}^3$)



	Reference		Coarse		Ultrafine	
	D	S	D	S	D	S
Benzene	17.1	19.1	6.1	5.8	11.7	17.8
Toluene	26.1	33.8			30.0	31.0
ethylbenzene	6.2	7.5	7.1	7.9	6.9	23.5
p-Xylene	10.0	13.3	10.5	11.4	13.0	34.4
Styrene						
Benzene, bromo-						
Benzene, 1,3,5-trimethyl-	12.9	14.8	46.8	9.2	22.0	12.8
Benzene, 1,2,4-trimethyl-	8.1	9.6	21.3	20.4	9.8	7.5
p-isopropiltoluene			4.5	5.3	3.8	5.6
Benzene, butyl-						
Benzene, 1,3,5-trichloro-						1.4
Benzene, 1,2,4-trichloro-						
total VOCs	80.3	98.0	96.3	60.0	97.1	133.9
T laying (°C)	180	163	160	150	173	166
wind speed (km/h)	3.3	3.2	1.6	2.3	2.3	3.9

Table 16 – VOC values of emissions sampled during laying of wearing course mixtures (values in $\mu\text{g}/\text{m}^3$)

	Reference		Coarse		Ultrafine		Ultrafine + additive	
	D	S	D	S	D	S	D	S
Naphtalene	1.24	1.17	1.00	1.92	0.95	1.81	0.89	1.49
Acenaphthylene							0.34	
Naphthalene, 1-bromo-								
Acenaphthene			0.19				0.24	0.22
Fluorene			0.10	0.09				
Phenanthrene								
Anthracene								
Fluoranthene	0.70	1.97	0.50	0.71	1.04	0.89	0.70	1.00
Pyrene	0.47	1.35	1.04	0.99	0.80	0.43	0.57	0.89
Triphenylene					0.24	0.06		
Benz[a]anthracene	0.08	0.18		0.08	1.15	0.12		0.11
Benzo[b]fluoranthene	0.14	0.23	0.15	0.10	0.23	0.25	0.10	0.15
Benzo[a]pyrene	0.00	0.55	0.17	0.23	0.61	0.83	0.20	0.59
indeno[1,2,3-cd]pirene	0.21	0.26			0.33			
dibenzo[a,h]anthracene	0.26		0.07	0.05		0.67	0.07	0.16
Benzo[ghi]perylene	0.34	0.24						
Total PAHs	2.20	4.82	2.22	2.30	4.45	3.29	2.26	3.12
T laying (°C)	173	188	163	150	195	163	178	130
wind speed (km/h)	1.5	2.3	1.7	3.5	1.9	3.1	2.2	2.9

Table 17 – PAH values of emissions sampled during laying of base course mixtures (values in $\mu\text{g}/\text{m}^3$)



	Reference		Coarse		Ultrafine	
	D	S	D	S	D	S
Naphtalene	0.54	1.22	0.90	1.48	0.75	2.78
Acenaphthylene						
Naphthalene, 1-bromo-						
Acenaphthene					0.37	
Fluorene			0.16			
Phenanthrene						
Anthracene						
Fluoranthene	1.75	1.75	0.66	0.96	1.58	0.80
Pyrene	1.31	1.04	0.35	0.67	1.20	0.54
Triphenylene	0.07	0.07	0.03	0.05	0.17	0.05
Benz[a]anthracene	0.23	0.11	0.04		0.16	
Benzo[b]fluoranthene	0.66	0.24	0.05	0.21	0.26	0.17
Benzo[a]pyrene	1.52	0.65	0.14	0.44	0.56	0.32
indeno[1,2,3-cd]pirene	0.74	0.76			0.20	
dibenzo[a,h]antracene	0.35	0.67		0.04	0.21	0.16
Benzo[ghi]perylene	0.11	0.08				
Total PAHs	6.73	5.37	1.44	2.37	4.73	2.04
T laying (°C)	180	163	160	150	173	166
wind speed (km/h)	3.3	3.2	1.6	2.3	2.3	3.9

Table 18 – PAH values of emissions sampled during laying of wearing course mixtures (values in $\mu\text{g}/\text{m}^3$)



For more info, please contact:

Città Metropolitana di Torino

Arch. Agata Fortunato

Tel: +39 011 8616872

Fax: +39 011 8616730

Email: tyrec4life@cittametropolitana.torino.it
www.tyrec4life.eu

