Action 3.2

Technical specifications for the mix design and quality assurance of bituminous mixtures containing crumb rubber from ELTs

POLITECNICO DI TORINO

Project partners

With the contribution of

Introduction

These technical specifications were prepared as a result of investigation activities carried out in Action 3.2, focused on the characterization of bituminous mixtures containing crumb rubber from end-of-life tyres (ELTs). They were thereafter employed as part of Actions 4.1 and 4.2, the goal of which was to implement innovative paving technologies through the construction of full-scale test sections in the infrastructure network of the Città Metropolitana di Torino and of the city of Settimo Torinese.

Based on the results of Action 3.2, it was decided that trial sections would involve the production and laying of gap-graded mixtures (with the possibility of using viscosity-reduction additives) and of dense-graded mixtures.

Gap-graded mixtures are characterized by a non-continuous size distribution of aggregates which requires the presence of significant percentages of coarse and fine aggregates but only a small quantity of intermediate size particles. Such a composition promotes the formation of a stone-to-stone internal structure which allows mixtures to contribute to the distribution of stresses under loading, thus positively affecting pavement design. However, employed binder contents are typically higher than those of standard dense-graded mixtures. By selecting an adequate mixture formulation, residual voids can be limited, but rather than being finely distributed within the bulk material as in the case of standard dense-graded mixtures, they occur in the form less numerous, larger air inclusions. When placed as wearing courses, gap-graded mixtures provide a significant macro-texture to the final pavement surface, with a corresponding skid resistance performance which tends to improve in the initial phases of use as the exposed binder films covering coarse aggregates are gradually worn off by traffic.

Studies documented in literature have shown that due to the enhanced stiffness and elasticity properties of the binder phase, rubberized paving mixtures exhibit a superior field performance in terms of resistance to rutting and fatigue cracking, and can be positively for their aptitude in retarding reflective cracking. By employing aggregates of selected quality and by controlling mixture composition, skid resistance can be significantly improved. Moreover, significant benefits have been reported in terms of their noise abatement potential, of the order of 3-4 dB, which stems from the combined effects of mixture porosity and binder ductility. Finally, from an environmental point of view it has been proven that the total life cycle impact of rubberized mixtures of various types is lower than that of standard materials in terms of overall energy consumption and carbon dioxide emissions.

1. Prequalification

1.1 Aggregates

Aggregates shall be identified according to UNI EN 13043. In particular, coarse and fine aggregates will be associated to d/D codes, where d and D are the openings (in mm) of the bottom and top sieve, respectively. Each aggregate supply shall be accompanied by CE marking documents proving compliance to Appendix AZ of harmonized standard UNI EN 13043.

Acceptance criteria are differentiated for coarse aggregates, fine aggregates and filler.

Coarse aggregate may be constituted by particles obtained from crushing of quarry rocks or alluvional material, or by natural elements with sharp edges. Particles may be of different origin or petrographical nature, but in any case they shall satisfy requirements listed in Table 1. As an exception to UNI EN 13043, the use, as fine aggregates, of a single fraction with maximum size D equal to 4 mm, is permitted.

Fine aggregates shall be exclusively constituted by crushed particles, and they will satisfy requirements listed in Table 2.

Filler, mostly passing the 0.063 mm sieve, may come from the fine fraction of aggregates or may be constituted by rock powder (preferably calcareous), cement or hydrated lime. In any case its size distribution shall respect constraints indicated by UNI EN 13043 and it will satisfy requirements listed in Table 3.

For the purpose of acceptance, before commencement of works, the Contractor shall prove qualification of aggregates (coarse and fine) and filler by means of test certificates issued by an Official Laboratory.

Table 1 – Requirements for coarse aggregates.

	Standard	**Unit**	**Requirement**	**UNI EN 13043 category**
Resistance to fragmentation (Los Angeles)	UNI EN 1097-2	%	≤ 20	LA_{20}
Percentage of crushed surfaces	UNI EN 933-5	%	100	$C_{100/0}$
Maximum size	UNI EN 933-1	mm	20	-
Passing 0,063 mm sieve	UNI EN 933-1	%	≤ 1	f_1
Resistance to freeze-thaw	UNI EN 1367-1	%	≤ 1	F_1
Aggregate-bitumen affinity	CNR 138/92	-	0	-
Flakiness index	UNI EN 933-3	%	≤ 20	FL_{20}
Water absorption	UNI EN 1097-6	%	≤ 1,5	$WA_{24}2$
Polished stone value	UNI EN 1097-8	%	≥ 45	PSV_{45}

Table 2 – Requirements for fine aggregates.

	Standard	**Unit**	**Requirement**	**UNI EN 13043 category**
Sand equivalent	UNI EN 933-8	%	≥ 80	-
Quantity of crushed particles	CNR 109/85	%	100	-
Passing 0,063 mm sieve	UNI EN 933-1	%	≤ 10	f_{10}

Table 3 – Requirements for filler.

	Standard	Unit	Requirement	UNI EN 13043 category
Plasticity index	UNI CEN ISO/TS 17892-12	%	N.P.	-
Porosity of dry compacted filler (Rigden)	UNI EN 1097-4	%	28-45	$V_{28/45}$
Stiffening Power - filler/binder =1,5	UNI EN 13179-1	°C	≥ 8	$\Delta_{R\&B}$8/16
Passing 0,063 mm sieve	UNI EN 933-1	%	≥ 80	-

1.2 Crumb rubber from end-of-life tyres

Crumb rubber from end-of-life tyres shall respect general requirements given by ASTM D6114 (“Standard Specification for Asphalt-Rubber Binder”) and shall have a maximum particle size not greater than 1.18 mm (corresponding to the opening of sieve n. 16 in the ASTM series).

The Contractor shall produce all the documents proving certification of the employed crumb rubber, with a clear indication of size distribution determine by referring to the ASTM E-11 sieve series.

1.3 Asphalt rubber binder

The asphalt rubber binder will be obtained from base bitumen by means of the “wet” modification technology which requires the use of crumb rubber from end-of-life tyres. The percentage of crumb rubber will be equal to at least 15% (by weight of the total binder) and each binder supply will be accompanied by CE marking documents.

Base bitumen shall be characterized according to UNI EN 12591 and will be additionally subjected to preliminary chemical analysis for the assessment of composition expressed in terms of the relative percentages of saturates, aromatics, resins and asphaltenes (SARA analysis).

The Contractor shall produce all the necessary documents to describe, from a technical point of view, procedures adopted for plant-mixing of components and for curing of the modified binder. In particular, the effective percentage of crumb rubber employed during production shall be explicitly declared.

Upon request of the Director of Works, the Contractor shall submit samples of component materials (base bitumen and crumb rubber) and of the modified binder taken at the production plant.

The modified asphalt rubber binder shall satisfy requirements listed in Table 4.

For the purpose of acceptance, before commencement of works, the Contractor shall prove qualification of the asphalt rubber binder by means of test certificates issued by the Supplier or by an Official Laboratory. Based on the provided data, the Contractor shall also declare the temperature which it will adopt to mix the binder with aggregates during production of bituminous mixtures.

Table 4 – Requirements for asphalt rubber binder.

	Standard	Unit	Requirement
Penetration at 25°C	UNI EN 1426	dmm	25-75
Softening point	UNI EN 1427	°C	≥ 54
Resilience at 25 °C	ASTM D 3407	%	≥ 20
Dynamic viscosity at 175°C, (20 rpm)	UNI EN 13302	mPa·s	1500-5000
After RTFOT (UNI EN 12607-1)			
Volatility	UNI EN 12607-1	%	≤ 0,8
Residual penetration at 25°C	UNI EN1426	%	≥ 60
Softening point increase	UNI EN1427	°C	≤ 12

1.4 Viscosity-reduction additives

Viscosity-reduction additives may be employed in the design and production of bituminous mixtures containing asphalt rubber binders in order to reduce production temperatures and costs, reduce compaction temperature, and improve workability in adverse conditions.

Permitted additives may have powder of liquid form, but in any case they shall be added to asphalt rubber before production of bituminous mixtures. The Contractor shall produce the necessary documents to describe, from a technical point of view, characteristics of the selected additive and procedures adopted for its mixing with asphalt rubber. In particular, additive percentage and mixing temperature shall be clearly stated.

Upon request of the Director of Works, the Contractor shall supply samples of the employed additive.

The asphalt rubber binder (before being mixed with the additive) shall satisfy requirements listed in Table 4. Samples of asphalt rubber binder containing the additive (i.e. sampled after mixing) will be subjected to the same tests. However, in this case the only requirement will be relative to dynamic viscosity (evaluate at 20 rpm), which shall be comprised between 1500 and 5000 mPa·s at 155°C.

For the purpose of acceptance, before commencement of works the Contractor shall prove qualification of the additive by means of test certificates issued by the Supplier or by an Official Laboratory. Based on the provided data, the Contractor shall also declare the temperature which it will adopt to mix the asphalt rubber binder containing the additive with aggregates during production of bituminous mixtures.

2. Mix design

The combination of aggregates adopted for production of bituminous mixtures shall have particle size distributions contained in the acceptance bands reported in Table 5. These bands shall be employed for design thicknesses of the wearing course layer not smaller than 30 mm. For smaller thicknesses, the passing at the 12.5 mm sieve shall be equal to 100%.

The asphalt rubber percentage, by weight of aggregates and filler, shall be comprised between 8 and 9% for gap-graded mixtures and between 5.5 and 6.5% for dense-graded mixtures.

Table 5 – Acceptance bands of particle size distribution.

Sieve opening [mm]	Passing [%]	
	Gap-graded	Dense-graded
20	100	100
16	92-100	100
14	86-100	100
12.5	80-97	100
10	67-83	87-96
8	53-70	70-90
6.3	40-56	60-80
4	24-36	40-60
2	12-24	25-38
1	10-19	19-30
0.5	8-14	13-22
0.063	2-5	6-9

Composition of the design mixtures, expressed in terms of percentages of aggregate fractions, filler and asphalt rubber, shall be established on the basis of a preliminary laboratory study. In such a study, conditioning temperatures of all components during mixing shall be clearly stated.

Requirements for the design mixtures are given in Table 6. They refer to specimens compacted with the Marshall compactor (50 or 75 blows on each side, for gap-graded and dense-graded mixtures, respectively, as per UNI EN 12697-34). For each mixture subjected to analysis, tests shall be performed on at least 4 specimens. Compaction temperature shall be equal to 175°C. In the case of “warm” mixtures, prepared by employing an asphalt rubber binder containing a viscosity-reduction additive, compaction temperature shall be equal to 155°C.

Table 6 – Requirements for design mixtures.

	Standard	Unit	Requirement	
			Gap-graded	Dense-graded
Residual voids (all specimens)	UNI EN 12697-8	%	5 ÷ 8	3 ÷ 7
Marshall stability (Marshall specimens)	UNI EN 12697-34	kN	≥ 7	≥ 11
Marshall stiffness (Marshall specimens)	UNI EN 12697-34	kN/mm	1.5 ÷ 3.0	3.0 ÷ 4.5
Stability loss after 15 days of water immersion (Marshall specimens)	CNR n. 149/92	%	≤ 25	≤ 25

3. Acceptance

The Contractor shall submit to the Director of Works, before the commencement of works, composition of the design mixture, either of the standard or “warm” type. Each mixture shall be supported by documentation of preparatory studies, which will include results of experimental tests, performed by an Official Laboratory, proving possession of the required characteristics listed in previous sections.

At each variation of the characteristics of component materials, a new study shall be submitted to the Director of Works, including analyses of components and design mixture.

Once the design mixture will be accepted by the Director of Works, the Contractor shall adhere to it rigorously, adopting all the necessary measures in order to respect variability limits imposed to binder content and aggregate size distribution (listed in paragraph 5).

4. Production and laying

Bituminous mixtures shall be produced in fixed plants, kept in a perfect state of functioning in every part. In each plant, production will never be pushed beyond its effective potential in order to guarantee perfect drying of aggregates, uniform heating of mixtures and a satisfactory sieving for the reclassification of single aggregate fractions. Continuous plants (of the drum-mixer type) may be employed if the dosage of components is carried out by weight by means of adequate control equipment, the efficiency of which will be constantly controlled.

The plant will in any case guarantee uniformity of production and will be capable of producing mixtures with the same characteristics declared in the study presented for acceptance.

Each plant will be capable of heating the binder at the required temperature and with a uniform viscosity until mixing. It will also guarantee perfect control of binder dosage.

The area for aggregate storage shall be preliminarily arranged in order to eliminate the presence of clay-like substances and water ponding which may jeopardize aggregate cleanliness. Moreover, stockpiles shall be clearly separate and feeding to the plant shall be carried out with maximum care.

Mixing time shall be established as a function of the characteristics of the plant in order to guarantee a total and uniform covering of aggregates with the binder.

Temperatures of aggregates and binder at the time of mixing shall be equal to those declared by the Contractor during the prequalification phase (ref. paragraph 2). For the verification of these temperatures, all components of the plant shall be equipped with fixed thermometers perfectly in order and periodically subjected to calibration.

Humidity of aggregates at the exit from the drier shall be not greater than 0.25% by weight.

Before commencement of permanent works, a full-scale trial section will be constructed in an area with a length of at least 80 m and width of at least 3.5 m.

Before laying of the bituminous mixture, the surface of the underlying layer shall be subjected to accurate cleaning by means of mechanical brushing and any horizontal marking, if present, shall be removed. The surface shall then be treated, in order to guarantee sufficient bond with the wearing course layer, by applying a tack coat bituminous emulsion.

Laying of the bituminous mixture shall be carried out by employing paving machines in a perfect state of efficiency and equipped with self-levelling mechanisms. Speed of laying shall never be greater than 3-4 /min with a continuous mixture feeding.

The layer shall be placed in a single lift, limiting interruptions and avoiding manual correction of anomalies.

In order to avoid quick cooling of the mixture, laying shall be interrupted in the case of ambient temperature lower than 15°C. For the same reason, in case the pavers are stopped or not fed for 15 minutes, they shall be removed from the paving area in order to allow thorough compaction.

The damaged bituminous mixture, if any, shall be immediately removed and will be laid again by the Contractor.

The paver shall in any case leave a finished layer with the required level and evenness, with no raveling and cracking and with no visible segregation of coarser particles.

During laying, maximum care will be taken in constructing longitudinal joints, preferably obtained by an immediate construction of adjacent strips. If the edge of strips shall be observed to be damaged or rounded, they will be subjected to mechanical cutting by employing adequate equipment.

Transverse joints which originate from daily interruptions shall be subjected to cutting and removal of the terminal part of the laid mixture.

Superposition of longitudinal joints with those of underlying layers shall be scheduled in order to guarantee an offset of at least 20 cm and it will be ensured that they will never fall in the two tracks of the slow lane which are normally subjected to heavy vehicle loading. Exceptionally, the edge of the strip may be heated by means of an infrared system mounted on the paver.

Transport of mixtures from the production plant to the laying site shall be carried out by means of trucks with an adequate capacity, efficient and fast, and in any case always equipped with coverings in order to avoid excessive cooling and formation of surface crusts.

Temperature of mixtures at the time of laying, controlled immediately after the paver, shall always be not lower than 175°C. Such a threshold temperature will be equal to 155°C in the case of “warm” mixtures containing viscosity-reduction additives.

Compaction shall start immediately after the paver and will be carried out with no interruptions. It shall be performed by means of a static roller of adequate type and weight in order to guarantee achievement of the desired void content and the smooth finishing of joints and restarts. Care shall be taken in order to perform compaction with the most adequate methodology to ensure uniform densification in every point and to avoid cracking and horizontal displacement of the newly-laid course.

Mixtures shall be laid after it has been verified by the Director of Works that the underlying layer is characterized by level, evenness, density and bearing capacity specified by design.

5. Control

Quality control of bituminous mixtures and of their laying shall be carried out by means of laboratory tests on component materials, on mixtures sampled in the loose state during laying, on cores extracted from the compacted layer and by means of tests performed on the finished pavement.

Location and frequency of tests are listed in Table 7. Each sampling operation will be performed with double replicates: one sample will be used to perform control tests in the laboratory, while the other will be kept in storage for further verifications, if needed. Storage of samples will be carried out in such a way not to alter them in time.

Requisites indicated in the following shall be satisfied during control tests performed during execution of trials sections and during permanent works.

In case requisites are not met for the trial section, it will be repeated with adequate modifications of component materials, job mix formula and/or laying and compaction techniques.

In case requisites are not met for permanent works, compacted layers will be removed and construction will be repeated.

Component materials will satisfy requirements listed in paragraph 1.

For the bituminous mixture, tests will be carried out for the determination of binder content, size distribution of extracted aggregates and volumetric and mechanical properties of compacted specimens (Marshall compactor).

In the case of aggregate size distribution, absolute variations of single percentages passing individual sieves with respect to design values will be limited within 3% for coarse aggregate (diameter greater than 2 mm), within 2% for fine aggregate (diameter smaller than 2 mm) and within 1.5% for filler. In any case, constraints indicated in paragraph 2 for total aggregate size distribution shall be satisfied.

In the case of binder content, absolute variations with respect to the design value will be limited within 0.25%. In any case, constraints indicated in paragraph 2 shall be satisfied.

In the case of volumetric and mechanical properties of compacted specimens (Marshall compactor), constraints indicated in Table 6 shall be satisfied.

In case requirements are not met for binder content, aggregate size distribution and volumetric and mechanical properties of compacted specimens, compacted layers will be removed and construction will be repeated.

As a supplement to control tests described above, by making use of adequate mixture samples taken from the paver, performance-related tests will be carried out and corresponding results will be used for structural-related evaluations.

In particular, tests will be carried out on roller-compacted slabs (as per UNI EN 12697-33) for the evaluation of accumulation of permanent deformation at 40 and 60°C (as per UNI

EN 12697-22). Slabs will be prepared at the same density measured on cores taken from the compacted layer.

In order to verify compaction achieved on site, density measurements will be performed on cores taken from the finished layer. For each laid mixture (even in more than one working day), density in at least 95% of measurement points shall not be smaller than 98% of the reference value measured in the laboratory on the design mixture. Such a reference value shall be indicated in the mixture study of the Contractor submitted before commencement of works to approval and acceptance of the Director of Works (ref. paragraph 3).

With respect to surface evenness, the finished layer of gap-graded mixture shall be perfectly planar, with deviations from design levels not greater than 3 mm. These shall be verified by means of a rigid bar of 4 m of length positioned in two orthogonal directions (as per UNI EN 13036-7).

In case such a requirement is not met, compacted layers shall be removed and construction will be repeated.

Verification of layer thickness will be carried out by means of direct measurements on cores taken from the finished and compacted layer. The Director of Works may require to supplement these measurements with surveys performed by employing a Ground Penetrating Radar (GPR). In such a case, in order to guarantee a sufficient reliability to measurements, the Director of Works will define a testing plan for GPR and the necessary coring calibration campaign.

No thickness shortage is admitted. In case thickness should be smaller than the design value, the compacted layer shall be removed and construction will be repeated.

Surface texture and skid resistance of the finished and compacted layer shall be evaluated as per UNI EN 13036-1 and UNI EN 13036-4, respectively. Measurements shall be performed in a time period comprised between the 15th and 180th day after opening to traffic. For each section associated to a working day and to an individual mixture, mean value of mean texture depth (MTD) shall be not smaller than 0.6 mm, while the value of Pendulum Test Value (PTV) shall be not smaller than 60.

The Director of Works may require the execution, on the finished pavement, of tests for the evaluation of bearing capacity characteristics by means of the Falling Weight Deflectometer (FWD). The corresponding back-calculation activities, for the calculation of elastic moduli of individual pavement layers, shall take into account effective layer thicknesses. These will be derived from GPR surveys, the use of which shall be supplemented by an adequate number of calibration cores.

Table 7 – Location and frequency of sampling and testing.

SAMPLE TYPE	LOCATION	FREQUENCY	
Coarse aggregate	Plant	Initial or at each supplier change	ref. Table 1.
Fine aggregate	Plant	Initial or at each supplier change	ref. Table 2.
Filler	Plant	Initial or at each supplier change	ref. Table 3.
Binder	Plant	Initial and daily	ref. Table 4..
Bituminous mixture	Paver	Daily	Binder content; Size distribution of extracted aggregates; Volumetric and mechanical characteristics of laboratory-compacted specimens.
Cores	Compacted layer	Daily and at least every 200 m.	Thickness; Density.
-	Compacted layer	Daily and at least every 200 m.	Surface roughness.
-	Compacted layer	Daily and at least every 200 m.	Macro-texture (MTD); Skid resistance (PTV).
Note: Frequency and location of samping and testing in the case of the site trial will be defined by the Director of Works.			

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