POLYMIX HANDBOOK

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Project data

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Project partners

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1. INTRODUCTION

1.1 PROBLEM ADDRESSED

Consumption of polymeric products has increased dramatically over the past few decades. This trend results in the generation of a vast waste stream that needs to be properly managed in order to avoid environmental damage.

Today, polymers are recycled or recovered at rates of 69% in Europe. However, there is still 30% of polymer waste that are accumulating in unproductive and virtually permanent landfills. This waste disposal contributes significantly to their environmental impact. In addition, they take a long time to break down when they are landfilled, and currently more and more polymer products in the market have a short lifetime.

Another environmental impact associated with plastic waste refers to the pollutant emissions (greenhouse gases, acidifying gases and tropospheric ozone precursors) that are generated in energy recovery plants where around 35% of total plastic waste is sent.

On the other hand, road transport infrastructure has a great impact on economy and society in Europe and globally, since it underpins economic growth through the creation of jobs and the mobility of people and goods. However, each kilometre of road requires a large amount of materials and energy not only in its construction but also during its maintenance and rehabilitation.

The EU 27 comprises more than 5.000.000 km of paved roads and close to 10% of the investment structural funds in the EU for 2007-2013 period was allocated to road maintenance and rehabilitation works, as a result of the lack of long term durability of pavements built in Europe.

POLYMIX (Polymer Modified Asphalt Mixes) incorporate polymer waste in their composition. Reusing this type of waste by adding them into the asphalt mixes brings not only environmental advantages, but also increases the added value of the product.

Four types of bituminous mixtures which include a percentage of plastic waste (polyethylene, polystyrene or polypropylene) or rubber from end-of-life tyres (ELT) in their composition have been developed in POLYMIX project. These mixtures have been characterized by obtaining their mechanical properties in the laboratory and by monitoring a real scale road. The results obtained show some improvements in relation to conventional mixtures normally used in road construction.

1.2 BACKGROUND

Although the use of polymers in asphalt mixtures began in the nineteenth century with the appearance of patents which used natural polymer, it was in the 80s when its usage was boosted by new polymers and technologies. Higher resistance against plastic deformation, better adhesiveness or less susceptibility to temperatures variations were obtained with the addition of these polymers to the asphalt mixture.

In general they have been used to modify the rheology of the bitumen, increasing bitumen viscosity at high temperatures, therefore enhancing its resistance; and reducing bitumen viscosity at low temperatures, decreasing fragility and retarding the appearance of cracks.

The polymers can be added to the mixture by two ways:

WET PROCESS

In the wet way the polymer is directly added to the bitumen, and both are mixed in a digestion process that is usually prolonged during hours, depending on the type of polymer and the mixing process. This technology is the most widespread and allows a good control over the final mixture. The produced modified bitumen is of a high quality but quite expensive.

DRY PROCESS

In the dry way the polymer is directly added to the mixer drum as another aggregate. This process is less complex than the wet way but improvements in the asphalt mixture performance can also be achieved. This process is simpler, does not need significant initial investment and can be carried out in virtually any asphalt plant without modifications. The technology is, therefore, easily exportable allowing the polymer waste to be recovered where produced, reducing environmental and economic impacts.

Therefore, although the dry way does not reach the performance of the wet way, it increases the possibilities of recycling polymeric waste and improves the prospect to spread the process of bituminous mixtures modifications.

Regarding the reutilization of polymer waste in bituminous mixture, one of the most important studies using the dry way process was carried out by the Central pollution control board of New Delhi, in India. In India, around 1200kms of roads manufactured with asphalt mixes that incorporate polymeric waste (mix of PE, PP and PS) have been laid. The polymer mix is sprayed above the hot aggregates at 170°C, coating them. Finally, the dosage of bitumen is added to the mixture (Central pollution control board, Ministry of Environment & Forests, New Delhi 2008). In 2012, a study was presented relating to this method in which Marshall values between 1.800Kp y 2.000Kp were specified, besides a reduction of plastic deformations and a decrease of the dosage of bitumen around 10% was observed (Vasudevan, Ramalinga Chandra Sekar et al. 2012).

1.3 POLYMIX PERFORMANCE

The polymeric waste used in this project were selected according to technical criteria (performance of the resulted mixture) and economic criteria (cost and availability). The selected polymeric waste, its maximum size and its source are shown in Table 2.

2mm Containers (PE)	8mm Hangers (PS)	6,3mm Caps (PP)	1mm ELT (Rubber)

Table 1. Selected polymers used in the POLYMIX mixtures

The polymers previously selected were added in different percentages to the asphalt mixture. These percentages of polymeric waste replace the same proportion of mineral aggregate in its smallest fraction: the filler. The designed mixtures were characterized at the laboratory in order to accurately analyse the influence of the recycled polymer additive type in the asphalt mixture. Resistance to plastic deformation, stiffness and dynamic modulus, fatigue resistance, skid resistance and static adherence between layers were evaluated.

According to the results obtained during the design and characterization of POLYMIX mixes, it was concluded that all of them met the technical requirements currently set out in the Spanish normative for their use in road construction both as wearing and base course. The optimal percentage was found to be 1%.

In addition, and comparing to the reference, the samples designed that incorporated polymer waste present, in all cases, better resistance to plastic deformation (wheel tracking test) and higher dynamic modulus while maintaining fatigue resilience.

On the other hand, no significant differences were observed regarding the adherence between asphalt layers. However, when the sample is worn POLYMIX mixes present less skid resistance than the reference.

In the following figures, laboratory results of POLYMIX mixes are shown.

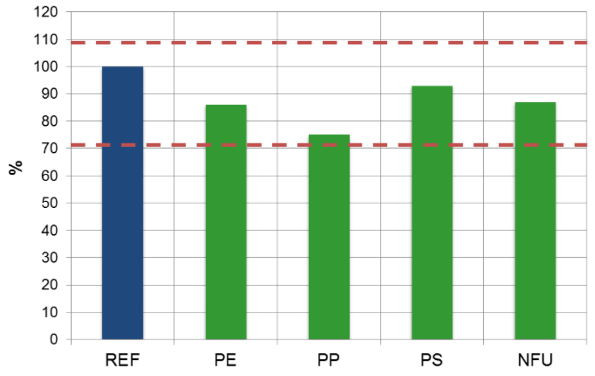

Figure 1. Voids content

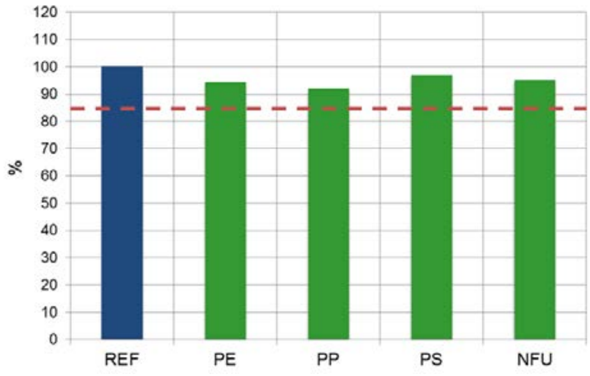

Figure 2. Voids in aggregates

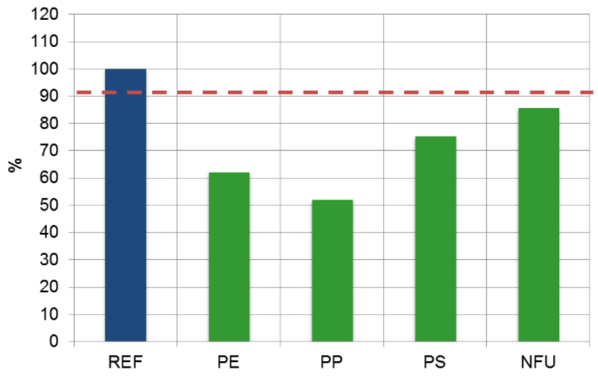

Figure 3.Wheel tracking test

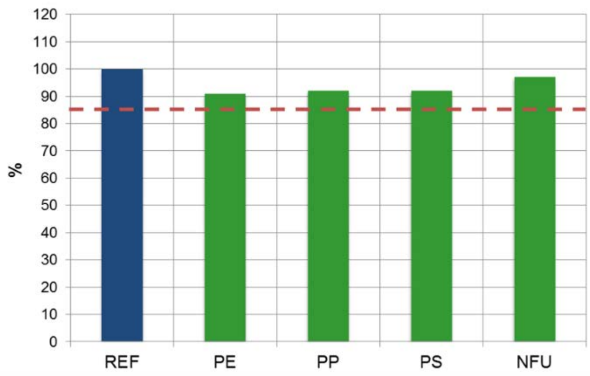

Figure 4. Water sensitivity

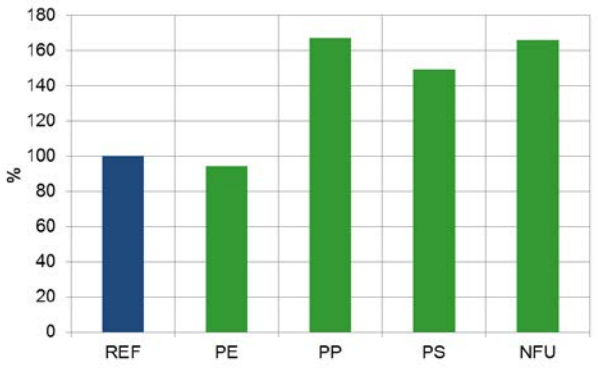

Figure 5. Stiffness modulus

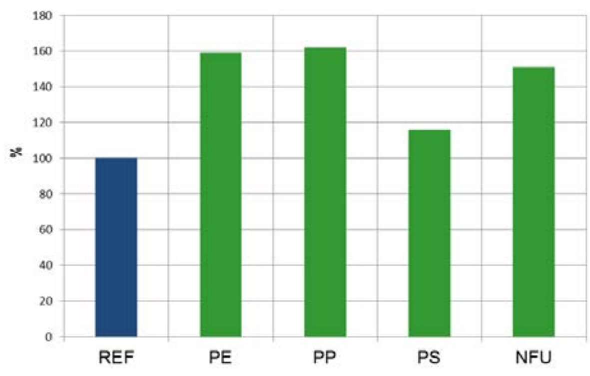

Figure 6. Dynamic modulus

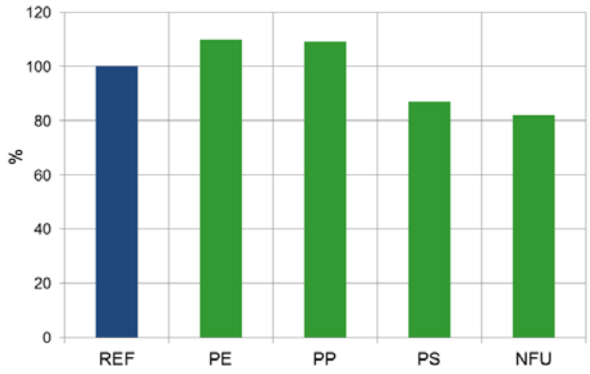

Figure 7. Static adherence

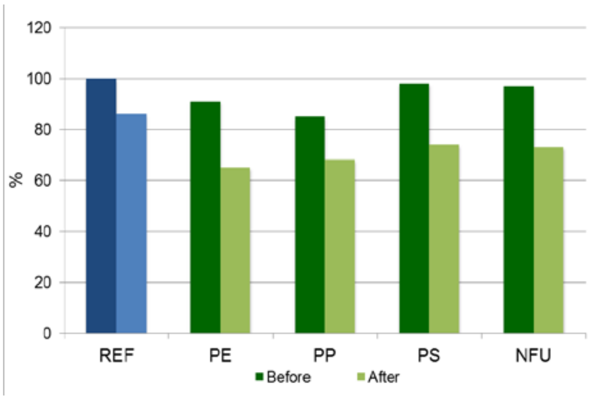

Figure 8. Skid resistance before and after wearing out

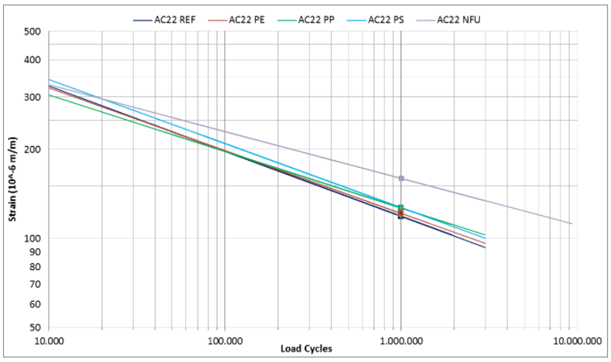

Figure 9. Fatigue resistant

WHERE AND WHY USE POLYMER MODIFIED ASPHALT?

According to the results, the POLYMIX mixtures achieve the requirements of the current Spanish normative (PG-3), and they are suitable to use in base, binder and surface layer. This implies that POLYMIX mixtures can be used in practically any road, from urban until main communication roads.

Its simple production allows to manufacture them in practically any asphalt plant, expanding its use to any area with the only limiting factor of the availability of the polymeric waste. This factor makes the POLYMIX mixtures especially suitable to those areas where there is a significant production of waste, as urban areas, industrial zones, or another area of influence of a waste manager, although POLYMIX mixture are not limited to these zones, it can be used in any place where the supply of the residual polymer is guaranteed.

The combination of high temperature and high traffic volumes are main factors in the development of rutting problems on road surfaces. The increase of temperatures due to climate change is increasing the number of rutting events in the European roads.

One of the main features of POLYMIX, that is common for all type of polymers studied in this project, is its better resistance to plastic deformation (rutting resistance) comparing with the reference. This characteristic has been validated at the laboratory both during the designing phase and at the real scale application. This characteristic makes POLYMIX especially suitable when high temperatures and high weight traffic is combined

2. POLYMIX MIXES DESIGN

2.1 MATERIALS

The selection of the materials to be used for producing asphalt mixtures is essential for the good performance of the mixture. It is important to know which materials are needed depending on the pavement option as well as which additives are needed to improve certain mixture parameters.

The materials depend on the type of asphalt mixture to be produced: surface layer, intermediate layer or base layer. In addition, a new choice can arise depending on the desired characteristics and usage of the pavement. In case of the surface layer different materials can be chosen: asphalt concrete, thin layers, porous asphalt, stone mastic asphalt, hot rolled asphalt, etc.

In this project only the asphalt concrete mixtures have been analysed; therefore, this process has not been checked with other types of mixture. In this handbook we will always refer to the asphalt concrete modified with polymers as the POLYMIX mixtures.

Excepting for the recycled polymer, POLYMIX mixes will use the same materials as conventional mixes. Bitumen and aggregates must fulfil the requirements stablished by the applicable normative in each country. In the case of Spain, the current technical specification PG-3 "Pliego de prescripciones técnicas generales para obras de carreteras y puentes" defines the type of mixture to produce based on the traffic level of the road. Specifically, article 542 of the PG-3 contains requirements regarding aggregates and bitumen to be used in asphalt concrete mixes.

AGGREGATES

Aggregates serve as reinforcement, to add strength to the overall material. It is a decisive material to ensure the good performance of the asphalt layer in the future pavement. Minimum quality requirement for aggregates will depend on the type of mixture and the equivalent traffic of the project.

In POLYMIX mixes, the same quality requirements as with conventional mixes must be complied. In the same way, same quality control should be undertaken to ensure that aggregates meet the technical specifications (PG-3 in Spain) and to check that their properties are compatible with the asphalt mixes.

According to the article 542 of the Spanish normative, aggregates must be subjected to the following tests:

- Particle size distribution (UNE-EN 933-1:1997)
- Polishing (accelerated polishing coefficient – ACP) (UNE-EN 1097-8:2012)
- Angels coefficient (UNE-EN 1097-2:1999)
- Crushed and broken surfaces (UNE-EN 933-5:1998)
- Flakiness index (UNE-EN 933-3)

When the origin of the aggregates is unknown, the following tests should be carried out:

- Relative density and absorption (UNE-EN-1097-6)
- Sand equivalent (UNE-EN 933-8)

BITUMEN

Bitumen selection will also depend on the type of asphalt mixture and the equivalent traffic of the project. Depending on the country, climate conditions must also be taken into account. Conventional unmodified bitumen and dosing procedure will be also used for the production of POLYMIX mixes. The bitumen must comply with the minimum requirement established by the technical specifications in each country (Article

211 of PG-3, in Spain). In the same way, Article 542 defines the minimum dosage and requirements for bituminous binders depending on the pavement course and type of mixture.

Tests required for the characterization of the hydrocarbon binder are the following:

- Penetration test for bituminous materials (UNE-EN-1426)
- Softening point of the binder (UNE-EN-1427)
- Rolling thin film oven test (UNE-EN-12607-1)
- Frass breaking point test (UNE-EN-12593)
- Flash point (UNE-EN-ISO 2592)
- Solubility (UNE-EN-12592)

POLYMER

The addition of polymers is the only difference between POLYMIX mixture and a conventional one. The type of polymeric waste to be used in POLYMIX mixes production is of paramount importance for their correct performance. In this project, the effect of one elastomeric polymer (rubber) and three plastomeric materials (polypropylene, polyethylene and polystyrene) on asphalt mixture performance was carried out. It should be noted that elastomers as ELT's have the roll of fillers in the asphalt mixture, whereas plastomeric polymers can provide additional functions.

It is of utmost importance that the polymeric source is homogeneous enough to avoid unexpected performance of the pavement due to non-uniform asphalt mixture composition.

Moreover, it is necessary to previously characterize the polymeric material in order to discard potential under-performance, due to inappropriate thermal behaviour of the recycled polymer when facing the high temperatures reached during the mixture production.

The use of these types of polymers is not standardized so differential scanning calorimetry is recommended in order to define:

- Composition of the material. Identification of the main polymer present in the sample, the relative weigh percentage and the possible presence of contaminants.
- The performance-temperature dependence

2.2 DESIGN METHODOLOGY

It must be noted that this procedure is based on the requirements stablished by Spanish specifications (PG-3). Specific requirement should be considered when using the methodology in a different country.

For the design of the mixtures, once the aggregates, bitumen and polymer waste have been selected; the dosage will be carried out according to conventional procedures.

1. A reference dosage is designed without adding recycled polymer. Marshall Method is used for designing the mixture.
2. 1% (volume) of the aggregates (filler fraction) is replaced for the selected polymer. Coarse and fine aggregates fractions remain unchanged.
3. Mixing procedure (laboratory stage):

   3.1 Mixing time:

   - Dry aggregates: 1 minute.
   - Aggregates with bitumen: 1 minute.
   - Plastic waste with aggregates and binder: 1 minute.

   3.2 Recommended temperature for pre-heating aggregates and bitumen:

- Minimum: 160ºC.
- Maximum: 180ºC.

4. The following tests should be performed on the designed mixture:
   4.1 Voids content.
   4.2 Wheel tracking test.
   4.3 Water sensitivity.

Note 1: In case of using polystyrene for modifying the mixture, it is recommended to determine the bitumen content of the designed mixture. PS melt almost completely, so the possibility to reduce virgin bitumen content should be checked as important economic savings are feasible.

Note 2: Crumb rubber is added together with the aggregates at the beginning of the mixing procedure.

MINIMUM REQUIREMENTS

According to the Spanish specifications minimum requirements are set as follows:

VOIDS IN MIXTURE (UNE 12697-8)

Parameter		**Equivalent traffic**			
		T00 & T0	T1 & T2	T3	T4
Voids in mixture (%)	Rolling course	4-6		3-5	
	Intermediate course	4-6	5-8	4-8	4-8
	Base course	5-8	6-9	5-9	-

Table 2. Table 542.13, PG-3.

WATER SENSITIVITY TEST (UNE 12697-12)

The aim of this test is to determine the loss of cohesion caused by water saturation and its effect on asphalt mixtures.

Water sensitivity (%)	Dense/semi- dense mixes	Rolling course	≥85 %
		Intermediate course	≥80 %

Table 3. Water sensitivity test specifications. PG-3.

WHEEL TRACKING TEST (UNE-EN 12697-22)

This test provides the resistance to plastic deformations.

Climatic zone	**Equivalent traffic**				
	T00 & T0	T1	T2	T3	T4
Warm	0.07			0.10	-
Medium	0.07		0.10		-

Mild	0.10	-

Table 4. Wheel tracking test specifications for surface and binder layer. PG-3, article 542.

<table>
<tr><th rowspan="2">Climatic zone</th><th colspan="3">Equivalent traffic</th></tr>
<tr><th>T00 & T0</th><th>T1</th><th>T2 & T31</th></tr>
<tr><td>Warm</td><td rowspan="2">0.07</td><td>0.07</td><td>0.10</td></tr>
<tr><td>Medium</td><td>0.10</td><td>-</td></tr>
<tr><td>Mild</td><td>0.10</td><td>-</td><td>-</td></tr>
</table>

Table 5. Wheel tracking test specifications for base layer. PG-3, article 542.

Besides these tests, specified by the normative as obligatory, it is also recommended to performed fatigue resistance and stiffness modulus so as to determine the future dynamic behaviour of the designed mixes.

3. POLYMIX MIXES PRODUCTION AND IMPLEMENTATION

3.1 ASPHALT PLANT

The production process at the asphalt plant is similar to the conventional procedure. The only modification is related to the addition of the polymer waste to the mixing drum. For this purpose, a particle feeder was implemented in the production line.

Figure 10. Polymeric waste feeder

The production process is divided in three main stages: preparation of materials, dosage and mixing.

1. Preparation and stockpiling of the materials (aggregates, bitumen and polymers) for the dosage.
    - Aggregates should be stockpiled in different areas according to their nature (porphyritic, limestone or siliceous aggregates) and also according to their upper and lower size limit that defines the fractions of the grading curve.
    - Bitumen should be stockpiled in trucks equipped with a tub, in optimal conditions of temperature and humidity.
    - Polymers need to be stored in separate bins in dry conditions.

Figure 11. Stockpiling at the plant

2. Dosage of the different aggregate fractions, according to the grading curve obtained at the laboratory.

   The asphalt plant should be programmed with the data regarding bitumen content, aggregates grading and the amount of waste polymer to be added. This data was obtained at the laboratory when the designing of the mixture took place.

3. Mixer drum:

   - Mixing of the different aggregate fractions: Firstly, the different aggregate fractions are homogeneized and mixed to obtain the planned grading curve. Mixing time: 2-5 s.

     Note: When working with crumb rubber to modify the mixture, this additive will be added in this moment together with the different aggregate fractions.

   - Heating the aggregates between 160º and 180º: The production process of asphalt mixtures requires high temperatures to guarantee the interaction between binder and aggregates. Temperature is a parameter of paramount importance for a correct bound of the binders into the bituminous matrix, so it must be very carefully controlled for all the materials.
   - Mixing of aggregates and binder (bitumen): later on, the binder/bitumen is added to the aggregate mixture for a time long enough to ensure a complete bound (thus avoiding stripping) between aggregates and bitumen. Mixing time: 20-24 s.
   - Dosage of polymeric waste: after the addition of bitumen, the following step is the dosage of the polymeric waste into the asphalt matrix. The expected time shall be similar to the determined at the laboratory tests (2-5 sec).

Note: In case of using polyethylene, it should be considered that both materials soften during the production process, interacting with the bitumen. However, if the mixture is not correctly made, lumps might formed with filler changing the grading curve and damaging the mixture.

3.2 TRANSPORTATION

When the asphalt mixture manufacturing is completed, the final product is poured out into the truck. A truck is placed under the asphalt plant and loaded prior to hauling.

Once the truck is loaded, the asphalt mixture is hauled to the worksite in optimal temperature and humidity conditions.

Figure 12. Transportation

3.3 LAYDOWN AND COMPACTION

Laydown and compaction procedures for the POLYMIX mixes is the same as for conventional mixes. Recommended compaction temperature is set at 155ºC.

Figure 13. Laydown and compaction

Note: When crumb rubber is used as modifier, it should be noted that rubber stick on the roller compactor and therefore, non-stick products should be sprayed on the metal roller.

3.4 QUALITY ASSURANCE

The quality control of POLYMIX mixes is the same as the quality control perform on conventional mixes. The number and type of tests and frequency will be specified by the applicable normative and specifications (in Spain the article 542.9.3 of the PG-3)

Besides, when the mixtures do not have the EC label, the stiffness modulus and the fatigue resistance must be determined when the supply or source of any of the materials that make the mixtures is changed, when the technical project manager deems it appropriate; or, in the case of Spanish normative, with the minimum frequency included in the Table 542.19 included in the article 542.

4. FACTORS AFFECTING PERFORMANCE

There are a number of factors that should be taken into account, since they might affect the mixture performance:

- The polymeric material should be as homogeneous as possible, both in composition and size grading, since it will be part of the aggregate structure of the resulting asphalt mixture. The minimum size grading is recommended in order to obtain a stable and homogeneous mixture.
- The addition of the polymer must be conducted after the addition of bitumen to the mixture, except in the case of crumb rubber, which is added to the aggregates prior to bitumen.
- The proposed mixing times are minimum values. Depending on the polymer used, an increase might be necessary.
- The recommended temperatures for manufacturing and compaction are 170º C and 155ºC respectively.
- When handling this type of mixtures, special care must be taken for keeping the manufacturing temperature, aiming at guaranteeing a correct laydown and compaction by avoiding temperature losses during haulage.

5. BENEFITS AND OTHER CONSIDERATIONS

5.1 COST FACTORS

Currently, POLYMIX mixes are more expensive than conventional mixes due to the higher cost of the recycled polymer as regards to natural aggregates. However, indirect economic benefits should be quantified derived from the better performance of POLYMIX mixes.

The increment of freight traffic and harsh climatic conditions in all European countries due to the climate change is increasing the need of maintenance inversions in old EU Member States. Conventional materials lack cost-efficiency when used in high stressed roads.

One of the main features of POLYMIX, that is common for all type of polymers studied in this project, is its better resistance to plastic deformation (rutting resistance) comparing with the reference. This characteristic makes these bituminous mixes especially suitable when high extreme temperatures and high weight traffic are combined. Therefore, the use of this technology by road asset managers will result in less maintenance costs.

Figure 14. POLYMIX pilot road

It should be also mentioned that according to the monitoring results, most of the PS was dissolved in the bitumen and an increase of the total bitumen content in the POLYMIX-PS mixture was observed. Because of this, the possibility to reduce the amount of virgin bitumen needed is expected. If this is confirmed, the cost of POLYMIX-PS would be significantly reduced.

5.2 ENVIRONMENTAL BENEFITS

Taking into account that POLYMIX mixtures incorporate 1% of polymeric waste, and the production of bituminous mixtures was around 276.4 millions of tons in Europe in 2012 (asphalt in figures, 2012, EAPA), only with a penetration of 5% of this technology in the market it would be possible to revalorize approximately 140,000 tons of polymeric waste in Europe.

The increase in the recycling of plastic waste has the following environmental benefits:

- Recycling of waste

During the construction of one km of a wearing course, around 1296 Tn. of the bituminous mixture are produced, laid down and compacted. Up to 10Tn of polymer waste might be recycled per km of road. This will encourage the development of more efficient plastic waste collection schemes to provide a stable supply of material. Waste plastic companies will not prepare sorting and production of recycled plastic if they have no security for a stable supply. New alternatives for the reuse of recycled materials increase their demand and the growth of business interests.

- Resource savings

The volume of polymer waste used in each mixture replaced the same volume of natural aggregates. A total amount of around 60 ton of aggregates were saved during the construction of the pilot road.

- Emission reductions

The recycling of the polymer waste (PS, ELTs, PE and PP) implies a reduction of the same amount of polymer waste that is sent to landfills or burned in an incineration plant.

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