SIGNUS Ecovalor, S.L.

C/ Caleruega, 102, 5ª
28033 Madrid
T: +34 91 768 07 66
info@signus.es

www.signus.es

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Guide for the Production and Laying of Rubberised Asphalt Paving Mixtures

Authors

Juan Gallego Medina
Full Professor,
Universidad Politécnica de Madrid

Leticia Saiz Rodríguez
Development and Innovation Manager,
SIGNUS Ecovalor

Roberto Pérez Aparicio
Development and Innovation Technician,
SIGNUS Ecovalor

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OUTLINE

SIGNUS Ecovalor is a non-profit organisation created as a mechanism for all those tyre manufacturers and importer/producers who wish to comply with the legal obligations related to the end of life tyres management.

The aim of SIGNUS is to guarantee the correct treatment of end of life tyres (ELT), from their generation until they are converted into valuable raw material; maximized through the development of new applications and new markets, one of the most important the asphalt mixtures.

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Acknowledgements

Following the remarkable acceptance and impact of the "Guide for the Production of Rubberised Binders" published in 2014, both at a national and international level, SIGNUS wished to count on the professionalism, knowledge and experience in rubberised asphalt mixtures of the Road Laboratory at the Universidad Politécnica de Madrid to carry out the experimental work and elaboration of this document within the agreement signed between SIGNUS and the Agustín de Betancourt Foundation.

Similarly, SIGNUS appreciates the contribution of all those professionals who indirectly have provided first-hand information for this Guide based on their experience regarding these types of asphalt mixtures.

Finally, SIGNUS would like to thank all those who have shown interest and who have selflessly helped to promote the last "Guide for the Production of Rubberised Binders", hoping that this new document will also become a valuable and useful tool for the market.

Guide Presentation

1

The use of crumb rubber[1] for roads is a usual technique, well consolidated in our country and therefore has played a pioneering role in the production of these asphalt mixtures. Over the last few years, the Ministry of Public Works and Transport and CEDEX have endeavoured to standardise the use of crumb rubber in road surfaces as well as working with different research agencies and related companies in order to achieve the technical viability of rubberised binders.

Nevertheless, the use of these binders has not been as extensive as was expected and therefore it is clear that the knowledge regarding these materials is clearly insufficient.

In order to bridge this gap, in the year 2014 SIGNUS published the "Guide for the Production of Rubberised Binders", together with the guidance of Juan Gallego, Professor at the Civil Engineering School of the Universidad Politécnica de Madrid (UPM). In this guide we presented the main aspects that need to be known by companies that wish to produce these binders in a simple and direct manner.

However, an additional effort is required in order to increase the knowledge and confidence of the public administration and production companies. It is necessary to explain clearly and concisely how the different types of asphalt mixtures are dosed, produced, and layed, as well as the details of their quality control when crumb rubber is incorporated.

"The knowledge regarding rubberised asphalt mixtures is still insufficient"

(1) Throughout this Guide, the authors use indistinctly the term ELT powder or crumb rubber in reference to the rubber powder obtained from the transformation process of end of life tyres (ELT).

Spain is approaching circumstances where the reparation and rehabilitation of the extensive road network will be unavoidable. The rubberised asphalt mixtures are ideal for conservation due to the flexibility, adhesiveness and costs. Consequently, this is the precise moment to publish this "Guide for the Production and Laying of Rubberised Asphalt Paving Mixtures" and lay out in a simple and direct manner the particularities of these types of asphalt mixtures and particularly regarding design, production, laying and compaction of the pavement layers and the final quality control.

In this sense, and continuing with the previous guide, a series of types of asphalt mixtures have been defined. These types, as a whole, constitute more than 90% of the asphalt mixtures that are usually employed in Spain. The aim of the Guide is to produce them with rubber at a laboratory scale and verify the compliance of the specifications from the Technical Specifications for Road Works and Bridges (PG-3) established by the Spanish Ministry of Public Works and Transport.

This document intends to provide a tool that may answer all those possible doubts regarding rubberised asphalt mixtures that professionals in different fields can have nowadays. In this way, the aim is to increase the use of rubberised asphalt mixtures and ensure that users comply with the additional requirements established in the strategic Plan regarding waste 2016-2022 by MAPAMA, as well as the politics of development and sustainability of economic activity promoted by the Circular Economic Package created by the European Union. SIGNUS, which is editing this Guide, is a non-profit organization formed with the primordial purpose of guaranteeing the correct management of end of life tyres (ELT) collected in Spain.

Reinigung von Form und Walzsegment:
KEINE Lösemittel !
STOP
Cleaning of Mould and Sector:
No Solvents !

Regulatory Framework for Rubberised Asphalt Mixtures in Spain

2

Spain has achieved noteworthy breakthroughs regarding the specifications of binders and asphalt mixtures with end of life tyre crumb rubber. The first milestone in the standardisation of rubberised asphalt mixtures was the "Manual de Empleo de Caucho de NFU en Mezclas Bituminosas (2007)" (Manual for the Use of ELT Crumb Rubber in Asphalt Mixtures), drafted by CEDEX on behalf of the Ministry of Environment and the Ministry of Public Works and Transport. That document outlined the three types of rubberised binders that are considered of interest in the Spanish panorama regarding asphalt mixtures.

In that document, the authors defined in increasing modification order; rubber enhanced (BC), rubber modified (PMBC) and high viscosity rubber modified binders (BMAVC). These all binders contain crumb rubber from ELT. In the same document, recommendations were made regarding the use of the different types of rubberised binders in asphalt concrete (AC), gap-graded (BBTM A, BBTM B), drainers (PA) and anti-reflective cracking mixtures.

The manual elaborated by CEDEX also examined the rubberised asphalt mixtures produced by the dry process, indicating the importance of the digestion process in order to guarantee the optimal performance of the asphalt mixture.

Following the previous publications, the Circular Orders 21/2007 and 21bis/2009 constituted the first regulation document of obligatory compliance regarding works by the Ministry of Public Works and Transport. These documents make reference to the technical specifications of rubberised binders (Tables 1 and 2) and handling at the worksite, as well as guiding indications concerning the most suitable type of rubberised asphalt mixtures depending on the project in hand and necessary requirements. When it comes to dry process, perhaps the most noteworthy information is that the use of this process is limited to roads with a medium or low traffic flow.

Characteristics		Reference Standard	Unit	BC35/50	BC50/70
Original bitumen					
Needle penetration at 25°C		EN 1426	0.1 mm	35-50	50-70
Softening point - Ring and Ball method		EN 1427	ºC	≥ 58	≥ 53
Fragility point Fraass		EN 12593	ºC	≤ -5	≤ -8
Force-ductility (5 cm/min)	5ºC	EN 13589 EN 13703	J/cm^2	≥ 0.5	
Elastic recovery at 25°C		EN 13398	%	≥ 10	
Storage stability (*)	Softening point difference	EN 13399	ºC	≤ 10	
	Penetration difference		0.1 mm	≤ 8	≤ 10
Solubility		EN 12592	%	≥ 92	
Flash point open cup		EN ISO 2592	ºC	≥ 235	
Durability - Resistance to RTFOT EN 12607-1					
Mass variation		EN 12607-1	%	≤ 1.0	
Retained penetration		EN 1426	% o.p.	≥ 65	≥ 60
Softening point variation		EN 1427	ºC	min -4, max +8	min -5, max +10

(*) Exclusively for binders not produced "in situ"

Table 1. Spanish specifications for rubber enhanced binders (BC)

<table>
<tr><th colspan="2">Characteristics</th><th>Reference Standard</th><th>Unit</th><th>BMAVC-1</th><th>BMAVC-2</th><th>BMAVC-3</th></tr>
<tr><td colspan="7">Original bitumen</td></tr>
<tr><td colspan="2">Needle penetration at 25°C</td><td>EN 1426</td><td>0.1 mm</td><td>15-30</td><td>35-50</td><td>55-70</td></tr>
<tr><td colspan="2">Softening point - Ring and Ball method</td><td>EN 1427</td><td>°C</td><td>≥ 75</td><td>≥ 70</td><td>≥ 70</td></tr>
<tr><td colspan="2">Fragility point Fraass</td><td>EN 12593</td><td>°C</td><td>≤ -4</td><td>≤ -8</td><td>≤ -15</td></tr>
<tr><td rowspan="2">Force-ductility (5 cm/min)</td><td>5°C</td><td rowspan="2">EN 13589
EN 13703</td><td rowspan="2">J/cm^2</td><td>-</td><td>≥ 2</td><td>≥ 3</td></tr>
<tr><td>10°C</td><td>≥ 2</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Consistency (Floater, 60°C)</td><td>NLT 183</td><td>s</td><td colspan="3">≥ 3000</td></tr>
<tr><td rowspan="2">Dynamic viscosity</td><td>135°C</td><td rowspan="2">EN 13302</td><td rowspan="2">mPa·s</td><td></td><td>≤ 7500</td><td>≤ 5000</td></tr>
<tr><td>170°C</td><td>≥ 2000</td><td>≥ 1200</td><td>≥ 800</td></tr>
<tr><td>Elastic recovery</td><td>25°C</td><td>EN 13398</td><td>%</td><td>≥ 10</td><td>≥ 20</td><td>≥ 30</td></tr>
<tr><td rowspan="2">Storage stability (*)</td><td>Softening point difference</td><td rowspan="2">EN 13399</td><td>°C</td><td colspan="3">≤ 5</td></tr>
<tr><td>Penetration difference</td><td>0.1 mm</td><td colspan="3">≤ 20</td></tr>
<tr><td colspan="2">Flash point open cup</td><td>EN ISO 2592</td><td>°C</td><td colspan="3">≥ 235</td></tr>
<tr><td colspan="7">Durability - Resistance to RTFOT EN 12607-1</td></tr>
<tr><td colspan="2">Mass variation</td><td>EN 12607-1</td><td>%</td><td>≤ 0.8</td><td>≤ 0.8</td><td>≤ 1.0</td></tr>
<tr><td colspan="2">Retained penetration</td><td>EN 1426</td><td>% o.p.</td><td colspan="3">≥ 60</td></tr>
<tr><td colspan="2">Softening point variation</td><td>EN 1427</td><td>°C</td><td colspan="2">min -4, max +10</td><td>min -5, max +12</td></tr>
</table>

(*) Exclusively for binders not produced "in situ"

Table 2. Spanish specifications for high viscosity rubber modified binders (BMAVC)

After the publication of the Manual, a series of projects have been carried out including rubberised asphalt mixtures by the wet and the dry process. This experience was collected and explained in the Spanish General Specifications PG-3, published in the FOM/2523/2014, 12 December. Beginning with the preamble, the reasons for updating the legislation are explained including "The incentive to make use of the recycled material from pavement layers and the inclusion of binders with crumb rubber obtained from ELT for sustainability reasons and environmental protection".

Among the most noteworthy contents of the document regarding rubberised binders, in article number 212 which refers to specifications of polymer modified binders (PMB), it is established that "when the polymer used primarily for the production of modified binder is ELT crumb rubber, the denomination must be followed by a capital C", that is to say, they must comply with the same technical specifications as the polymer modified binders, but the use of crumb rubber in the modification of the binder must be indicated with the letter C at the end (Table 3). Similarly, the technical specification table clarifies that the storage stability characteristics are not required to the in-situ modified binders.

Characteristics		Reference Standard	Unit	PMB 10/40 -70C	PMB 25/55 -65 C	PMB 45/80 -60 C	PMB 45/80 -65C	PMB 45/80 -75 C	PMB 75/130 -60 C
Needle penetration at 25°C		EN 1426	0.1 mm	10-40	25-55	45-80	45-80	45-80	75-130
Softening point - Ring and Ball method		EN 1427	°C	≥ 70	≥ 65	≥ 60	≥ 65	≥ 75	≥ 60
Force-ductility (5 cm/min)		EN 13589 EN 13703	J/cm²	≥ 2 to 15°C	≥ 2 to 10°C	≥ 2 to 5°C	≥ 3 to 5°C	≥ 3 to 5°C	≥ 1 to 5°C
Fragility point Fraass		EN 12593	°C	≤ -5	≤ -7	≤ -12	≤ -15	≤ -15	≤ -15
Elastic recovery at 25°C		EN 13398	%	TBR	≥ 50	≥ 50	≥ 70	≥ 80	≥ 60
Storage stability (*)	Softening point difference	EN 13399 EN 1427	°C	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
	Penetration difference	EN 13399 EN 1426	0.1 mm	≤ 9	≤ 9	≤ 9	≤ 9	≤ 13	≤ 13
Flash point open cup		EN ISO 2592	°C	≥ 235	≥ 235	≥ 235	≥ 235	≥ 235	≥ 220
Durability - Resistance to RTFOT EN 12607-1									
Mass variation		EN 12607-1	%	≤ 0.8	≤ 0.8	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Retained Penetration		EN 1426	%	≥ 60	≥ 60	≥ 60	≥ 60	≥ 60	≥ 60
Softening point increase		EN 1427	°C	≤ 8	≤ 8	≤ 10	≤ 10	≤ 10	≤ 10
Softening point decrease		EN 1427	°C	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5

(*) Exclusively for binders not produced "in situ"

TBR: To be reported

Table 3. Spanish specifications for rubber modified binders

Regarding this Guide, the most important articles contained in the PG-3, are articles 542 and 543, which respectively refer to specific asphalt concrete mixtures AC (Tables 4 and 5), gap-graded mixtures (BBTM A and BBTM B) and porous mixtures (PA) (Table 6). In the binder selection, it is clearly indicated that when crumb rubber is incorporated, the standard specifications must be met. Specifications for rubberised asphalt paving materials in Spain can be found in OC 21/2007 and 21bis/2009 by the Ministry of Public Works and Transport.

<table>
<tr><th rowspan="2">SUMMER THERMAL ZONE</th><th colspan="6">HEAVY TRAFFIC CATEGORY</th></tr>
<tr><th>T00</th><th>T0</th><th>T1</th><th>T2 and T31</th><th>T32 and hard shoulder</th><th>T4</th></tr>
<tr><td>WARM</td><td colspan="2">35/50
BC35/50
PMB 25/55-65
PMB 45/80-65
PMB 25/55-65 C
PMB 45/80-65 C</td><td>35/50
BC35/50
PMB 25/55-65
PMB 45/80-60
PMB 45/80-65
PMB 25/55-65 C
PMB 45/80-60 C
PMB 45/80-65 C</td><td>35/50
50/70
BC35/50
BC50/70
PMB 45/80-60
PMB 45/80-60 C</td><td>50/70
BC50/70</td><td rowspan="3">50/70
70/100
BC50/70</td></tr>
<tr><td>MEDIUM</td><td colspan="2">35/50
BC35/50
PMB 45/80-60
PMB 45/80-65
PMB 45/80-60 C
PMB 45/80-65 C</td><td>35/50
50/70
BC35/50
BC50/70
PMB 45/80-60
PMB 45/80-60 C</td><td>50/70
BC50/70
PMB 45/80-60
PMB 45/80-60 C</td><td rowspan="2">50/70
70/100
BC50/70</td></tr>
<tr><td>MODERATE</td><td colspan="2">50/70
BC50/70
PMB 45/80-60
PMB 45/80-65
PMB 45/80-60 C
PMB 45/80-65 C</td><td colspan="2">50/70
70/100
BC50/70
PMB 45/80-60
PMB 45/80-60 C</td></tr>
</table>

Table 4. Type of asphalt binders to be used in wearing course and following (Article 542 from Spanish General Specifications PG-3)

<table>
<tr><th rowspan="2">SUMMER THERMAL ZONE</th><th colspan="4">HEAVY TRAFFIC CATEGORY</th></tr>
<tr><th>T00</th><th>T0</th><th>T1</th><th>T2 and T3</th></tr>
<tr><td>WARM</td><td colspan="2" rowspan="2">35/50
BC35/50
PMB 25/55-65
PMB 25/55-65 C</td><td rowspan="2">35/50
50/70
BC35/50
BC35/70</td><td>50/70
BC50/70</td></tr>
<tr><td>MEDIUM</td><td>50/70
70/100
BC50/70</td></tr>
<tr><td>MODERATE</td><td colspan="3">50/70
70/100
BC50/70</td><td>70/100</td></tr>
</table>

Table 5. Type of asphalt binders to be used as a base layer, below another two (Article 542 from Spanish General Specifications PG-3)

TYPE OF ASPHALT MIXTURE	HEAVY TRAFFIC CATEGORY				
	T00 and T0	T1	T2(*) and T31	T32 and hard shoulder	T4
GAP-GRADED	PMB 45/80-65 **PMB 45/80-65 C**	PMB 45/80-65 PMB 45/80-60 **PMB 45/80-65 C** **PMB 45/80-60 C**	PMB 45/80-60 **PMB 45/80-60 C** 50/70 **BC50/70**	50/70 70/100 **BC50/70**	
POROUS	PMB 45/80-65 **PMB 45/80-65 C**	PMB 45/80-65 PMB 45/80-60 **PMB 45/80-65 C** **PMB 45/80-60 C**	PMB 45/80-60 **PMB 45/80-60 C** 50/70 **BC50/70**	50/70 70/100 **BC50/70**	

Table 6. Type of hydrocarbon binder to be used (Article 543 from Spanish General Specifications PG-3)

(*) For T2 traffic modified binders are to be used for highways or when ADT is above 5,000 vehicles/lane.

Beyond compliance with these technical specifications, articles 542 and 543 of the PG-3 promote the incorporation of crumb rubber: "According to section 8 in the General Plan for Waste Material 2008-2015 approved by the Spanish Council of Ministers, 26 December 2008, the use of crumb rubber from ELT will be promoted as long as it is technically and economically viable."

Ultimately, it may be said that the present Spanish regulations recommend the use of rubberised binders for all applications where binders without rubber are presently used. The enhanced binders are assimilated to net bitumens; rubber and polymer modified binders are equated to polymer modified binders (PMB), and high viscosity rubber modified binders, that were not previously approved in the regulations, are recommended for use in high performance projects.

Rubberised asphalt mixtures produced by the dry process are allowed for medium or light traffic roads until further information is available.

Although at the time of publication of the Spanish version of this Guide, Stone Matrix Asphalt (SMA) mixes were not included in the Spanish specifications, the provisional specifications proposed by CEDEX was followed in this Guide. The document available at present that is nearest to SMA specifications was elaborated and proposed by CEDEX in the year 2013.

Finally, according to the OC 21/2007 the anti-cracking asphalt mixtures produced with binders BMAVC are ideal for rehabilitation works where resistance to reflection cracking is required. As they don´t have specific grading in the Spanish legislation, for the design of this type of mixtures the Guide has considered the previous experiences in Spain.

Taking the aforementioned legislation frame as a reference, the actual Guide covers a series of points regarding design, production, laying and quality control of rubberised asphalt mixtures. This approach will help the pavement engineer to meet the requirements of the legislation, including wet and dry processes in all types of mixtures.

Effects of Rubber on Asphalt Mixtures

3

It is generally accepted that rubber acts as a rheology modifier of asphalt binders, in a similar way as polymers work.

During the wet process or the dry process, a digestion of the rubber particles takes place, as shown in Figure 1. Moreover, this occurs to a greater extent in the wet process.

In the following sections the differences between both processes in terms of rubber-bitumen interaction are detailed.

3.1 Effect of crumb rubber incorporated by the wet process as a binder modifier

The wet process consists of a highly energetic mixing process of bitumen and crumb rubber at a temperature of 185 y 195°C. This is carried out during a time period that guarantees the digestion process (approximately 60 minutes). The most important factors involved in this process are: temperature, energy, mixing time, aromatic content in the bitumen, rubber particle size and natural rubber content.

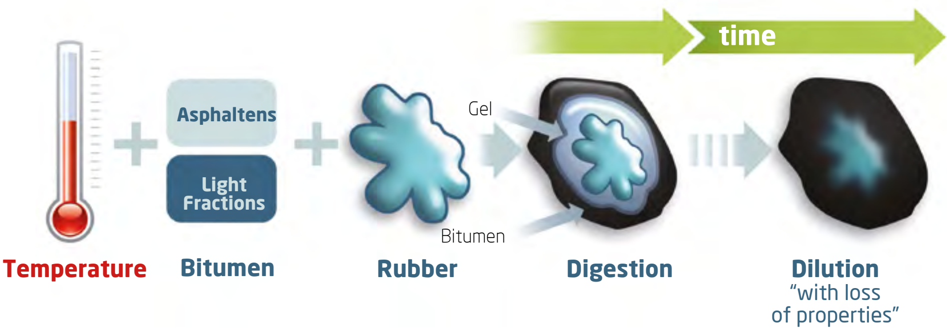


Figure 1. Evolution of the interaction bitumen-rubber

This process of adding crumb rubber to the bitumen noticeably improves the rheology of the mixture and reduces susceptibility to temperature and increases elasticity.

The Guide for the Production of Rubberised Binders published by Signus in the year 2014, explained the different modification levels that are possible according to the Asphalt Binders´ Spanish specifications. Rubber may be used as an exclusive modifier or combined with polymers to reduce its contents and therefore reduce the cost of the modified binder.

Once the bitumen has been modified with crumb rubber by the wet process, it can be used for the production of asphalt mixtures which enhanced performance.

3.2 Effect of crumb rubber incorporated by the dry process: elastic aggregate and partial binder modifier

The dry process consists of the addition of crumb rubber during the production process of the asphalt mixture as if it was a fraction of fine aggregate.

Until recently, the separation between the dry process and the wet process was considered clearly distinctive. The first method used the rubber as a modifier of the binder while the second method was employed as an elastic aggregate. However, the work carried out in the laboratory has demonstrated that if a digestion period is allowed to the asphalt mixture, the rubber added using the dry method loses part of its elastic performance and may perform partially as a binder modifier.

In fact, during the transport and laying procedures of the asphalt mixture, the crumb rubber is in contact with the asphalt bitumen at a temperature of 150-160ºC and, simultaneously as it loses the elastic properties, a partial modification of the asphalt bitumen takes place.

Hereafter an example of the behaviour of the crumb rubber in dry process is shown in function of digestion time. The influence on compaction is measured. In this case, it is a rubberised asphalt mixture with 1.5% crumb rubber. The digestion periods tested at laboratory were 60, 120, and 240 minutes, during which time the uncompacted asphalt mixture was kept at 150ºC[2].

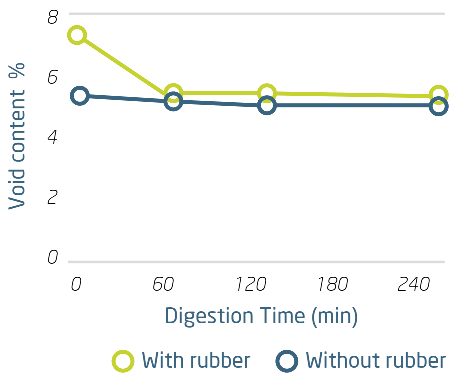


Figure 2. Evolution of compaction with digestion time by the dry process

The longer the digestion time, the lower the air void content of the asphalt mixture. If the digestion period continues for over one hour there are no additional improvements regarding compaction.

These results seem to indicate that during the first hour of digestion the rubber particles lose part of the elastic properties that encumber compaction. The voids in the reference mixture hardly depend on time in the oven, that reveals the remarkable

(2) "Mezclas bituminosas modificadas por adición de polvo de neumáticos". J. Gallego. CEDEX (2001). ISBN: 84-7790-363-8

variation of void content registered in the rubberised asphalt mixture as a function of the digestion time.

The following example (Figure 3) also indicates a partial modification of the recovered binder. In the following graph, the longer the digestion time, the higher the softening point. Nevertheless, the increase of softening point is higher for the binder recovered from the asphalt mixture by the dry process.

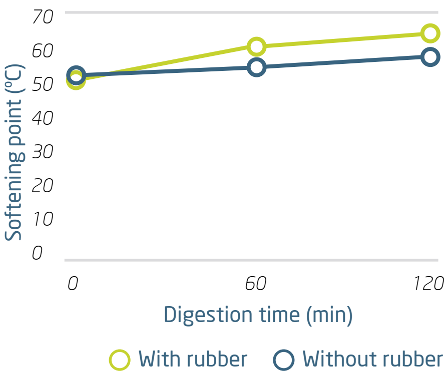


Figure 3. Evolution of the bitumen´s softening point with the digestion time by the dry process

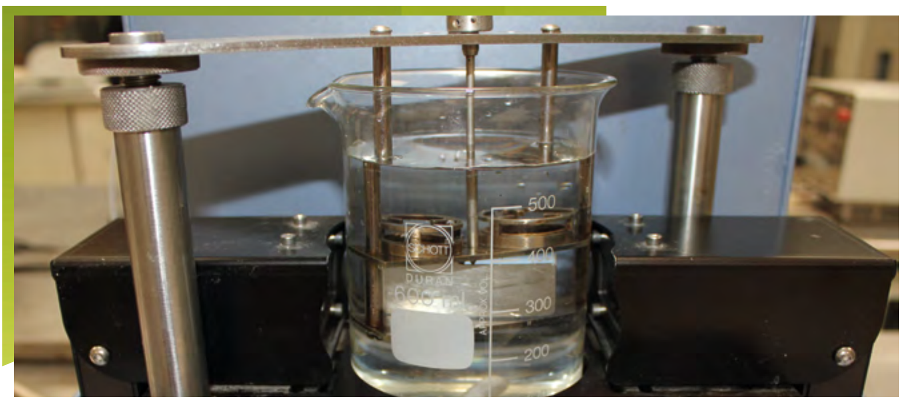
Nevertheless, this modification does not reach the levels obtained using the wet process due to the fact that the interaction bitumen-rubber does not include the high energy stirring used in the wet process. Even the aggregates with their absorption compete with the rubber particles for the bitumen.

3.3 Characteristics of the crumb rubber used for asphalt mixtures

Regarding the properties of the ELT crumb rubber used, the most important factor is its particle size distribution. Generally speaking, coarser gradings slow down the rubber-bitumen interaction and accentuate the settlement (wet process) and compaction difficulties. Continuous gradings are advisable and a maximum particle size of 0.8 mm is suitable for the wet process and 0.5 mm for the dry process.

The chemical composition of the rubber will also influence the final characteristics. The control parameter should be the percentage of the elastomeric fraction, as well as the natural rubber content. High values are preferable in the case of both parameters.

Finally, it is important to consider the milling method used: at room temperature or cryogenic. As a rule, it is advisable to mill at room temperature, as it provides the rubber particles with higher specific surface area. Moreover, rubber grounded at room temperature is more commonly available in the market.



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Design of Rubberised Asphalt Mixtures

4

The usual components for asphalt mixtures are aggregates, mineral powder, and a hydrocarbon binder. The different combinations of these components enable the manufacture of several types of asphalt mixtures, each one particularly suited for a specific application.

The design process begins with the choice of asphalt mixture, the most adequate aggregates, the type of mineral powder, the grading for the mineral particles and type of binder. Once these decisions have been made, the dosage process begins in the laboratory where production and testing will take place until the optimal composition is found.

The result is a working formula that contains the optimal proportion of each component as well as relevant information regarding production temperature and compaction. This will also be completed with characteristics of the asphalt mixture: density, void content, water resistance, plastic deformation and other information that may be of interest.

Probably the asphalt mixtures prepared for the wearing course are the ones with the highest performance features. These are in direct contact with the traffic load and they are particularly vulnerable to weather conditions: rain, temperature variations, etc. Therefore, the materials used to manufacture these, aggregates and binders, present superior features compared to the underlying layers. We are referring to porous asphalt mixtures (PA), gap-graded (BBTM), special anti-cracking mixtures and Stone Matrix Asphalt (SMA). In all cases, the aggregates should resist traffic polishing and the asphalt mixture shall resist water attack, rutting and if possible, cracking. In the case of open mixtures (PA and BBTM B) they also are required to allow rapid draining of rainwater toward the drains to prevent aquaplaning.

The rest of the layers provide the structural condition of the pavement, transmitting attenuated efforts to the subgrade. They need to be resistant to rutting and structurally robust, although in practice, it is common to use aggregates and binders that offer a slightly lower performance, due to the fact that the stress they receive and the weather agents that affect them are less intense. Generally speaking, these lower layers use asphalt mixtures of continuous grading, Asphalt Concrete (AC).

As seen in Chapter 3 the ELT crumb rubber may be incorporated by the dry process or the wet process. In the case of both wearing courses and lower layers the rubber introduces important properties that from a technical point of view allow the asphalt mixtures to comply the specialization required by each different layer. Therefore, the design of the mixtures should consider certain peculiarities regarding rubberised asphalt mixtures. Nevertheless, apart from this there are no major complications when including rubber in the asphalt mixtures.

This chapter focuses on the design process of rubberised asphalt mixtures and will specifically focus on the peculiarities regarding design and dosage to achieve the optimal results from the rubber.

4.1 Misconceptions regarding dosage of rubberised asphalt mixtures

Before giving certain guidelines regarding the design of asphalt mixtures, it is convenient to refute some ideas that are mistaken and often considered as generality:

- It is not correct to apply pre-existing working formulas to new rubberised asphalt mixtures. For example, if a plant normally produces an asphalt mixture such as AC 16 surf 50/70 S and starts to produce an AC 16 surf BC 50/70 S a complete laboratory design should be carried out, or at least all the tests required for AC mixtures should be checked so that the new properties of the asphalt mixture may be confirmed and thus, continue to comply with the specifications and also evaluate the effect the binder has had. In some cases, it may be necessary to make adjustments to the working formula without rubber. This example is applicable to all rubberised asphalt mixtures.

- Although it is true that when rubber is added the void content increases slightly, the void content is usually like mixtures without rubber. In any case the difference is only a few tenths and therefore the changes required are minimum or even unnecessary. When the presence of rubber means a significant increase in the void content, as recommended in this Guide, the production temperatures should be checked as well as the correct digestion of the rubber. This is particularly so in the case of dry process. Only in some cases it is necessary to adjust the grading ad hoc, in view of the laboratory results.

- It is necessary to point out that the rubberised asphalt mixtures can function correctly with the same binder content as the analogous mixtures, especially when using wet process. However, in the case of dry process, two tenths of the binder is usually added in order to ensure the same void content as those mixtures without rubber. Nevertheless, regarding mechanical performance, if digestion is completed it is usually not necessary to increase the binder content. However, the magnificent resistance to plastic deformation that rubberised asphalt mixtures provide, enables the increase of binder content to achieve a superior durability.

In any case, the dosage process in the laboratory should evince the properties of the mixture and define the most adequate working formula.

4.2 Grading and void content of rubberised asphalt mixtures

Rubberised binders retain a proportion of rubber particles that are not fully integrated into the bitumen. These particles maintain a certain elasticity. In dry process this phenomenon is more accentuated.

The presence of these particles may affect the final structure of the mineral skeleton because a new solid has been added (the rubber particles remaining non-integrated in the bitumen) and simultaneously these particles provide a certain elasticity which results in an obstacle during compaction for the optimal and long-lasting accommodation of the mineral particles. Indeed, it has been demonstrated that these rubber particles decompress the asphalt mixture after compaction if the temperature of the mixture allows certain mobility to the mineral particles.

However, the grading does not need to be adjusted due to the presence of rubber, at least in principle and as long as the rubber particle size distribution and content follows the recommendations in this Guide and the digestion process has been completed. This last aspect requires special attention when working by the dry process.

Hence, the grading of the asphalt mixture will correspond with the type of mixture being produced: AC, BBTM, SMA or anti-cracking. During dosage in the laboratory the void content percentage should be measured and therefore adjusted to the prescribed general characteristics depending on the type of mixture. If the void content percentage is higher than desired, the percentage of fine powder or binder may be increased as in the general case. However, before taking this step, the possibility of acting on the following crumb rubber parameters must be considered:

WET PROCESS:

- Revise the crumb rubber particle content in the binder and its viscosity.
- Increase by 5-10°C the manufacturing temperature of the asphalt mixture to improve the workability of the mixture.

DRY PROCESS:

- Reduce the rubber particle size distribution. The smaller the maximum size of the crumb rubber the easier the compaction.
- Reduce the rubber content of the asphalt mixture. The lower the crumb rubber content the easier the compaction.
- Check that the asphalt mixture has had enough time to digest the crumb rubber.
- Increase the manufacturing temperature by 5-10°C to facilitate the digestion of the rubber and workability of the mixture.

To minimize the compaction difficulties of rubberised asphalt mixtures, it is recommended to use a rubber particle size of 0-0.5 mm by the dry process and 0-0.8 mm by the wet process. Nevertheless, even in wet process, if the mixer has a limited energy capacity rubber particles sizes of 0-0.5 mm are advisable.

In the Annex I of this Guide an example of the most common formulations for rubberised asphalt mixtures is presented. The same grading and binder content with and without rubber has been used for every type of mixture, as shown in Table 7. The presence of rubber shows certain minor variations regarding the void content. Nevertheless, it has not been necessary to adjust the grading of the aggregates.

Type of asphalt mixture	Type of binder	Binder o/a (%)	Void content in mixture (%)		
			With no rubber	Wet process	Dry process
BBTM 11 A	PMB 45/80-60, PMB 45/80-60C	5.5	4.3	4.8	4.4
BBTM 11 B	PMB 45/80-65, PMB 45/80-65C	5.0	16.3	16.6	-
PA 11	PMB 45/80-65, PMB 45/80-65C	4.5	24.2	23.3	-
SMA 11	PMB 45/80-65+fibre, PMB 45/80-65C	6.2	4.5	4.8	4.8
ANTI-CRACKING	BMAVC-1	9.0	-	4.4	-
AC 16 surf S	50/70, BC 50/70	5.0	4.5	4.5	-
AC 22 bin S	50/70, BC 50/70	4.5	4.9	5.4	5.5
AC 32 base S	35/50, BC 35/50	4.5	6.4	6.7	-

Table 7. Void content in the asphalt mixture (%). Annex I

Nevertheless, and according to the engineer's criteria, the binder content may be increased slightly as the addition of crumb rubber stabilizes the mixture in regard with plastic deformation, which generally allows a small margin to increase the binder content (Annex 1).

4.3 Mixing and compaction temperatures

Manufacturing temperatures are fundamental regarding the coating process of the aggregates; so that the binder creates a film around them enhancing the bonding properties. It is important that all the aggregate is covered by the binder to achieve the mechanical resistance and water resistance desired. Higher temperatures favour this process.

In the case of rubberised asphalt mixtures, the manufacturing temperature is even more important. This is due to:

- In wet process, rubberised binders are more viscous than the binders without rubber and therefore require higher temperatures for an optimal coating of the aggregates. This is particularly true as the crumb rubber content in the binder increases.
- In dry method, crumb rubber needs to be digested. The temperature is maintained for around one hour as the digesting process evolves. Without enough temperature the digestion process will not take place.

For both reasons the rubberised asphalt mixtures require high temperatures.

In Annex I, different examples of dosage are shown. The manufacturing temperatures are summarised in Table 8 and may serve as a recommendation for each type of mixture.

Type of asphalt mixture	Type of binder	Binder o/a (%)	Temperature (°C)			
			With no rubber	Wet process	Dry process	
					Production	Digestion t> 90 min(*)
BBTM 11 A	PMB 45/80-60 PMB 45/80-60C	5.5	165	165	170	160
BBTM 11 B	PMB 45/80-65 PMB 45/80-65C	5.0	165	165	-	
PA 11	PMB 45/80-65 PMB 45/80-65C	4.5	165	165	-	
SMA 11	PMB 45/80-65+fibre PMB 45/80-65C	6.2	165	165	170	160
ANTI-CRACKING	BMAVC-1	9.0	-	175	-	-
AC 16 surf S	50/70 BC 50/70	5.0	160	165	-	
AC 22 bin S	50/70 BC 50/70	4.5	160	165	170	160
AC 32 base S	35/50 BC 35/50	4.5	160	165	-	

(*) to ensure rubber digestion

Table 8. Mixing or manufacturing temperatures of rubberised asphalt mixtures (°C). Annex I

As may be observed in Table 8, the manufacturing temperature for base bitumen was 160°C, for rubber enhanced and rubber/ polymer modified bitumens was 165°C and for rubberised asphalt mixtures by dry process was up to 170°C. Moreover, in this last example the mixture remained in an oven at 160°C for 90 minutes to ensure digestion.

Compaction temperatures were 10°C below manufacturing temperatures except for the dry process mixtures which were compacted at 5°C below the digestion temperature.

4.4 Trials for the elaboration of the working formula

The asphalt mixtures studied in this present Guide, together with the crumb rubber content recommended, should be formulated according to the usual procedures carried out in Spain and are stipulated in the following regulation:

	Type of asphalt mixture
Article 543 from PG-3	BBTM A BBTM B PA
Article 542 from PG-3	AC

Table 9. Technical specifications for each type of asphalt mixture

Regarding the SMA mixtures, at the date of this Guide´s publication, there are not Spanish specifications. However, there is a technical specifications sheet by CEDEX, called "Hot asphalt mixtures SMA (specification proposal)", and has been used in this Guide as a reference document until the specifications is officially approved by the Spanish administration. Lastly, the anti-cracking mixtures with BMVAC-1 have been formulated according to Spanish experience.

Hereafter, the principal properties of the asphalt mixtures and the testing standards are detailed.

4.4 1 Asphalt mixture properties and testing standards in the laboratory

The most elementary properties of an asphalt mixture are those called volumetric, especially concerning density and void content.

The density of an asphalt mixture has two variants: bulk density of the compacted mixture, that of the asphalt mixture including the remaining air voids (EN 12697-6) and the maximum density of the loose mixture, excluding the air voids and which is determined using a pycnometer (EN 12697-5). This last density is merely a theoretical concept and is useful for calculating the air void content in compacted mixtures (EN 12697-8). This is done using the apparent density value and the maximum density value with the pycnometer.

Density is a property that is not subject to specifications, particularly because its value varies considerably depending on the type of aggregate used without influencing behaviour of the asphalt mixture. Nevertheless, the air void content is of great importance: in AC mixtures a minimum content is stipulated to guarantee that during the warming period the binder may dilate and fill the air voids. However, in other mixtures such as BBTM B or PA a higher air void content is required to allow water circulation through the voids during rainy episodes and towards the drainage areas ensuring that the water does not accumulate on the road surface.

In any case, it is necessary to clarify that the air voids in the mixture must result from a robust compaction on the aggregate grading and the specific binder content conceived to achieve the void content and not as a result of insufficient compaction.

In the case of SMA mixtures, in addition to the above properties, two additional parameters, also volumetric, are considered: the content of voids in aggregates and the percentage of voids in aggregates filled with bitumen. The aggregate voids must be sufficient to accommodate the bitumen that will coat the aggregates and the air voids. The percentage of voids filled must allow space for the air voids that the bitumen will occupy when it expands in the summer season.

Once the formulation complies with the volumetric properties, the mechanical properties need to be studied.

In the case of AC mixtures, resistance to water action (EN 12697-12) and resistance to rutting (EN 12697-22) are studied. The first test determines the loss of adherence in the aggregate-binder interface which takes place due to saturation and water action. On the other hand, the aim of the tracking test is to determine the susceptibility of the asphalt mixtures to plastic deformation during summer. This causes rutting due to the performance of the material at high temperatures.

In the case of BBTM A and BBTM B mixtures, the aforementioned properties are also studied. However, the specifications of these types of mixtures are more demanding since the grading and position in the wearing course made them more vulnerable to water action. For the design of the anti-cracking asphalt mixture with high viscosity rubber modified binder bitumen (BMAVC-1), the same tests have been carried out.

In the case of PA mixtures, furthers tests are required: the Cantabro test (EN 12697-17) and the binder drainage test (EN 12697-18). The porous mixtures have a certain amount of mastic which makes them more vulnerable to disaggregation. For this reason, the Cantabro test is carried out. And precisely due to the high void content and limited sand there may be problems with binder drainage especially during transport. With this in mind, the asphalt mixture formulation is tested by carrying out the binder drainage test.

4.4.2 Interpretation of tests on rubberised asphalt mixtures

- **Rubberised asphalt mixtures by the Wet process**

Due to the fact that crumb rubber is added to the binder and the specifications are the same for asphalt mixtures with or without rubber, there are no changes regarding the tests or their interpretation worth mentioning. In general, the tendencies observed in rubberised asphalt mixtures by the wet process in comparison with the conventional mixture are:

- A slight increase in void content, which could be compensated with a slight increase of the binder content o grading adjustment if it were necessary.

- Slightly less resistance to water action, although it is not difficult to comply with the specifications.

- Increased resistance to plastic deformation.

- **Rubberised asphalt mixtures by the dry process**

When crumb rubber is added by the dry process the same properties and values are required as with asphalt mixtures without rubber. However, due to the digestion process that takes place within the asphalt mixture, all the test results depend on the progress of the digestion process. Effectively, the longer the digestion period the lower presence of the elastic rubber particle. In this sense, the digestion process has the following effects on the asphalt mixture:

- The voids decrease as the compaction efficacy improves.

  The resistance to water action increases as there is an interface binder-rubber of high affinity.

  The resistance to disaggregation also decreases in the case of the porous mixtures.

Solely the resistance to plastic deformation evolves slightly in function of digestion time. The beneficial effects on rutting resistance can be observed even before digestion.

Due to all these changes during digestion, certain measures should be taken in the laboratory so that prior to evaluating the properties mentioned, the asphalt mixture should dispose of a similar digestion time and temperature as at laying site. If this is not carried out, this would result in property values that may not be representative of the asphalt mixtures laid on site.

4.5 Standards of Good Laboratory Practice

Laboratory work with rubberised asphalt mixtures is not very different to mixtures without rubber. Nevertheless, it is convenient to make certain recommendations for good practice.

- **Rubberised asphalt mixtures by wet process**

As it was mentioned in section 4.3, rubber modified binders are produced at the same temperature as polymer modified binders. Rubber enhanced binders are produced at 5°C above the temperature employed for binders without rubber and finally, high viscosity rubber modified binders are produced at 175°C.

In any event, rubberised binders must be mixed with a spatula or a ladle, before taking a portion for each sample. The reason for doing so is to make sure the binder is a homogeneous mixture as well as correcting possible settlement problems. This problem is minimized when all the asphalt mixture is kneaded in one go and then the mass is divided to produce several samples. However, the binder should be stirred or mixed before being added to the aggregate to ensure homogeneity.

It is advisable to begin with the mixing of all the aggregates, followed by the mixing with the binder and lastly the incorporation of the mineral powder. Then, due to the increase of viscosity of these binders it may be necessary to prolong the coating time by 15 seconds more than the time needed for mixtures without rubber. In practice, the first mixing will recommend the suitable time period for each binder and for each aggregate grading. In any case, complete coating of the aggregates must be achieved and this can be verified at a glance especially with the coarser particles of the aggregate.

The rest of the operations will not vary much compared to the asphalt mixtures without rubber.

- **Rubberised asphalt mixtures by dry process**

Generally, rubberised asphalt mixtures by dry process, in the proportions recommended in this Guide, should be produced at 10°C above the temperature used for mixtures without rubber but in no event below 170°C.

In this case it is not necessary to stir the binder because it does not contain rubber. However, it is important to pay attention to the order in which the components are included: mixing of the aggregates, mixing with the rubber until uniformity, and then the binder must be added until a perfect coating of the aggregates is obtained (rubber coating is difficult to see). Finally, the mineral powder is added and the mixing is completed. The total coating time is usually around 30 seconds more than the asphalt mixture without rubber.

Once the coating is completed, time must be allowed for the digestion process. As explained in Chapter 3, this is a progressive phenomenon, enhanced by the temperature and therefore the newly produced asphalt mixture before compaction should be placed inside an oven at 10°C below production temperature during a period of time that will ensure correct digestion.

The following recommendations regarding digestion process in the laboratory should be heeded. First of all, the mixed mass should be placed on metal trays in portions that correspond with the samples to be produced. It is convenient to cover the mixture, it is usually sufficient to cover it with an aluminium sheet, which is then discarded, to limit its contact with air. The reason for this is that the reduced size of the portions oxidise more than the mixture in-situ would if it were part of the lorry load surrounded by more mixture and within the tank inside the lorry. Another reason is that the temperatures used for digestion cause the mixture to emit a smell which is reduced by covering. Due to this aforementioned motive, the ovens that are used for digestion by dry method should be situated in well ventilated areas of the laboratory.

Once the desired digestion period is complete, the individual samples are removed from the oven and compacted. If digestion has not been completed the compaction will not be optimal. In this sense, it is necessary to compact certain samples following 2 hours digestion period, this will ensure a digestion that guarantees a reference value for bulk density: this will serve to verify that with lower digestion times compaction is adequate. If the density obtained during compaction is insufficient, we need to revise the whole process: grading and rubber content, temperature and digestion time.

Regarding the estimation of density and air void content by the dry process, it is recommended the methods based on maximum and bulk density compiled in: EN 12697-5, EN 12697-6 and EN 12697-8. The methods based on the density of aggregates in the pycnometer are difficult to apply in practice, because the rubber particles present among the aggregate behave in a different way and thus make testing complicated.

4.6 Elaboration of the working formula

The working formula of an asphalt mixture is a technical document that indicates, according to the test carried out in the laboratory, the procedure that the asphalt mixing plant must follow during industrial production.

The elements that comprise the working formula are, in the case of mixtures without rubber, as follow:

- Identification and proportion to be used of each aggregate fraction
- Grading of the combined aggregates
- Dosage of mineral powder
- Binder type and content
- Temperature of the aggregates before mixing

- Aggregate mixing time and mixing time with binder
- Mixing temperature and minimum temperature required after mixing
- Maximum temperature of the mixture prior to compaction and the minimum temperature once concluded

In the case of rubberised asphalt mixtures, the working formula will contain all the aforementioned elements but with different values in some cases. In this way, when working with rubber by the wet process, the type of binder referred to will be one of the rubberised binders; enhanced, modified or high viscosity.

However, when the crumb rubber is added by the dry process the working formula should include new elements specifically used with this technology. More specifically, it should define:

- Rubber content

- Rubber particle size distribution
- Order in the mixing process: aggregates + crumb rubber + bitumen + mineral powder
- Minimum digestion time

Therefore, the working formula of a rubberised asphalt mixture by wet process is similar to that of a mixture without rubber. However, the rubberised asphalt mixture by the dry process should define all with regards to crumb rubber and its addition to the mixture.

Besides that, the working formula should include the characteristics of the asphalt mixture produced in the laboratory during the design process, as is shown in Table 10:

ALL ASPHALT MIXTURES:	POROUS MIXTURES:
- Air void percentage - Bulk density - Resistance to water action - Resistance to plastic deformation	- Particle lost resistance (Cantabro) - Binder drainage
	SMA:
	- Voids in aggregate

Table 10. Characteristics of asphalt mixtures required in working formulas


GRANALU
GRANALU
5063 CMK
VOLVO
VOLVO

Production of rubberised asphalt mixtures

5

Once a working formula is available and elaborated in the laboratory, it may now be manufactured at a production plant. The crumb rubber may be introduced in the following two manners:

- **Wet process:** production of rubberised binder and posterior manufacture of asphalt mixtures. Two manufacture procedures may be identified:
  - Binders produced at terminal blending and then transported and stored in an asphalt mixing plant until required for use.
  - Binders produced in-situ and in real time in a mobile blender unit located in the asphalt mixing plant and which may also be stored for several hours before use.
- **Dry process:** production of asphalt mixtures where the crumb rubber is added directly into the mixer in the asphalt mixing plant together with the aggregates and the bitumen base.

These variants lead to different procedures which need to be considered in the asphalt mixing plant and which will be analysed in this chapter.

Furthermore, and considering that the discontinuous production plants are more and more common, certain comments shall be introduced specifically regarding this type of installation.

5.1 Manufacturing of rubberised asphalt mixtures with binders from terminal blending facilities

In this case the operating system in the mixing plant is similar to the general case of binders without rubber. The most frequent type of rubberised binders served from production plants are rubber enhanced binders (BC) and rubber/polymer modified binders (PMB-C).

Figure 4. Terminal blending facility

Figure 5. Tanker truck supplying binder

5.1.1 Storage and handling of rubberised binders

These rubberised binders produced in terminal blending facilities are delivered to the asphalt mixing plants using tanker trucks. On arrival, the binder is transferred to the plant tanks. The tanker truck is equipped with the necessary pumps and hoses to carry out this type of work.

The rubberised binders tend to decant since particles of rubber subsist in suspension. It is probable that the rubberised binders produced in the terminal blending plants are more stable but, in any case, it is advisable to take measures to avoid certain incidents related to possible settlements.

In this sense, the tanks where the rubberised binders are deposited should dispose of a heating system in the exterior covering of the tank and an insulation system as well as a stirring system to maintain the mixture in constant movement. It is preferable to use vertical tanks because this disposition can favour convection flows.

As a general rule, during the storage period and until the binder is used, the following indications should be followed:

- Storage temperature should be around 160°C for all rubberised binders coming from the terminal blending.
- For storage periods over 24 hours slightly lower temperatures may be used; around 145-150°C, increasing the temperature of the tank a few hours prior to use.
- Storage periods longer than 72 hours are not recommended.

These indications are given so that the binder temperature will be sufficient to use it directly in the manufacture of the asphalt mixtures and, at the same time, ensure a slower progress of the properties; this progress is accelerated by temperature.

BMAVC binders have not been included in this section because they are not usually produced in terminal blending plant but rather in-situ, due to its high viscosity.

Figure 6. Vertical storage tanks

Figure 7. Discontinuos plant for asphalt mixtures

5.1.2 Working temperatures

In the following operation stages at the plant, it is fundamental to respect the indications regarding the working formula. The following temperatures are recommended:

- Bitumen temperature before addition in mixer: 160-165°C.
- Maximum and minimum temperatures of aggregates: 165-175°C.
- Mixing temperature: 165°C.

It is desirable that the asphalt mixture with this type of binder leaves the production plant at a temperature of 160-165°C.

5.1.3 Digestion time

Rubberised binders from the terminal blending facilities has completed the digestion process when they reach the plant and have spent several hours in the tanker truck. Therefore, it will not be necessary to establish measures to verify the digestion.

5.1.4 Mixing time

This type of binders does not suppose any additional difficulties regarding coating at an industrial level. Therefore, the use of this rubberised binders from terminal blending plant does not require an increase in coating time and thus an hourly output reduction, at least regarding this concept.

5.1.5 Hourly output at the plant

In this case, the capacity of the asphalt mixing plant is not affected by rubberised binders. However, the following aspects should be considered:

- Guarantee the stock of rubberised binder: sufficient bitumen for two days of work should be available in tanks. With this in mind, the plant needs sufficient and adequate tanks.
- The pumps that drive the rubberised binder to the weighing device at the plant must have sufficient power and needs to be checked. Even though these binders have a similar viscosity compared to polymer

Figure 8. Continuous asphalt mixing plant

modified binders, it is advisable to check that the plant pumps are able to fill the weighing device in the available cycle time. If this is not so, the cycle will increase, and the hourly output will decrease.

5.1.6 Manufacturing in continuous asphalt mixing plants

Regarding the incorporation of the binders to the aggregates at this type of production plant, it is widely known that instead of weighing devices, volumetric pumps and mass flowmeters are used that allow continuous dosing of the binder in proportion to the input of aggregates into the mixing drying drum.

When the rubberised binder comes from the terminal blending facility, the process is identical to that employed for binders without rubber. It will be necessary to verify that in these plants the pumps and measuring devices are able to handle the rubberised binder.

5.2 Manufacturing of rubberised asphalt mixtures in-situ

In this case, the rubberised binders are produced in a manufacturing unit placed at the asphalt mixing plant.

These units can be fixed and associated with a specific manufacturing plant or mobile; these may be placed at a plant in order to carry out a specific project.

The manufacturing unit´s aim is to facilitate the interaction between the bitumen and the crumb rubber with the maximum efficacy possible. There are different types of manufacturing units for rubberised binders and this information may be consulted in the "Guide for the Production of Rubberised Binders" edited by Signus.

Schematically, in all cases the manufacturing unit must dispose of the following elements:

- An inlet in the asphalt mixing plant tanks to supply bitumen to the blending unit.
- A thermal plant, that works as a heat exchanger in case it becomes necessary to increase the temperature of the bitumen that enters the system and all the thermal circuit that cover the different elements of the unit.
- A loading hopper for the crumb rubber. There may even be two to simultaneously use with rubber and polymer.
- A deposit to include additives in the case of semi-warm mixtures or other additives required.

- Weighing devices and volumetric dosage devices for bitumen, crumb rubber, polymers, and additives.
- A mixer for robust stirring of all the different components to obtain optimal integration.
- A digestion tank, where the digestion process takes place (the mixing tank and the digestion tank may all in one, as long as the first tank is large enough).
- A pumping system, to send the rubberised binder from the digestion tank into the mixing tank or into any storage tanks.
- A control system, from where it is possible to program and supervise the whole operation.

Figure 9. Manufacturing unit in-situ for rubberised binders

The rubberised binders that are usually supplied with these installations are enhanced binders (BC), rubber and polymer modified binders (PMB-C) and high viscosity rubber modified binders (BMAVC).

5.2.1 Connection between the rubberised binder unit and the asphalt mixing plant

The manufacturing unit for rubberised binders should be integrated into the asphalt mixing plant operation system (Figure 10). From a material point of view, this integration requires the following elements:

- Connection with the net bitumen tanks at the plant in order to supply the unit with the bitumen ready to be modified.
- Connection with the plant weighing device or with the storage tanks to supply the manufactured rubberised binder.

These requirements are normally solved by installing a three-way valve that allows various configurations. This will depend on the use required by the unit.

In regard to the control and electrical systems of the plant and the rubberised binder unit, connections are also required:

- Connection between the two control systems, especially in the case that the rubberised binder is supplied directly to the weighing unit at the plant; in this case, there must be perfect synchronization between both installations. This requires an electrical connection installed by an electro-mechanic specialist. Nevertheless, if the rubberised binder unit is going to transport the product to the storage tanks at the plant, it will be carried out by the control system of the unit autonomously and independently from the control at the plant. The control at the plant will govern only the supply from the storage tanks.
- Electric-supply connection; which is usually done from an electric transformer that powers the plant. If the contracted power supply is not enough, which can occur in the case of mobile units at the

plant, it will be necessary to use an electro-generator. This option is the least recommendable due to the size and noise made by the generator.

Finally, if the rubberised binder unit does not have its own thermal system, it will be necessary to connect the blending unit to the thermal circuit of the asphalt mixing plant. However, this is not recommended as the temperatures are extremely important for optimal production and subsequent handling of the rubberised binder. Therefore, it is advisable to employ an independent production unit at least concerning the thermal circuit.

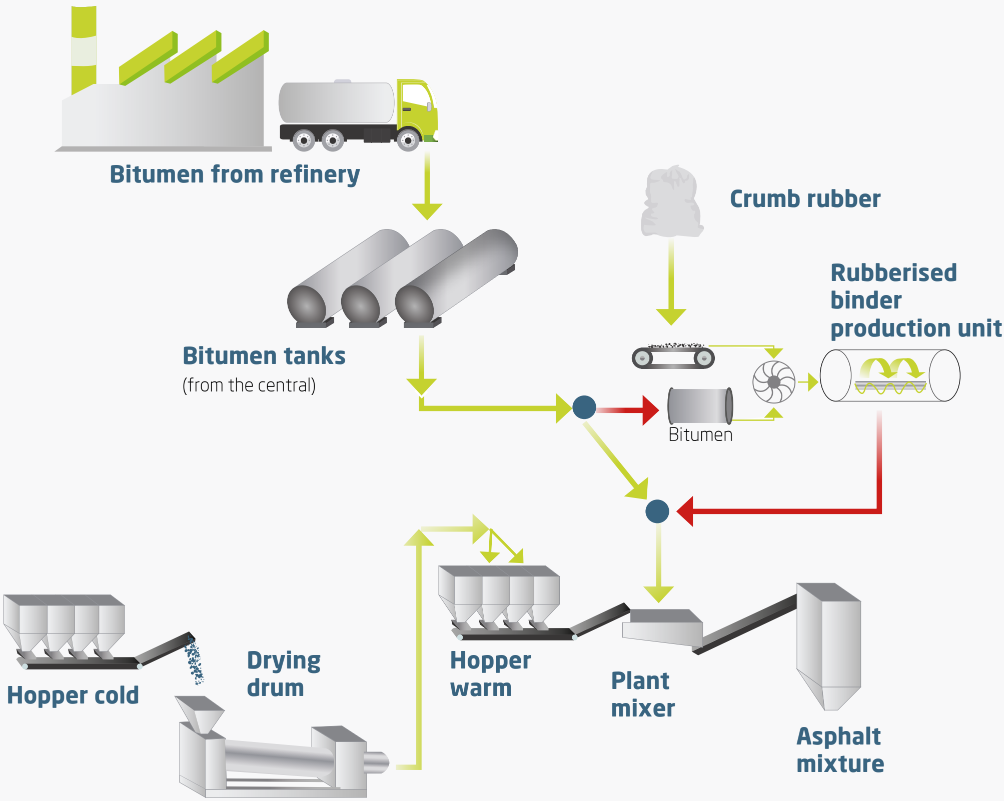


Figure 10. Scheme regarding the deployment of a rubberised binder at the production plant

Another important aspect to consider is the physical implementation of the unit at the available plant areas. Although the configuration of each asphalt mixing plant might recommend a different set-up for the rubberised binder unit, there are certain principals that the experience has proved highly worthwhile:

- The production unit takes up around 60 m^2. Therefore, the plant will need a surface area to accommodate a unit of his size.
- Furthermore, there should be enough space to fill the loading hoppers with crumb rubber and polymer which usually requires machinery to manage the big-bags used to transport this material.
- The placement should be as near as possible to the plant tanks to minimize the supply distance and length of the heater conducts. It should also be near to the weighing devices or the storage tanks for the same reason.
- When installing the unit, the effect on the plant should be minimal so as not to hinder the loading of the aggregate, loading of bitumen tanks and particularly the transport route used by the trucks. A disorder of this nature will reduce the hourly output and result in financial loss.

5.2.2 Storage of crumb rubber and polymers

Both crumb rubber and polymers may be supplied to the plant in bulk and be deposited in the storage silos. However, at present it is more common to be delivered in big-bags, of an approximate weight of 1 tonne. When manufacturing modified binder with rubber and polymer the latter can be supplied in two ways:

- Premixed with the rubber in adequate proportions. This is the most suitable system when the rubberised binder production unit has a unique loading hopper by which to dose the modifying products.
- In big-bag different from those used for rubber. In this case, the rubberised binder production unit should be equipped with loading hoppers to dose separately the rubber and the polymer.

Each big-bag of modifying product, rubber or polymer, occupies an area of approximately 1.2 m^2. There should be enough big-bags of rubber and polymer for at least three day´s work in order to avoid stoppages caused by supply incidents. On the basis of the expected daily production it is easy to calculate the required modifier stock that should be available at the plant.

As for the characteristics of the storage area, it is preferable to be indoor and protected from rainfall. If the rubber or polymer becomes damp during storage it will produce water vapour and froth once in contact with the bitumen at high temperature. This will result in a decrease in hourly output as it will be necessary to reduce the froth volume, overflow problems and even the possibility of accidents involving the workers of the unit.

Nevertheless, in many plants there is no indoor or protected area and thus it will be necessary to demand the delivery of rubber and polymer in bags with polyethylene lining. This will help to protect the material from humidity during wet weather.

Figure 11. Stock of big-bags containing crumb rubber

5.2.3 Storage of rubberised binder until use

The mixing unit disposes of, as mentioned, a digestion tank (or a large mixer that allows a second digestion stage) equipped with a stirring device to keep the rubberised binder in movement and avoid settlement and ensuring a complete digestion. The rubberised binder supplied to the asphalt mixing plant has completed the digestion process and is ready for use.

However, for logistical reasons it may be convenient dispose of storage tanks at the plant since:

- The hourly output of rubberised binder may be insufficient for the labour requirements. In these cases, the storage tanks can perform as regulators that receive the rubberised binder from the unit during long working hours, 12 hours or more, and supplying the plant during 8 h sessions.
- The advantages of having enough rubberised binder stock means being able to deal with any contingency such as: a break down at the rubberised binder production unit or a lack of supply of bitumen, rubber or polymers. Having stock will allow work to continue.

The storage tanks must comply with section 5.1.1 of this Guide.

5.2.4 Working temperatures

The working formula of the asphalt mixture indicates the temperatures during the whole process: these working temperatures are summarised in Table 11.

	Enhanced binders (BC) and rubber and polymer modified binders (PMB-C)	High viscosity rubber modified binders (BMAVC)
Temperature of binder entering the mixer	160-165ºC	170-175ºC
Minimum and maximum temperatures of aggregates	165-175ºC	175-185ºC
Mixing temperature	165ºC	175ºC

Table 11. Working temperatures for different binders

It is preferable that the asphalt mixture with the rubber enhanced binders (BC) and rubber and polymer modified binders (PMB-C) leave the production plant at 160 -165°C. Nevertheless, in the case of high viscosity rubber modified binders (BMAVC), the asphalt mixture should not leave the plant at less than 170 -175 °C.

5.2.5 Digestion time

The rubberised binders produced in-situ, due to the digestion time that forms part of the manufacturing process, are delivered to the plant with a completed digestion process, even when produced and delivered directly (without tank storage at the plant). When the plant does offer storage tanks where it is possible to store and serve the plant, the digestion process continues to advance and excessive progress may be problematic. For this reason, storage time is limited to 72 hours.

5.2.6 Coating time

When the binder produced in-situ is rubber enhanced (BC) or rubber and polymer modified (PMB-C) the coating time at the plant is similar to the time period required by binders without rubber. Therefore, the use of these binders in-situ does not imply any extra work time during the work cycle.

However, this is a general rule and may not apply in certain cases; high content of fine aggregates or limited quantities of binder. Thus, during the initial stage of the work process, it would be advisable to check for coating problems and prolong the mixing cycle during a few seconds, if necessary.

5.2.7 Hourly output at the plant

As has been mentioned, the coating stage does not necessarily need to be longer. But there are some other factors that might slow down the hourly production at the plant:

- The hourly production of the rubberised binder unit. If the unit produces, for example, 12 t/h, the plant will not be able to produce, at the same, more tonnes of asphalt mixture than the amount corresponding to that amount of binder. This problem may be solved with storage tanks and work periods at the rubberised binder production unit longer than manufacturing and laying of asphalt mixture.
- The capacity of the pumps at the plant. In the case of rubber enhanced (BC) and rubber modified binders (PMB-C) viscosity is noy usually problematic, but in the case of high viscosity rubber modified binders (BMAVC) more powerful pumps are required. If power is insufficient and the flow is lower, the weighing process at the scale could be longer, and therefore the consequent manufacturing cycle will be delayed. As a result, the hourly output will be reduced. To avoid such an event, it is advisable to check the power of the available pumps at the rubberised binder unit or at the asphalt mixing plant is powerful enough.
- The weighing device capacity may also limit the process when working with BMAVC. The asphalt mixtures with these binders have high binder contents, around 8-9% by weight of the aggregates. Owing to the fact that conventional asphalt mixtures do not exceed 5-6%, the weighing devices are sized accordingly. When a problem like this arises, the only solution is to change the size of the weighing device which is not easy. The alternative is to manufacture smaller batches with the same cycle duration which means a reduction in hourly output. This risk deserves preparatory analysis to avoid this kind of limitation.

5.2.8 Manufacturing in continuous plants

These plants do not dispose of a weighing device for binders, they continuously pump and the binder provision is controlled by volumetric pumps and mass flowmeters. Therefore, it will be necessary to check that the pump and devices at these plants are able to function with the viscosity and the flow rate demanded by the rubberised binders manufactured in-situ.

5.3 Manufacturing of rubberised binders by dry process

The dry process consists of adding crumb rubber to the asphalt mixture at the plant mixer at the moment of production, as if it were a fraction of the aggregate.

Nevertheless, the rubber particles interact with the binder mixture modifying it partially during the process known as digestion. As explained, this is favoured by time and temperature. For this reason, the work plan must consider these parameters to guarantee the quality of the material on site.

5.3.1 Storage of crumb rubber

A stock of crumb rubber will be needed at the asphalt mixing plant; at least enough for 3 days work. In this way, supply interruptions will be prevented.

As for storage conditions and area required at the asphalt mixing plant, the recommendations made in section 5.2.2 regarding rubber stock are applicable in the case of rubber modified binders in- situ.

5.3.2 Procedure for adding rubber in the plant mixer

The addition of crumb rubber into the mixer that has been packed in polyethylene bags, used in the past, should be discarded as it can lead to errors and inaccuracies.

In this sense, weight dispensers should be used. These consist of a loading hopper to contain the rubber and a dispenser controlled by an automatic weighing system, which will introduce the exact amount of rubber required according to the working formula. These devices should be precise within 0.1% by the total weight of the mass manufactured.

These dispensers should also be synchronised with the manufacturing cycle at the plant as the correct addition order of the components is (Figure 12): aggregates and rubber (+ mixing), bitumen (+mixing) and mineral powder (+mixing). In this way, when the bitumen enters the mixer, it will be added to a homogeneous mixture of aggregates and rubber.

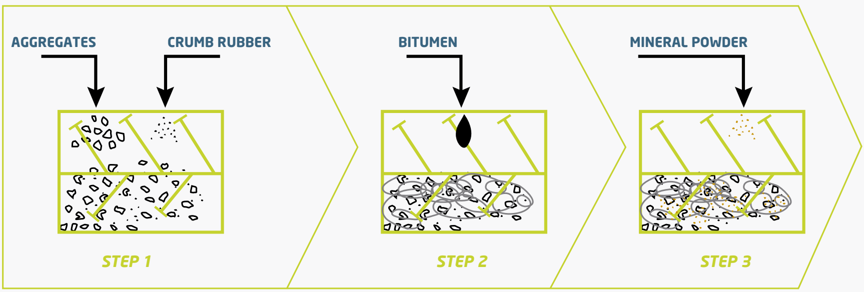


Figure 12. Entrance sequence of materials into the mixer in the dry process

5.3.3 Working temperatures

The working formula indicates the correct temperatures during the process. The two most important check points and the recommended temperatures in the case of rubberised asphalt mixtures in dry process are:

	Dry process
Temperature of bitumen entering the mixer	165ºC
Minimum and maximum temperature of aggregates	170-180ºC
Mixing temperature	170ºC

Table 12. Working temperatures in dry process

It is advisable that this kind of asphalt mixture leaves the production plant at 165-170ºC.

5.3.4 Mixing time

The presence of rubber particles makes the coating process more difficult. So, to guarantee a correct coating of the mineral particles and the rubber particles, it is necessary to prolong the coating time and consequently the whole cycle. Although the increase in time will depend on the plant and its characteristics, the cycle may increase by a total of 10% with respect to the mixing without rubber.

5.3.5 Digestion time in dry process

The digestion time for a rubberised asphalt mixture by dry process is the time elapsed from its manufacture until it is laid out on the pavement and the temperature drops noticeably below 150ºC. Therefore, the digestion time available on-site is the result of: the time the mixture remains hot in the calorifuged regulation hoppers, if available, the transport time of the mixture to the paving site, the waiting time in tanker trucks and even the minutes spent in the paver hopper.

These time periods that exist in each road work, should be enough so that the bitumen-rubber interaction progresses until a suitable interface is created. The exchange that takes place involves a slight modification of the binder in the asphalt mixture as well as a decrease in size and the elastic characteristics of the rubber particles.

Nevertheless, at industrial level and in real-life conditions it is not economically feasible to prolong digestion time more than the available after applying the criteria for optimal productivity. In this sense, the process is rather the contrary; following the estimated digestion time available at work, the digestion time apply for the laboratory tests is defined and then translating to the working formula. Hence, the mixture is kept in the oven during that time before compaction. When the working formula is drafted, it should highlight the percentage and particle size distribution of the crumb rubber and the digestion time in the laboratory which it will be considered for the full-scale works. Although it is not a general rule, the dry process rubberised asphalt mixtures presented in this Guide should never have a digestion time less than 90 minutes.

5.3.6 Hourly output at the plant and operating costs

A decrease of hourly output or an increase of the operating costs regarding asphalt mixture manufacture by dry process stem from two factors:

- Mixing cycle duration; this may be 10% longer and will affect costs.

- The need for additional digestion time, for example, when the paving site is very near to the production plant. If the plant disposes of regulating loading hoppers the warm mix will not suffer a decrease in hourly output, but if the tanker trucks need to wait for digestion to conclude, costs will of course increase.

When working with dry process, it is necessary to accommodate the rubber content and particle size distribution with the available working digestion time and this avoid an increase in operating costs with the sole purpose of having additional digestion times.

5.3.7 Production in continuous and batch plants

The main difference between rubberised asphalt mixture production by dry process at continuous and batch plants consists in the way the crumb rubber is introduced into the mixer.

- In batch plants the crumb rubber is added at once, and the amount corresponds to the weight of the batch being produced.

- In continuous plants the crumb rubber is added continuously at a fixed point in the dryer-mixer drum that is not directly exposed to the flame, which could damage the rubber. The same entry point is normally used to add recycled material and the additives and at the same stage as the dry aggregates are added to the bitumen.

This difference means that a dynamic weighing system is required for the rubber which should have, as the general case, a precision of 0.1% by weight of mixture.

In the same way, the rotation speed and the drum configuration must be adjusted to ensure that the mixing time is enough to allow for the correct coating of the mineral particles and the rubber.

5.4 Other aspects regarding operating with rubberised asphalt mixtures at the plant

In addition to what has been explained in this Guide, it may be interesting to end on certain considerations regarding maintenance and cleaning at the plant when working with crumb rubber. More specifically, when working by wet process the hoses and pipes should be cleaned following use. Indeed, over several days of use with rubberised asphalt mixtures there may be deposits of rubber particles along the walls of the conducts. This is easily avoided by running pure bitumen through the circuit as this will remove deposits of rubber. This simple task can help prevent further complications.

The dry process obviously does not require this type of maintenance.

5.5. CE marking of rubberised asphalt mixtures

Within the European Union context, the CE marking is a process by which a producer or an importer informs users and the authorities that the marketed product complies with the legislations regarding essential requirements. The general procedure is shown below in the diagram:

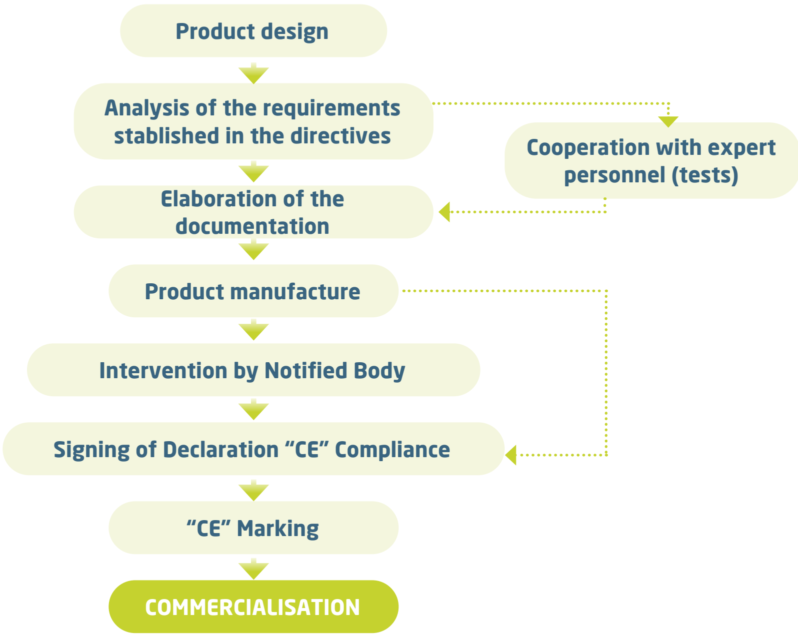


Figure 13. General procedure for CE marking of products

Most of the products marketed in Europe are subject to the obligation of obtaining the CE marking. This also applies to binders and asphalt mixtures.

5.5.1. CE marking of asphalt mixtures

The marketing of asphalt mixtures in the European Union is regulated in Regulation No 305/2011 by the European Parliament and Council dated 9 March 2011, which laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/CEE.

The manufacturer is responsible for ensuring all products comply with the essential requirements in the Directive. In the case of asphalt mixtures, the standards applied are EN 13108, that specifically applies to different types of asphalt mixtures. As for the mixtures included in this Guide the standards are included in EN 13108-1 concerning bituminous concrete AC, EN 13108-2 concerning fine layer bituminous mixtures BBTM A and B, EN 13108-5 concerning SMA mixtures and EN 13108-7 concerning porous asphalt mixtures. They are completed, with regard to procedures of CE marking, with standards EN 13108-20 for initial type testing, and EN 13108-21 regarding production control at plants. Finally, these test methods are basically compiled in the harmonized standards EN 12697.

The evaluation system that the Regulation requires for CE marking of asphalt mixtures is type 2+, that assigns tasks to the manufacturer as well as the notified body, externally, and approved by the National Accreditation Entity.

According to this diagram, three tasks are carried out by the manufacturer:

- Carry out initial type testing (the manufacturer may perform these tests or commission them to an approved external laboratory).
- Elaborate a protocol "Factory Production Control".
- Test the samples periodically at the production plant according to an established plan.

The tasks required by the external notified body are:

- Initial inspection of the plant in order to issue a Certificate of Conformity of Factory Production Control.
- Annual inspections to renew the Certificate of Conformity.

Once the CE marking is put into effect an asphalt mixture production plant will dispose of three documents that enable marketing of the asphalt mixtures:

1) **Certificate of Conformity by CE Marking regarding Production Plant Control**. Normally each plant disposes of a certificate that includes in an annex a list of the types of asphalt mixtures produced and marketed by the plant.

2) **Declaration of Performance (DP), with features that the mixture complies with**. There is a specific document for each asphalt mixture produced and marketed by the plant.

3) **CE marking for the asphalt mixture**. Each mixture manufactured and marketed has a specific document.

5.5.2. CE marking for rubberised asphalt mixtures

For CE marking of rubberised asphalt mixtures it is convenient to distinguish between asphalt mixtures by wet process and by dry process.

- CE marking for rubberised asphalt mixtures by wet process

On one hand, the Certificate of Conformity CE marking regarding production control at the plant should include the new rubberised asphalt mixture in the list of mixtures produced and marketed at the plant; for this the Notified Body needs to be involved.

Furthermore, a new Declaration of Performance is required, due to the fact that although the plant already disposes of a DP for a similar mixture, the change concerning the new binder requires a new DP. Consider that even in the field of conventional bitumen, a change of a 35/50 penetration binder to a 50/70 penetration binder calls for a new Declaration of Performance.

Finally, regarding the CE marking of the asphalt mixture, a new document is also required.

The process is similar for any new asphalt mixture without rubber and is facilitated by the prior CE marking of the rubberised binders to be used in the manufacture of rubberised asphalt mixtures by wet process.

- CE marking for rubberised asphalt mixtures by dry process

In this case, the CE marking needs to be dealt with considering the crumb rubber added to the asphalt mixture as an additive. The CE marking procedure already foresees the use of additives and should be contemplated in the Declaration of Performance when obtaining the marking.

Furthermore, the procedure and mechanisms for the addition of rubber as an additive at a plant should be revised by the notifying body, in view of an inspection for the obtention and update of the Certificate of Conformity of the CE Marking of the Factory Production Control.

5.5.3. CE marking as a guarantee of quality

While it is true that the obtention and update of the CE marking for asphalt mixtures means a quality label, in practice, all works in Spain are thoroughly inspected by the Public Agencies to ensure quality levels and which are foreseen in the Technical Specifications of all projects. These are usually compiled in the PG-3 by the Ministry of Public Works and Transport concerning road-works.

In other words, the CE marking has become a compulsory procedure but in practice it has not substituted the regular quality controls carried out. This situation is also applicable to asphalt mixtures that incorporate crumb rubber.

Laying and compaction of the pavement layer

6

Once the rubberised asphalt mixture has been manufactured it is transported to the site for laying and compaction. The work teams and procedures differ very little compared to conventional asphalt mixtures. However, in this chapter we provide some of the peculiarities that should be considered in order to achieve optimal results when working with crumb rubber. The majority of these issues are related to operating temperatures that affect these mixtures a little more than conventional mixtures.

6.1 Transport of asphalt mixtures

The mixture will be transported to the site in conventional flatbed trucks. If in the general case the truck bed should be treated with an anti-adherent agent, it is even more necessary in this case. A soapy solution or a similar product may be used but not in excess to avoid water-logging at the base. In any case, petroleum-based products should be avoided as these tend to soften the binder.

Rubberised asphalt mixtures have a lower grading segregation than conventional mixtures. Nevertheless, during loading and transport care should be taken to avoid and minimize this phenomenon: loading must be carried out so that the coarser particles move and roll around as little as possible, thus avoiding segregation. This may be observed in Figure. 14.

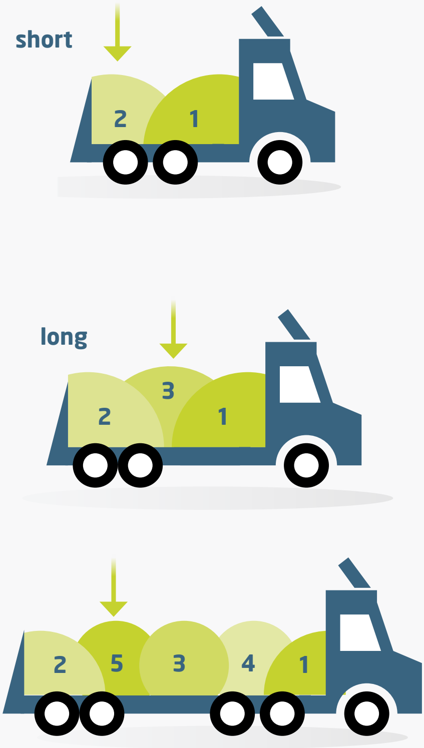


Figure 14. Diagram of truck loading

The temperature of the asphalt mixture during loading must never be lower than the temperature indicated in the working formula. In general, it is around 160 -165 °C in the case of mixtures with rubber enhanced or rubber and polymer modified binders, 165 -170 °C for rubberised asphalt mixtures by dry process, and around 170 -175°C in the case of high viscosity rubberised binders.

Type of asphalt mixture	Loading Temperature
Asphalt mixtures with BC and PMB-C	160 -165 °C
Rubberised asphalt mixtures by dry process	165 -170 °C
Asphalt mixtures with BMAVC	170 -175 °C

Table 13. Temperature during loading

In order to reduce temperature loss during transportation the load should be covered with a canvas cover. During unloading at the site into the paver, the team should respect the minimum temperatures established in the working formula. As a general rule, during transport the mixture should never lose more than 10°C.

Figure 15. Protection of the asphalt mixture with canvas cover during transportation

Some constraints may make it difficult to achieve this objective. Low ambient temperature and transport time are the most negative constraints; this includes unloading delays. Regarding low temperatures, since it is not advisable to lay the mixture at temperatures below 10°C, it will not be common to transport the mixture on cold days. However, transport time may lengthen due to distances or traffic jams. Queues or long waits while other trucks unload should also be accounted for. Although traffic jams are often inevitable and external to work, long waits at the site depends on organization and may be solved by careful planning of unloading and laying. Nowadays, with the help of mobile phones it is much easier to coordinate production at the plant and laying site. Thanks to the telecommunications, it is easier to reduce waiting times of trucks.

6.2 Surface preparation

Before laying a new layer, the existing road pavement should be cleaned up and prepared in the case of a rehabilitation projects. Potholes should be filled, areas of poor conditions should be repaired and other routine works must be completed. Finally, the surface must be prepared with an tack coat.

As for the type of bituminous emulsion and the rate to be applied, the general criteria are applicable except in case of rubberised binders modified with polymers and high viscosity rubber modified binders where it is recommended to apply emulsions of bitumens modified with polymers. In the same way, thermo-adhesive emulsions may be employed.

6.3 Unloading and laying of asphalt mixtures

In general, the laying work should never be carried out when the ambient temperature is below 10°C and particularly if more favourable conditions are not expected. Laying should not be done in rainy conditions; not even light rain. If these conditions are met the laying work may be carried out.

Unloading is done directly from the loading hopper into the paver. When possible, a mobile transfer silo can be placed in between the two vehicles in order to homogenize the asphalt mixture both thermically and regarding grading and to regulate the demand and thus avoid stops of the paver. Unnecessary stopping and starting of the paver should be avoided as this has a negative effect on the superficial regularity of the asphalt mixture.

Unloading temperatures must be at least 155°C in the case of rubber enhanced binders and those modified with rubber and polymers and, around 160°C for rubberised asphalt mixtures by dry process or with high viscosity rubber modified binders.

The paver should be equipped with a heated tamper in order to ensure a pre-compacted layer. Furthermore, the paver should have a heater device for the longitudinal joint completion.

Figure 16. Laying of an asphalt mixture layer

The complementary works carried out manually at the joints should be minimum, particularly in the case of gap-graded mixtures, porous mixtures and SMA. This is because it is more difficult than when working with mixtures without rubber. Extra care should be taken with the adjacent paving so as to reduce excess material. When manual reworking is imperative it must be done quickly before the mixture cools down.

The transversal joints should be minimum. They should always be cut vertically, heated (if cold) and impregnated with adhesive emulsion. The longitudinal joints are nearly always cold. With this in mind, they must be cut vertically, impregnated with adhesive emulsion and heated. In this way the paver must be equipped with heating elements for the joint.

6.4 Layer compaction

Compaction must commence as soon as possible. The initial compaction temperatures must not be below 150°C in the case of mixtures with enhanced or rubber and polymers modified binders and never below 155°C in the case of high viscosity rubber modified binders or in dry process. Depending on the type of asphalt mixture the most appropriate compactors are:

- AC mixtures: Metallic vibrating roller + pneumatic roller.
- BBTM mixtures, PA and SMA: Metallic roller without vibration.

The best results with type AC mixtures are obtained with a metallic vibrating roller, ending off with a pneumatic roller. This last roller must take care so as to avoid particles sticking to the tyres; this can be done using a soapy solution and a skirt which helps to maintain the tyre temperature. However, if material continues to stick to the tyres, this roller should not be used as the final result can be affected.

As for BBTM, PA and SMA mixtures, a metallic roller is the best option. The layers of these mixtures are somewhat thinner, and vibration should be avoided; the mineral particles could also break down.

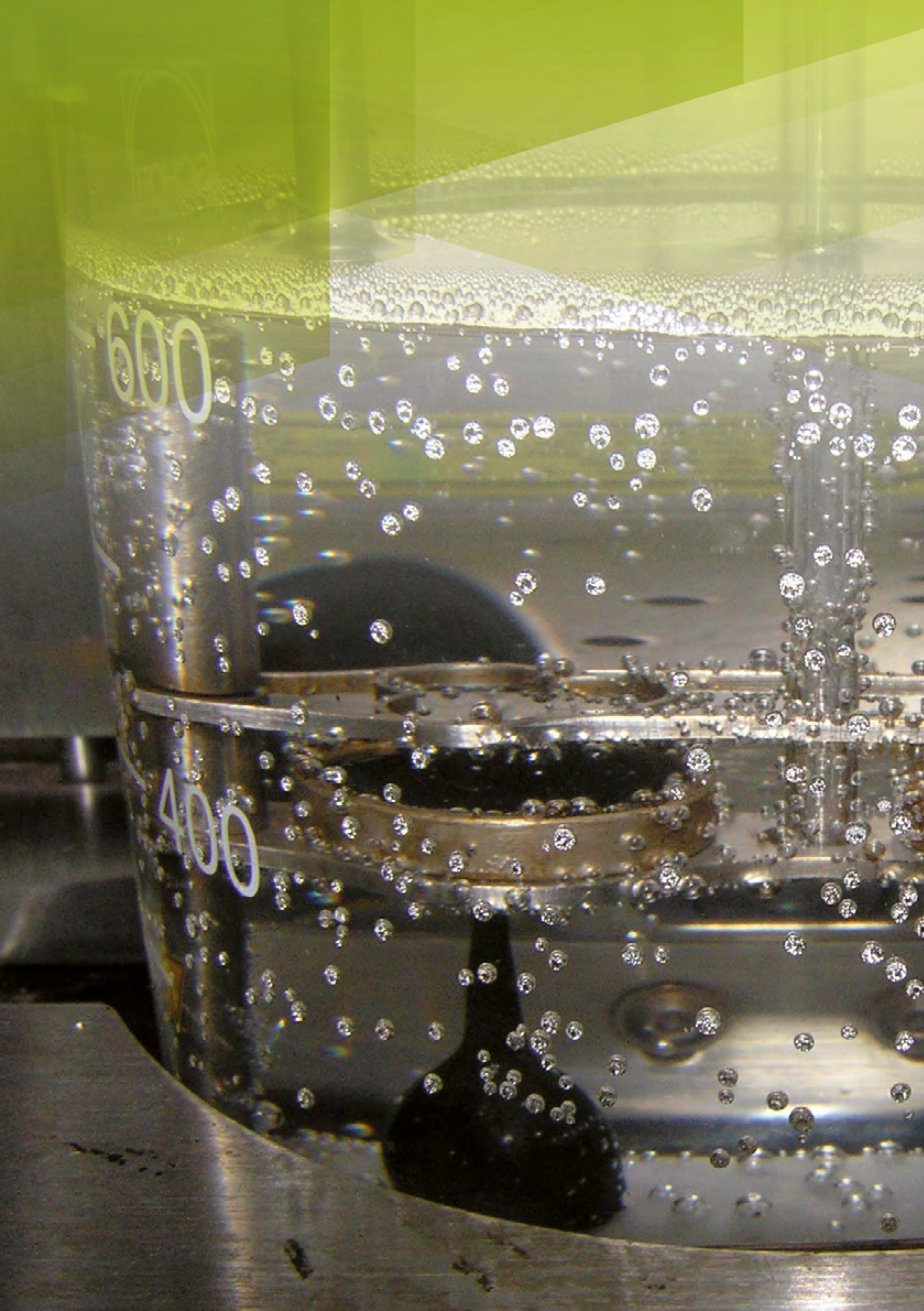
In any event, before beginning work it is advisable to choose a test area to determine the best roller as well as the number of passes to achieve optimal results. Furthermore, initial and final temperatures of compaction should be checked with the working formula. Sometimes small changes are required. The criterion must be to reach the density specified for the in situ works.

However, in the case of rubberised asphalt mixtures by dry process, it is possible that the elastic particles try to regain their shape even after a layer has reached the required density. The last part of compaction won't be in function of the required density but will continue until the final compaction temperature is reached; for dry process around 120°C.

Figure 17. Compaction with a smooth roller

6.5 Opening up to traffic

In some circumstances, once the road is opened up to traffic, particles stick to the tyres of the first vehicles. This can be avoided by opening to traffic only once the layer has reached 60°C. When the weather is hot, and when it is urgent to open up to traffic, the asphalt may be watered in order to reduce temperatures a little faster.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Quality Control

7

Quality control in the area of construction is formed by a series of procedures that allow to attest that all materials, processes and final products comply with the minimum established standards.

Over the last decade, Europe has implemented within the road construction sector a quality control based on the CE marking (or European Conformity). This marking provides information explaining that the marketed material complies with the essential requirements established by the European Directives and that are applicable.

Both binders as well as asphalt mixtures can dispose of this marking. Each manufacturer will have to apply and obtain this by following the procedure established in the European regulations 305/2011.

When a certain material –a binder or an asphalt mixture- carries the CE marking, on delivery at the work site, the constructor is able to simply verify all the declared values on the documents that accompany the material. Given the importance that the CE marking has acquired in the field of asphalt mixtures, section 5.5 of this Guide indicates all the procedures required to obtain and maintain this marking, particularly in the case of rubberised binders and rubberised asphalt mixtures.

Nevertheless, in spite of having the CE marking, it is commonplace that the public agencies carry out a series of quality controls once the material has been delivered, during the manufacture of the asphalt mixtures and even once the layers have been placed in the pavement. This is precisely why is referred to in this present chapter.

On the other hand, if the CE marking was not provided, the procedures and the tests that shall be commented herewith are indispensable. As shall be see, they are practically the same as those carried out on asphalt mixtures without rubber, which goes to show the lack of obstacles for the implementation of these asphalt mixtures with crumb rubber.

7. 1 Quality control of crumb rubber

Generally, the quality control tests carried out on crumb rubber are particle size distribution analysis, humidity tests, textile content, steel content and other impurities content.

- Sample collection:

The standard CEN/TS 14243:2010 includes a section that indicates that in order to obtain a representative sample, it is preferable with the material in movement, e.g., on a conveyor belt. Nevertheless, usually the material is supplied in a big bag and therefore stationary. In this sense, it is necessary to point out that on publication of this document, at European level and included in the Standardization Technical Committee TC366, regulations regarding sample taking procedures are being elaborated for granulate and powder rubber stored in big bags. Small amounts of rubber will be taken from different levels in the big bag in order to take a representative sample for testing in the laboratory.

- Moisture content:

This analysis is carried out according to UNE 103-300-3 (except for oven temperature which shall be 105±5°C and the minimum sample mass will be 100 g). In this standard, the test method is explained to determine the soil moisture using a drying oven.

- Particle size distribution and impurity content (textile, steel and others):

The test methods to determine the particle size distribution and impurity content in crumb rubber is outlined in CEN/TS 14243:2010 of experimental character, entitled: "Materials produced from end of life tyres - Specification of categories based on their dimension(s) and impurities and methods for determining their dimension(s) and impurities". A description of these test methods was included in "Guide for the Production of Rubberised Binders" published by Signus. Nevertheless, it should be noted that on publication of this Guide, a work regarding the validation of this standard

is being concluded and anticipates certain parameter changes and test methods.

7.2 Quality control of rubberised binders

Due to the existence of various types of rubberised binders and to the fact that these may be produced at a terminal blending or in-situ with a production unit at the mixing plant, the quality controls differ depending on each case.

As for the batch definition and sampling frequencies, the articles 211 and 212 of the Spanish PG-3 for binders without rubber are still perfectly valid.

7.2.1 Quality control for paving grade bitumen (in-situ and dry process production)

At the beginning of work and at least once a month a complete study will be carried out

in order to check compliance concerning all the characteristics established in Art. 211 from the PG-3.

Once work has begun, each tank that arrives at the production plant shall be tested to assess needle penetration (EN 1426).

During production, samples will be taken from the piping from the storage tanks to the production unit or from the bitumen weighing device in the case of dry process. This should be done once a week. Needle penetration tests (EN 1426) and softening point (EN 1427) will be carried out to calculate the penetration index (Annex A EN 12591).

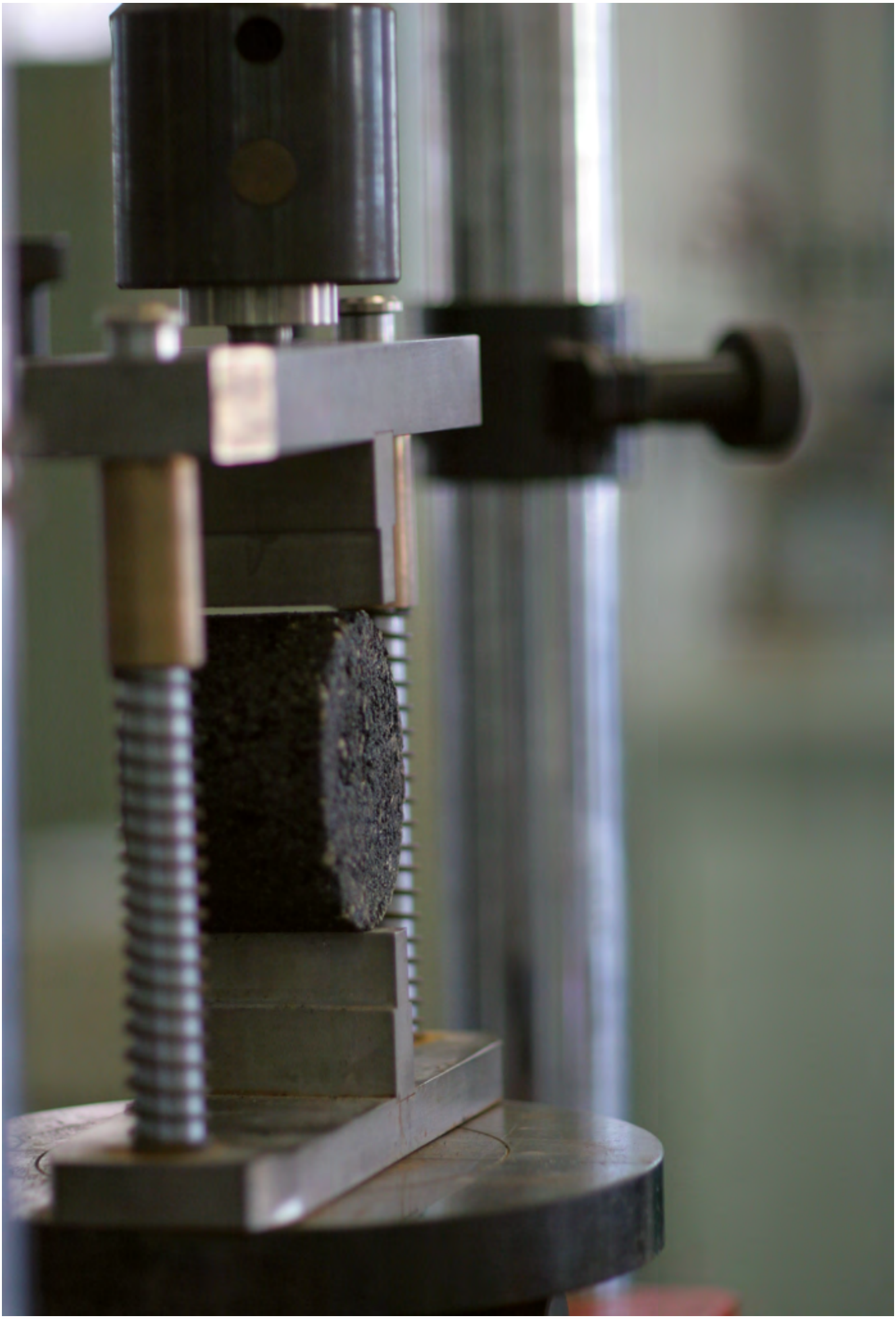
7.2.2 Control of rubber enhanced binders and rubber and polymers modified binders, produced at terminal blending facility

At the beginning of the work process and at least once a week, a complete study shall be carried out to ensure the binder complies with Spanish Circular Order 21/2007 specifications for rubber enhanced binders or Article 212 of Spanish PG-3 in the case of modified binders with rubber and polymers.

Once work has started and when the tanker arrives at the plant, each tank of bitumen should undergo a routine needle penetration test (EN 1426), as well as softening point (EN 1427) and elastic recovery (EN 13398).

During the work process and once a week, samples should be taken from the pipe from storage tank to the weighing device to check needle penetration (EN 1426) as well as softening point (EN 1427).

During storage periods of more than 3 days, penetration variation (EN 1426) and softening point variation should be tested (EN 1427). These samples should be taken from the top part and the bottom part of the storage tanks.



7.2.3 Control of rubber enhanced binders and rubber and polymers modified binders produced in-situ

At the commencement of work a complete study should be carried out to ensure that the binder produced in-situ complies with the established requirements of the Spanish Circular Order 21/2007 regarding rubber enhanced binders and Art. 212 of Spanish PG-3 for rubber and polymers modified binders.

Once work has begun, samples need to be taken at least twice a day at the outlet and the penetration properties must be tested (EN 1426) as well as softening point (EN 1427). Everyday elastic recovery must be tested (EN 13398).

If the binder produced in-situ is stored for more than 3 days, the penetration variation must be tested (EN 1426) as well as softening point variation (EN 1427). Samples must be taken from the top of the storage tank and from the bottom.

7.2.4 Control of high viscosity rubber modified binders produced in-situ

At the beginning of the work process a complete study will be carried out to ensure that the binder produced in-situ complies with the established requirements of the Spanish Circular Order 21/2007 regarding high viscosity rubber modified binders produced in-situ.

During work samples will be taken at the outlet of the digestion tank every hour. The aim of these samples is to detect in real time any important anomaly during the process which would affect the viscosity (EN 13302). The samples for these tests are taken using 5 kg capacity metal containers which allow in-situ testing with a manual viscometer and sufficient thermal stability.

Furthermore, during the work process samples should be taken at least twice daily to test penetration properties (EN 1426) and softening point (EN 1427).

7.3 Quality control during production of asphalt mixtures

Quality control must first be compiled on the binders, seen in the previous sections, and then the aggregates which is similar to the conventional mixtures included in Spanish PG-3 Art. 542 for AC mixtures and Art. 543 for BBTM A, BBTM B and PA mixtures, and in the Draft Statement regarding warm asphalt mixture SMA, prepared by CEDEX.

This must be completed with the manufacture and laying of the asphalt mixtures whose principal aspects are presented hereunder.

7.3.1 AC asphalt mixtures

At least once a week the correct functioning and precision of the weighing devices and thermometers of the installation should be tested and checked.

As for the control of the asphalt mixture, texture and temperature must be tested at the outlet of the mixer. Moreover, samples should be taken frequently depending on the control level established in the specifications for conventional mixtures (X is recommended for wearing and intermediate courses with traffic flow from T00 till T2, and Y for the rest of the cases, as established in PG-3) as well as the conformity level according to standard EN 13108-21. In these asphalt mixture samples the binder content may be obtained (EN 12697-1) as well as the grading of the extracted aggregates (EN 12697-2).

Furthermore, the water sensitivity should be tested at least once a week using the indirect tensile test (EN 12697-12). At least once a month the resistance to plastic deformation needs to be tested using the wheel tracking test (EN 12697-22).

As for laying and compaction, the batch controlled is defined as the minor after applying the following criteria: 500 m road length, 3,500 m^2 road surface or the fraction built each day.

For each batch a sample is taken at the plant outlet or from the paver hopper, and then, 3 test pieces are compacted in the laboratory by 75 blows per side. The bulk density is then determined in these samples (EN 12697-6) as well as the void content (EN 12697-8).

From the executed batch, at least 3 cores are extracted for each layer and the thickness of each compacted layer will be tested. Likewise, the bulk density and void content shall be obtained and then compared with those obtained from the same laboratory batch. Using the core samples, an adherence test may also be carried out (NLT-382).

Finally, international regularity index, IRI, should be checked on the layer surface following standard NLT-330. In the case of wearing course, the surface macro-texture should alsobe verified (EN 13036-1) taken from three random points as well as the skid resistance all along the work area (UNE 41201 IN).

Concerning the values to comply with, the same values drafted in Art. 542 of Spanish PG-3 for asphalt mixtures without rubber must be followed.

7.3.2 Asphalt mixtures type BBTM A, BBTM B, PA, SMA and Anti-Cracking mixtures

At least once a week the precision and correct operation of the weighing device and thermometers should be checked.

Grading tests should be carried out daily on the warm aggregates (EN 933-1).

As for the control of the asphalt mixture itself, temperature and aspect should be checked at the mixer outlet. Moreover, samples are needed and the frequency will depend on the control level that has been selected (X is recommended for traffic from T00 to T2 and Y for the all other cases, as established in PG-3) as well as the conformity level obtained according to EN 13108-21. With these asphalt mixtures samples the binder content will also be calculated (EN 12697-1) and also the grading of the extracted aggregates (EN 12697-2).

Furthermore, at least once a week water sensitivity should be tested. This should be

carried out using the indirect tensile strength ratio test (EN 12697-12) for asphalt mixtures BBTM A, BBTM B, PA and SMA.

At least once a month the plastic deformation test shall be carried out on BBTM A, BBTM B and SMA mixtures using the wheel tracking test (EN 12697-22).

Mixtures type PA should be checked once a week for particle loss (EN 12697-17) and at least once a month the binder drainage should be checked (EN 12697-18).

Regarding laying and compaction, the batch control is defined as the minor after applying the following criteria: 500 m road length, 3,500 m^2 road surface or the fraction built each day.

For each batch, a sample will be taken at the plant outlet or from the paver hopper, and three samples will be compacted in the laboratory with 50 blows per side by a Marshall compactor (EN 12697-30) for BBTM A, BBTM B, PA, SMA mixtures and anti-cracking mixtures. The bulk density of these samples will be tested (EN 12697-6) and also the void content (EN 12697-8).

At the same time, at least 3 core samples shall be taken from the laid pavement in order to test the thickness of the compacted layer and thus, obtain the bulk density and the void content of the mixture and compare these results with those obtained from the same batch at the laboratory .For BBTM A and SMA mixtures the bulk density is used as a reference and the voice content for mixtures type BBTM B and PA. The adherence test will also be carried out on the core samples (NLT-382).

Finally, the International Roughness Index, IRI, should be checked in the paved layer using standard NLT-330. In the case of wearing course, the surface macro-texture should also be verified (EN 13036-1) taken from three random points as well as the skid resistance all along the work area (UNE 41201 IN).

As for the values to be complied with, the same values that appear in Art. 543 of PG-3 for asphalt mixtures that do not contain rubber will be adopted.

Rubberised Asphalt Mixtures Sheets

ANNEX 11

Hereafter, some examples of formulation sheets for rubberised asphalt mixtures are presented included a comparison to same mixtures without rubber. These are real examples that can help to understand the influence on the mixture features of rubberised binders or rubber incorporated by dry process.

The sheets show the grading used, the type of aggregates and binder, production temperature, compaction energy and temperature, as well as the most important properties in each case.

In any case, as explained in chapters 4 and 5, regarding design and production of asphalt mixtures at the laboratory and at asphalt mixing plant, for each project the working formula for aggregates and binders requires preliminary study. What is more, ideally the formula with crumb rubber should be subjected to the CE marking so that the plant may routinely produce the asphalt mixture in each one of the subsequent works.

ASPHALT MIXTURE BBTM 11A

Coarse aggregate: Porphyry; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	16	11.2	8	4	2	0.5	0.063
Pass (%)	100	99.3	65	31.1	30	16.1	8.2

Characteristics	Standard	BBTM 11A	BBTM 11A Wet process	BBTM 11A Dry process	PG-3 Article 543
Binder content (%)		5.5	5.5		>5.2%
Type of binder		PMB 45/80-60	PMB 45/80-60 C	50/70 and 1% crumb rubber by wet process	---
Relation mineral powder/ binder		1.5	1.5		≥ 1.2 and ≤ 1.6
Production/compaction temperature (°C)	---	165/155	165/155	170/155	---
Compaction (blows/side)	EN 12697-30	50	50	50	50
Maximum density(g/cm^3)	EN 12697-5	2.496	2.494	2.480	---
Bulk density (g/cm^3)	EN 12697-6	2.39	2.374	2.371	---
Void content (%)	EN 12697-8	4.25	4.81	4.40	≥ 4
Indirect tensile and water sensitivity results					
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	1.864	1.578	1.559	---
Indirect tensile strength, wet samples, ITS (MPa)	EN 12697-22	1.752	1.562	1.434	---
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	94	99	92	≥ 90
Resistance to plastic deformation					
Density (g/cm^3)	EN 12697-22	2.365	2.350	2.347	---
Temperature (°C)		60	60	60	---
Sample thickness (mm)		40	40	40	---
WTS_{air} (mm/10^3 cycles)		0.025	0.030	0.025	≤ 0.07
PRD_{air} (%)		4.76	4.78	5.51	---

ASPHALT MIXTURE BBTM 11B

Coarse aggregate: Porphyry; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	16	11.2	8	4	2	0.5	0.063
Pass (%)	100	99.4	69	26.3	25	15.1	5.5

Characteristics	Standard	BBTM 11B	BBTM 11B Wet process	PG-3 Article 543
Binder content (%))		5	5	>4,75
Binder type		PMB 45/80-65	PMB 45/80-65C	---
Relation mineral powder/binder		1.1	1.1	≥ 1.0 and ≤ 1.2
Production/compaction temperature (°C)	---	165/155	165/155	---
Compaction (blows/side)	EN 12697-30	50	50	50
Maximum density (g/cm^3)	EN 12697-5	2.516	2.510	---
Bulk density (g/cm^3)	EN 12697-6	2.107	2.098	---
Void content (%)	EN 12697-8	16.25	16.55	≥ 12 and ≤ 18
Indirect tensile and water sensitivity results				
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	1.497	1.092	---
Indirect tensile resistance, wet samples, ITS (MPa)	EN 12697-22	1.353	981	---
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	90.4	90	≥ 90
Resistance to plastic deformation				
Density (g/cm^3)	EN 12697-22	2.09	2.08	---
Temperature (°C)		60	60	---
Sample thickness (mm)		40	40	---
WTS_{air} (mm/10^3 cycles)		0.061	0.066	≤ 0.07
PRD_{air} (%)		7.139	5.43	---

ASPHALT POROUS MIXTURE PA11

Coarse aggregate: Porphyry; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	16	11.2	8	4	2	0.5	0.063
Pass (%)	100	99.2	59	20.2	12.1	7.6	4.6

Characteristics	Standard	PA11	PA 11 Wet process	PG-3 Article 543
Binder content (%)		4.5	4.5	>4.3%
Binder type		PMB 45/80-65	PMB 45/80-65 C	---
Relation mineral powder/binder		1.02	1.02	≥ 0.9 and ≤ 1.1
Production/compaction temperature (°C)	---	165/155	165/155	---
Compaction (blows/side)	EN 12697-30	50	50	50
Maximum density (g/cm³)	EN 12697-5	2.541	2.514	---
Bulk density (g/cm³)	EN 12697-6	1.925	1.928	---
Void content (%)	EN 12697-8	24.2	23.3	≥ 20
Indirect tensile and water sensitivity results				
Indirect tensile resistance. dry samples. ITS (MPa)	EN 12697-22	1.050	0.935	---
Indirect tensile resistance. wet samples. ITS (MPa)	EN 12697-22	0.968	0.792	---
Indirect tensile strength ratio. ITSR (%)	EN 12697-12	92.2	84.7	≥ 85
Resistance to plastic deformation				
Loss of particles in porous mixture (%)	EN 12697-17	16.4	19.6	> 20
Binder drainage	EN 12697-18	null	null	null

ASPHALT MIXTURE SMA 11

Coarse aggregate: Porphyry; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	16	11.2	8	4	2	0.5	0.063
Pass (%)	100	100	67	27	25	16.2	8.4

Characteristics	Standard	SMA 11	SMA 11 Wet process	SMA 11 Dry process	Draft spec.
Binder content (%)		6.2	6.2	6.2	>5.8%
Binder type		PMB 45/80-65	PMB 45/80-65 C	50/70 and 125% crumb rubber by dry process	---
Relation mineral powder/ binder		y 0.5% fibre	1.36	1.36	≥ 1.2 and ≤ 1.6
Production/compaction temperature (°C)	---	1.36	165/155	170/155	---
Compaction (blows/side)	EN 12697-30	165/155	50	50	50
Maximum density (g/cm^3)	EN 12697-5	50	2.474	2.455	---
Bulk density (g/cm^3)	EN 12697-6	2.463	2.356	2.337	---
Void content (%)	EN 12697-8	2.328	4.8	4.8	≥ 4 and ≤ 6
Resultados de tracción indirecta y sensibilidad al agua					
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	1.699	1.478	1.479	---
Indirect tensile resistance, wet samples, ITS (MPa)	EN 12697-22	1.630	1.433	1.433	
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	96	97	97	≥ 90
Resistance to plastic deformation					
Density (g/cm^3)	EN 12697-22	2.301	2.343	2.320	
Temperature (°C)		60	60	60	---
Sample thickness (mm)		40	40	40	---
WTS_{air} (mm/10^3 cycles)		0.056	0.038	0.061	≤ 0.07
PRD_{air} (%)		5.2	4.5	5.2	---

ANTI-CRACKING ASPHALT MIXTURE (BMAVC-1)

Coarse aggregate: Porphyry; Fine aggregate: Silica; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	16	11.2	8	4	2	0.5	0.063
Pass (%)	100	99.4	69	26.3	25	15.1	5.5

Characteristics	Standard	ANTI-CRACKING
Binder content (%)		9.0
Binder type		BMAVC-1
Relation mineral powder/ binder		0.33
Production/compaction temperature (°C)		175/160
Compaction (blows/side)	EN 12697-30	50
Maximum density(g/cm^3)	EN 12697-5	2.387
Bulk density (g/cm^3)	EN 12697-6	2.283
Void content (%)	EN 12697-8	4.4
Indirect tensile and water sensitivity results		
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	1.412
Indirect tensile resistance, wet samples, ITS (MPa)	EN 12697-22	1.394
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	92.4
Resistance to plastic deformation		
Density (g/cm^3)	EN 12697-22	2.261
Temperature (°C)		60
Sample thickness (mm)		60
WTS_{air} (mm/10^3 cycles)		0.064
PRD_{air} (%)		5.77

ASPHALT MIXTURE AC16 S

Coarse aggregate: Porphyry; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	22	16	8	4	2	0.5	0.063
Pass (%)	100	100	71.0	36.2	25.2	13.3	9.3

Characteristics	Standard	AC16 S	AC16 S Wet process	PG-3 Article 542
Binder content (%)		5	5	>4.5
Binder type		50/70	BC 50/70	---
Relation mineral powder/binder		1.1	1.1	1.1
Production/compaction temperature (°C)	---	160/150	165/155	---
Compaction (blows/side)	EN 12697-30	75	75	75
Maximum density (g/cm^3)	EN 12697-5	2.499	2.478	---
Bulk density (g/cm^3)	EN 12697-6	2.387	2.367	---
Void content (%)	EN 12697-8	4.5	4.5	$\geq$ 4 and $\leq$ 6
Indirect tensile and water sensitivity results				
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	2.263	2.024	---
Indirect tensile resistance, wet samples, ITS (MPa)	EN 12697-22	2.146	1.951	---
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	95	96	$\geq$ 90
Density (g/cm^3)	EN 12697-22	2.370	2.346	---
Temperature (°C)		60	60	---
Sample thickness (mm)		40	40	---
WTS_{air} (mm/10^3 cycles)		0.097	0.054	$\leq$ 0.07
PRD_{air} (%)		5.7	3.5	---

ASPHALT MIXTURE AC22 S

Coarse aggregate: Silica; Fine aggregate: Calcareous; Mineral powder: Calcium Carbonate

Sieve (mm) EN 933-2	32	22	16	8	4	2	0.5	0.063
Pass (%)	100	95	78	56	27.6	13.9	10	5.1

Characteristics	Standard	AC22 S	AC22 S Wet process	AC22 S Dry process	PG-3 Article 542
Binder content (%)		4.5	4.5	4.5	≥ 4
Binder type		50/70	BC 50/70	B70/100 + 1% crumb rubber	---
Relation mineral powder/binder		1.13	1.13	1.13	1.1
Production/compaction temperature (°C)	---	160/150	165/155	170/155	---
Compaction (blows/side)	EN 12697-30	75	75	75	75
Maximum density (g/cm^3)	EN 12697-5	2.467	2.478	2.464	---
Bulk density (g/cm^3)	EN 12697-6	2.346	2.345	2.328	---
Void content (%)	EN 12697-8	4.90	5.37	5.5	≥ 4 and ≤ 6
Indirect tensile and water sensitivity results					
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	2.764	2.187	2.220	---
Indirect tensile resistance, wet samples, ITS (MPa)	EN 12697-22	2.428	2.092	1.903	---
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	88	96	96	≥ 80
Resistance to plastic deformation					
Density (g/cm^3)	EN 12697-22	2.331	2.346	2.311	---
Temperature (°C)		60	60	60	---
Sample thickness (mm)		60	30	60	---
WTS_{air} (mm/10^3 cycles)		0.066	0.056	0.059	≤ 0.07
PRD_{air} (%)		6.8	4.1	3.6	---

ASPHALT MIXTURE AC32 G

Coarse aggregate: Calcareous; Fine aggregate: Calcareous; Mineral powder: Calcium carbonate

Sieve (mm) EN 933-2	45	32	16	8	2	0.5	0.25	0.063
Pass (%)	100	99.7	69	47	25	12.1	8.1	4.2

Characteristics	Standard	AC32 G	AC32 G Wet process	PG-3 Article 542
Binder content (%)		4.5	4.5	> 4%
Type of binder		35/50	BC 35/50	---
Relation mineral powder/binder		0.93	0.93	≥ 0.9 and ≤ 1
Production/ compaction temperature (°C)	---	160/150	165/155	---
Compaction (blows/side)	EN 12697-30	75	75	75
Maximum density (g/cm^3)	EN 12697-5	2.477	2.479	---
Bulk density (g/cm^3)	EN 12697-6	2.318	2.313	---
Void content (%)	EN 12697-8	6.4	6.7	≥ 4 and ≤ 8
Indirect tensile and water sensitivity results				
Indirect tensile resistance, dry samples, ITS (MPa)	EN 12697-22	2.11	1.830	---
Indirect tensile strength, wet samples, ITS (MPa)	EN 12697-22	1.75	1.466	---
Indirect tensile strength ratio, ITSR (%)	EN 12697-12	82	80	≥ 80
Resistance to plastic deformation				
Density (g/cm^3)	EN 12697-22	2.203	2.278	---
Temperature (°C)		60	60	---
Sample thickness (mm)		60	60	---
WTS_{air} (mm/10^3 cycles)		0.66	0.029	≤ 0.07
PRD_{air} (%)		3.6	2.9	---

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Original Work

Guía para la fabricación y puesta en obra de mezclas bituminosas con polvo de neumático

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The contents established in this guide are the analysis results of different authors' experiences previous to this Project and the synthesis of the experimental results carried out with different bitumens and crumb rubber in the laboratory.

The authors of the present study have developed the Guide with the highest technical accuracy and criteria. However, ultimately, it is up to the good judgement of the user to guarantee satisfactory results and therefore the authors and SIGNUS Ecovalor shall not be held liable regarding any derived practical implementation.