Sustainability & Environment

Recycled plastics from different sources for asphalt pavement

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Abstract

New construction projects are developed with the aim of incorporating used polymeric material to the asphalt mixes to reduce the environmental impact and to improve the performance of the asphalt layers. The polymers and plastics are part of the solid waste as the consumption of these materials grows continuously in the modern society. Their volume contribution to the total waste is very high. The amount of the synthetic polymers in landfills in the world has increased in the last decades and in various countries, only a small percentage of the generated waste is recycled. The main plastic waste sources are industrial (scrap and non-conforming plastic material), agricultural (plastic recipients and films) and urban (human consumption and solid urban - dubbed USW, urban solid waste). Most of the USW may be divided in three classes: • simple plastic waste, adequately classified and separated, • mixed plastic waste, as the different plastic types are mixed, and, • mixed plastic waste combined with paper, cardboard and/or metals Between the benefits derived from this project is the reduction of environmental problems such as: landfill waste accumulation, contamination, quarries exploitation impact. In addition, improvement of the resistance of the asphaltic mixtures and road maintenance reduction are two of the most relevant advantages of this technology implementation. We consider in the scope of this project, the technical support to the national responsible entity in charge of the definition of alternatives for waste management and the drafting of the regulatory framework for the public hiring of the road construction.

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4. INTRODUCTION

For more than 3 decades, YPF, an Argentinean O&G based company, has tested innovations in bitumen. Examples of these innovations have been diesel resistant bitumen, bitumen with recycled pneumatics and bitumen with reused plastics. Over time, various public and private players have participated in these initiatives.

The present study involves the assessment in the lab and later in the field, of asphalts that incorporated recycled plastics. It has been developed considering the imminent need to migrate from the current usual linear economic model to a circular one, as in the latter prevails the material reutilisation, recycling and usage reduction.

If costs are reduced with the waste reutilisation, economic benefits for the consumer will result with the subsequent social and environmental favourable impacts. Due to the large volumes of the different waste materials that are generated, the identification of potential uses for each waste is high in the global agenda resulting in a change of paradigm.

Various European initiatives [1] are examples of how the shift towards an efficient economy in the use of resources and low carbon emissions generates a framework which should result in economic improvements, guarantee the supply of essential resources, face climate change and limit the environmental impact.

The amount of the synthetic polymers in landfills in the world has increased in the last decades and in various countries, only a small percentage of the generated waste is recycled. The main plastic waste sources are industrial (scrap and non-conforming plastic material), agricultural (plastic recipients and films) and urban (human consumption and solid urban - dubbed USW, urban solid waste).

Among the different types of waste that are daily generated, this study proposes an alternative for the sustainable management of polyethylene (PE) packaging waste coming from the agricultural activities, the lubricant and other automotive fluid plastic packaging wastes, which may be incorporated into bitumen destined to road construction.

There are precedents such as the research by Huang et al. [2] on the use of solid waste in the construction of flexible pavements that concluded that the use of these materials in asphalt pavements presents a valuable opportunity if such waste materials are properly identified and selected to achieve a solution both technically and economically feasible at an industrial level. Hence, the physical-chemical compatibility between the bitumen and the recycled material, the available recyclable volume and its cost need to be analysed.

In this study, the addition of recycled plastic to bitumen is assessed both in the “wet way”, which involves adding the recycled plastic to the bitumen and in the “dry way”, where the recycled plastic is added as a fraction of the aggregates. This topic has been studied by several researchers [3, 4, 5, 6, 7]. In Argentina, Angelone et al. [8] analysed the influence of the incorporation by the dry process, of different percentages of recycled polyethylene coming from discarded "silo bags", ground in flakes and in pellets to an asphalt mixture, finding that it is possible to add recycled plastic in the laboratory without altering the routine manufacture of specimens and their addition improves the performance of asphalt mixtures mainly in relation to the behaviour against permanent deformations.

Hinishoglu and Agar [9] have investigated the use of recycled high-density polyethylene (HDPE) as a bitumen modifier in asphalt mixtures and concluded that these mixtures provide better resistance to permanent deformation due to their high Marshall stability. Attaelmanan et al. [10] also investigated the feasibility of using high density polyethylene as a modifier of the bituminous materials in pavements and the results obtained showed that their performance was better than that of conventional mixtures and that the thermal and humidity susceptibility can be reduced with the polyethylene aggregate. Similar conclusions are reported by Zoorob and Suparma [11].

On the other hand, the considerable increase in the number of heavy vehicles that circulate on the roads of Argentina as well as the magnitude of the loads they transport, led in many cases to the premature deterioration of these roads, such as the continuous deformation called "rutting", one of the most frequent damages associated with the repeated traffic loads on asphalt pavements.

The objective of this work is to identify a technological proposal to mitigate the bitumen roads damages while using recycled polymer in Argentina. The incorporation of recycled high- and low-density polyethylene (generically noted as PE) from different origins is assessed, to evaluate the methodology of incorporating plastics to the asphalt and compare the products obtained, through their main properties and rheological values, with asphalts made with both non-modified and modified bitumen.

This study was carried out by YPF with the Institute of Applied Mechanics and Structures of the National University of Rosario, in Argentina, the ACA (Argentine Cooperatives Association), which owns a plastic recycling plant and provided the recycled plastic and the road construction company “Unidad Ejecutora Corredor Vial Nº4 de la RP18”. It includes the characterization of the different bitumen and their use in asphalts to evaluate their mechanical behaviour as well as their use in the construction of paved road sections.

5. LABORATORY AND EXPERIMENTAL WORKS AND CONCLUSIONS

5.1. Materials

In the following subsections, the different raw materials used in the preliminary laboratory work and the later pavement construction are described.

5.2. Overview of the recycled plastics used

Two different kinds of recycled plastic were used, one of them made mainly of High-Density Polyethylene (HDPE-1) and the other, made of Low-Density Polyethylene (LDPE-2). These plastics came from the Plastic Residues Recycling plant owned by the ACA Cooperative, a private institution in Argentina. This recycling plant is in the industrial area of Cañada de Gómez, in the Santa Fe province.

Two homogeneous recycled plastic samples in granulated form were analysed, one composed of opaque green plastic lentils (Green Plastic, coded PV, from now on) and the other made of black plastic lentils (Black Plastic, coded PN) respectively. Each lentil granule had an average diameter of 0.5 cm with an approximate weight of 30 mg each, with an important apparent hardness.

Figure 1. Green Plastic (PV) and Black Plastic (PN) lentils

Using the Differential Scanning Calorimetry (DSC) technique, the constituent polymers of the two samples were identified. The main polymer identified was polyethylene (generically noted as PE in this study) in its various degrees of crystallinity. These determinations were made considering the main thermal transitions in the DSC technique of each material such as their Glass Transition (Tg), their Melting Point (Tm) and their Crystallization Point (Tc).

The PV and PN samples’ thermal profiles were carried out using a METTLER TOLEDO DSC 822e equipment configured to a dynamic heating from 30 °C to 350 °C with a speed of 10 °C min- 1 referred to an alumina standard and an atmosphere of constant nitrogen flow (50 mL min^{-1}). Sample ranging from 2.5 to 5.0 mg were weighed in aluminium crucibles of 4 µL. Each sample was subjected to several thermal sweeps.

5.3. Green Plastic (PV) analysis

The PV material was obtained from the recycling of used phytosanitary drums which had been subjected to the triple wash and puncture conditioning process, as stated by the IRAM 12069 argentine standard for the safe and environmentally responsible handling of phytosanitary waste.

To characterise this material, a PV sample was subjected to 3 thermal sweeps, exhibiting different transitions of the first order. The obtained results are shown below in Figure 2 and Table 1. In the first scan (PV1), there was an endothermic peak of melting point (Tm) at 133 °C, typical of a thermoplastic with amorphous crystalline arrangement typical of the high-density polyethylene (HDPE) type. Subsequently, an exothermic transition is observed at 240 °C that may be assigned to a degradation process. Starting at 300 °C, this material showed a degradation profile due to the evident drop in the level of heat flow.

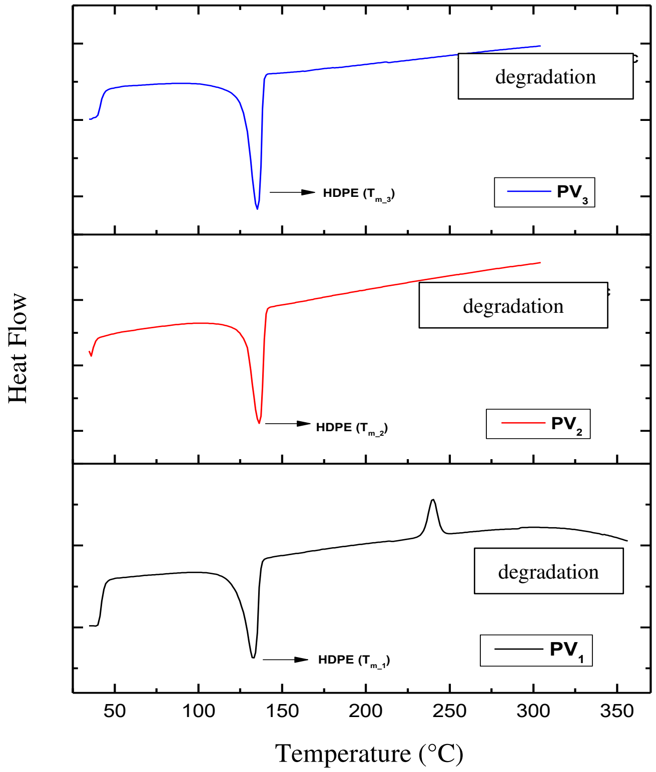

Figure 2. Green Plastic (PV) thermograms; PV1 first, PV2 second and PV3 third runs.

Considering that the HDPE presents a high thermal stability and a structural rearrangement, in the second sweep (PV2), it undergoes a slight shift at 136 °C that remains unchanged in the third sweep (PV3).

Table 1. Characterisations of the different thermal sweeps.

N° of sweep	T_m (°C)	Characterisation	T_c (°C)	Characterisation
PV_1	133	HDPE	> 300	Degradation
PV_2	136	HDPE	> 300	Degradation
PV_3	135	HDPE	> 300	Degradation

5.4. Black Plastic (PN) analysis

The PN sample was obtained from the recycling of “silo bags”. These “silo bags” are extensively used in Argentina to provide low cost temporary hermetic storage of grains. Dirk E. Maier and Sam Cook [12] highlighted in 2014 that “Silo bag use for grain storage was developed in Argentina in the early 2000s but is now gaining popularity worldwide as a lower cost storage solution for producers are commercial grain managers, especially during times of record harvests and transportation delays”.

When analysed this material in the DSC, three thermal sweeps of a PN sample showed a similar profile to the previously analysed PV sample, indicating that the PN sample consists also in a mixture of different thermoplastics as it is shown below in Figure 2 and Table 3. There was evidence of the presence of two types of polyethylene with different structural grades. In the first run (PN1), the glass transition (Tg) of the medium density polyethylene (MDPE) is located at 39 °C, giving rise later to an endothermic transition at 124 °C. In addition, a slight peak at 109 °C is observed which may be assigned to low-density polyethylene (LDPE).

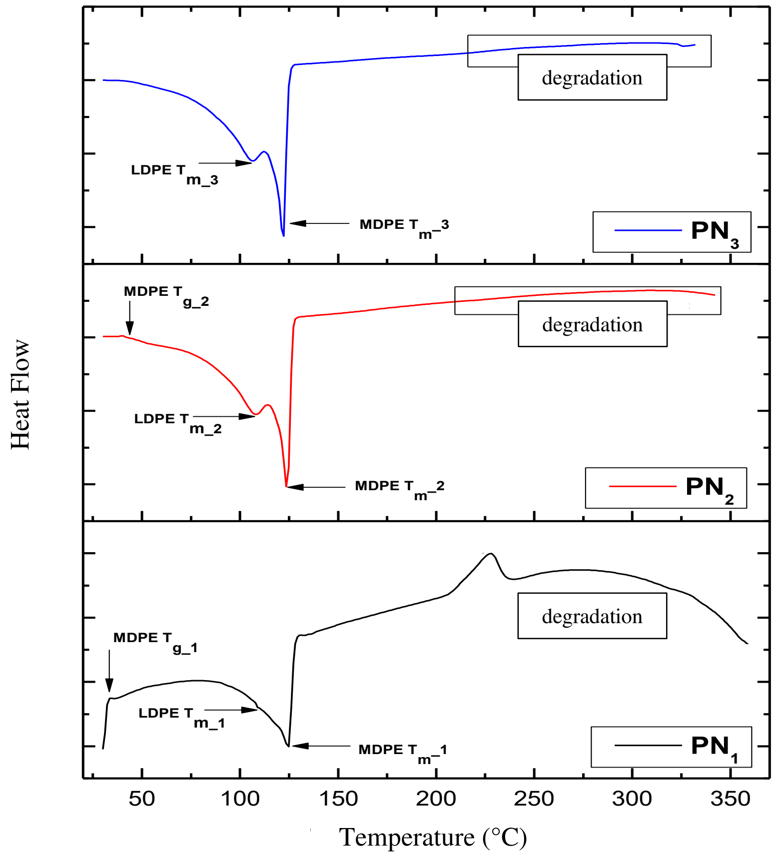

Figure 3. Black Plastic (PN) thermograms; PN1 first, PN2 second and PN3 third runs.

During the temperature rise, an exothermic crystallization transition is observed in the PN1 thermogram, centred at 240 °C, and a later melting point can be identified at around 350 °C. Between the PN2 and PN3 thermograms, the differences are very subtle. However, the distinctive appearance of two peaks which correspond to LDPE and MDPE is more evident. This behaviour is typical of thermoplastic polymers whose thermal stability is characteristic.

Table 2 Characterisations of the different thermal sweeps

N° of sweep	Tg (°C)	Characterisation	Tm (°C)	Characterisation	Tc (°C)	Characterisation
PN_1	39	MDPE	109	LDPE	>300	Degradation
PN_2	40	MDPE	126	MDPE	> 300	Degradation
PN_3	-	-	124	MDPE	> 300	Degradation

5.5. Recycled plastics DSC results discussion

The Green Plastic (PV) sample analysed showed that it was composed of high-density polyethylene (HDPE) since its melting point was identified at 133 °C.

The Black Plastic (PN) sample analysis showed that it is made of low and medium density polyethylene (LDPE and MDPE), per the detection of their melting points at 109 °C and 124 °C, respectively. At the same time, a crystalline transition was observed centred at 240 °C.

Per literature, HDPE is one of the most important thermoplastic materials in the industry, whose melting point is 135 ºC. The thermal analysis performed on the plastics was consistent with this thermal transition for HDPE-1 made with no additives. Differently, LDPE-2 exhibits a reduction of its melting point at 126 ºC that may be explained by the presence of anhydride maleic, which alters its thermal behaviour [7].

5.6. Overview of the different bitumen used

In lab studies conducted before the field test, a softer CA20 bitumen was selected for the incorporation of the recycled polyethylene in pellets and powder in four increasing amounts, from 1% to 4%. These samples were compared with two other bitumen control samples, a conventional CA30 bitumen and a commercially available polymer modified bitumen named AM3.

The CA30 was a regular bitumen while the AM3 is a styrene modified bitumen. Both bitumen met their respective related Argentinean specifications. The respective CA20's, the CA30's and AM3's physical and rheological characteristics are indicated in Table 3.

A good compatibility between the recycled plastics used and the bitumen would be expected, as both materials come from the petroleum industry. However, in previous tests [12], it had been found that levels of 4% of PE when added to a CA30 bitumen, did not always result in a homogenous distribution of the PE material.

These previous lab studies also highlighted that adequate mixings' temperatures, speed and time were key in the mixing step to get homogeneous final products. For these reasons, a CA20 bitumen type was chosen as the best option to ensure an adequate plastic-bitumen compatibility.

Table 3. Characterisation of the bitumen samples

Assay	CA20	CA30	AM3	Standard
Penetration at 25ºC, 0.1 mm	85.7	59.8	59.7	IRAM 6576:2004
Softening Point, ºC	46.0	48.6	80.5	IRAM 6841:2011
Penetration index, IP	-0.94	-1.14	4.89	IRAM 6604:2002
G* a 60ºC, kPa	1.95	3.11	7.16	ASTM D 7175:2008
δ a 60ºC, º	85.8	85.4	60.9	ASTM D 7175:2008
G* .sen δ a 60ºC, kPa	1.94	3.10	6.26	
G* / sen δ a 60ºC, kPa	1.96	3.12	8.19	
Torsional recovery, %	5.0	5.0	82.2	IRAM 6830:2011
Viscosity at 135ºc, S21, dPas	4.50	5.50	44.56	IRAM 6837:2011

5.7. Experimental Pavement sections

Between late 2018 and January 2019, five experimental sections were then constructed on the descending lane towards Rosario city of the Provincial Route N°18, in the Santa Fe province, from Km 11.0 to Km 11.5. Four of the 5 pavement sections, of approximately 100 m each, were built using modified bitumen with either recycled Green plastic (PV) or Black plastic (PN), incorporated by the "dry process" (VS) or the "wet process" (VH). A fifth asphalted section used a conventional CA30 bitumen, which was selected as the reference pavement for this experimental work. Figure 4 shows a scheme of the constructed pavement sections:

← Descending lane towards Rosario city

Section 1	Section 2	Section 3	Section 4	Section 5
CA20 – PN/VS	CA20 – PN/VH	CA20 – PV/VS	CA20 – PV/VH	CA30
		CA20 – PN/VH		
100 metres	100 metres	100 metres	100 metres	100 metres

Figure 4 – Pavement section scheme

5.8. Asphalt production method used when the recycled plastic was incorporated per the "dry" process (CA20-PN/VS and CA20-PV/VS types)

Based on the lab experimental work previously described, a recycled plastic amount of 2% by weight of the final asphalt mix was selected when the "dry" process was used, regardless of the type of plastic (PN or PV) to be used. The elaboration method chosen was as follows:

a) The amount needed of lime and recycled plastic in pellets (either the PN or the PV type) were calculated
b) Once these amounts were premixed in a mixer, the mixed material was placed in bags
c) The bagged material above mentioned, was then loaded to the filler silo
d) The related asphalts were then made at 170 °C by the "dry" process, using non-modified CA20 bitumen

5.9. Asphalt production method used when the recycled plastic was incorporated per the "wet" process (CA20-PN/VH and CA20-PV/VH types)

A recycled plastic amount of 3% was selected as the amount to be added to the CA20 bitumen when the "wet" process was used, regardless of the type of plastic (PN or PV). The elaboration method chosen was as follows:

a) The C20 bitumen was preheated up to 170 °C
b) The recycled plastic was added to the C20 bitumen in form of "rain" of pellets using an on-site mill, in batches of 2 Tons.
c) This process continued till a bright, lump-free modified bitumen was obtained. The PN plastic mixing time needed to achieve this was 2 to 3 hours, while the PV needed from 3 to 5 hours.
d) The modified bitumen so obtained by this "wet" process, was then pumped in the same way of the conventional bitumen.

The "wet" process modified bitumen samples' results are compared to the non-modified bitumen types in Table 4:

Table 4. Modified bitumen obtained by the "wet" process during the construction

Tests	Units	CA20 – PN/VH	CA20 – PV/VH	CA20	CA30
Mixing time @ 170 °C	Hours	3	4	‘	‘
Penetration	0.1 mm	47	40	86	60
Softening Point	°C	67	65	46	49
Rotational Visc. @ 135 °C	mPa*s	9.7	9.2	4.5	5.5
Torsional Recovery	%	15.0	15.5	5.0	5.0
PG Grade per SHRP	-.-	70-22	82-16	64-22	70-16

All the pavement sections used the same bitumen content as well as the same layer depth (between 35 mm to 40 mm) and lane width (of 3.65 m).

5.10. Physical and Mechanical tests conducted

The methods of compaction usually allowed for the preparation of the test specimens are those corresponding to the procedures EN 12697-32: 2007 (vibratory compactor) and EN 12697-33: 2007 (roller compactor). In this opportunity, the roller compactor was used.

The maximum theoretical densities were obtained from the moulding and compaction of Marshall specimens following the guidelines indicated in point 4 of Standard IRAM-6845 (Draft 2011) and summarised together with, other lab results in Table 5:

Table 5 – Tests on the samples extracted during the pavement construction

Tests	CA20 – PN/VS	CA20 – PN/VH	CA20 – PV/VS	CA20 - PV/VH	CA30
Measured density	2.325	2.447	2.300	2.426	2.414
Maximum theoretical density	2.443	2.540	2.465	2.557	2.562
Air Voids [%]	4.8	3.7	6.7	5.1	5.8
VMA [%]	16.4	15.9	18.2	17.2	17.9
Voids filled with asphalt [%]	70.8	77.0	63.4	70.4.	67.7
Stability [kN]	17.4	12.3	20.5	13.2	12.2
Flow [mm]	5.04	4.88	6.59	4.28	3.9
S/F [kN/mm]	3.5	2.5	3.1	3.1	3.1
Tensile Strength Ratio - TSR [%]	93.0	99.0	85.0	72.0	59

The Stability to Flow ratio (S/F) for all samples were similar and are shown in Table 5.

The respective resistances of the asphalt samples to moisture induced damage were assessed measuring the Indirect Tensile Strength at 25 °C and at constant vertical deformation of 50 mm/min of a set of moisture conditioned specimens and compared to the Indirect Tensile Strength of a set of specimens without moisture conditioning. The Tensile Strength of the conditioned subset of specimens divided by the Tensile Strength of the dry subset is the Tensile Strength Ratio (TSR) and was determined for each asphalt sample. As shown in Table 5, the plastic incorporation to the CA20 bitumen substantially improved their TSR when compared to the TSR of the non-modified CA30 sample adopted as reference.

The susceptibility of bituminous materials to deform was assessed by the rut created by the repeated passes of a loaded wheel at constant temperature for a stipulated number of load cycles. The procedure B for small scale device of this standard was used, adopting 60 ° C as test temperature and 10,000 as the number of load cycles.

The parameters that were considered for the assessment of the behaviour of asphalt mix against rutting, for the case of small-scale device, are the:

- WTS (wheel tracking slope) deformation speed expressed in mm every 1000 load cycles, and,
- PRD (proportional rut depth) expressed as a percentage of the total thickness

For the PN modified compounded asphalts obtained by the "dry" and "wet" process, the following results were measured:

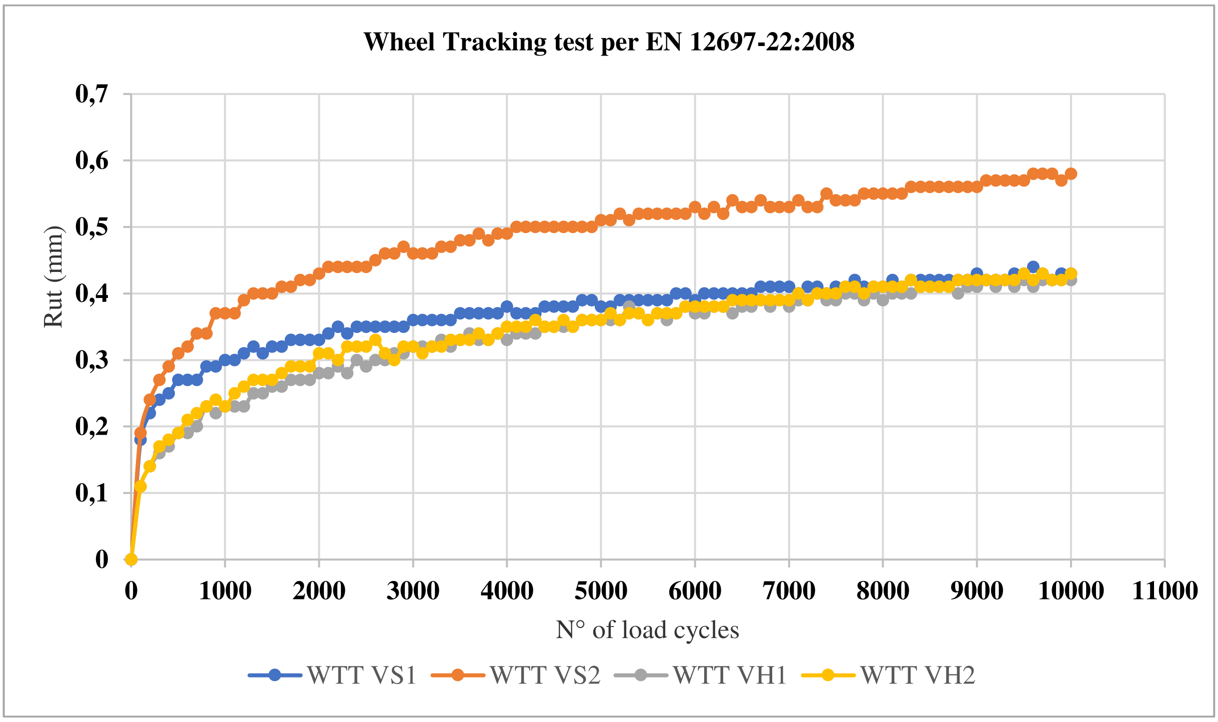

Figure 5 - Wheel Tracking Test on "dry" (VS) and "wet" (VH) process PN modified compounded asphalts

Table 6 - Wheel Tracking Test on "dry" (VS) and "wet" (VH) process PN modified compounded asphalts

Wheel Tracking Test	**Units**	**CA20 – PN/VS**		**CA20 – PN/VH**	
Specimen subcode ➔		**VS1**	**VS2**	**VH1**	**VH2**
Wheel Tracking Slope (WTS)	mm*10^3	0.0096	0.0141	0.014	0.012
Rut Depth (RD)	mm	0.43	0.58	0.43	0.42
Proportional Rut Depth (PRD)	%	0.86	1.06	0.86	0.84

For the case of the PV modified compounded asphalts obtained by the "dry" and "wet" process, the following results were measured:

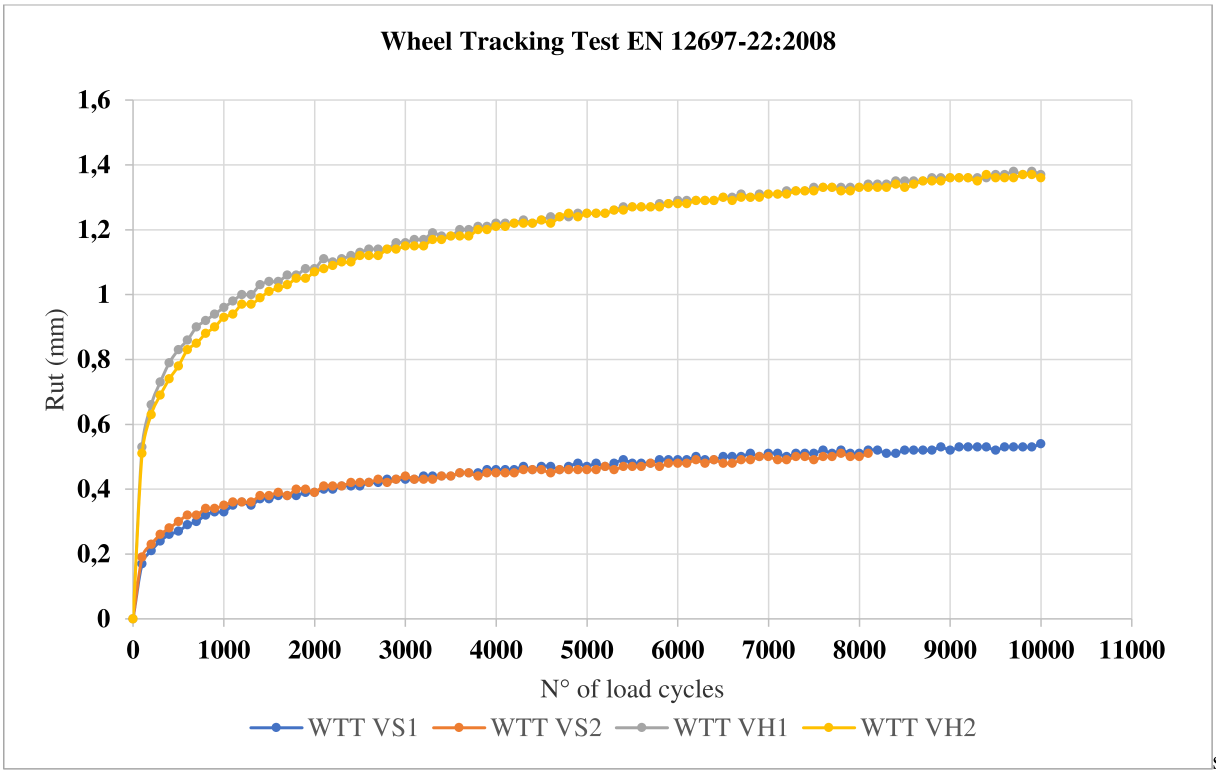

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Figure 6 - Wheel Tracking Test on "dry" (VS) and "wet" (VH) process PV modified compounded asphalts

Table 7 - Wheel Tracking Test on "dry" (VS) and "wet" (VH) process PV modified compounded asphalts

Wheel Tracking Test	**Units**	**CA20 – PV/VS**		**CA20 – PV/VH**	
Specimen subcode ➔		**VS1**	**VS2**	**VH1**	**VH2**
Wheel Tracking Slope (WTS)	mm*10^3	0.01322	0.01225	0.0244	0.0225
Rut Depth (RD)	mm	0.54	0.51	1.37	1.36
Proportional Rut Depth (PRD)	%	0.86	1.06	2.74	2.72

5.11. Conclusions

This was the first asphalt pavement construction in Argentina where recycled plastics from drums and silo bags were used, to foster a circular economy as the main objective. Four pavement sections of 100 m length using differently modified asphalts were constructed using recycled plastics, obtained from ACA's used plastic recycling plant. Also, a CA30 control section was built.

The lab results of the asphalts obtained from the experimental paved sections were in good agreement with the product previously made and analysed in the lab, however, the voids measured in the experimental sections showed a higher value, between 7 to 12%, when compared to the lab ones.

An improved resistance to moisture induced damage was detected in all asphalts that incorporated recycled plastics as measured by the Tensile Strength Ratio when compared to the CA20 asphalt that was adopted as reference.

Also, a better performance with regards to the permanent deformation response was detected in the asphalt samples made with the modified bitumen by the "wet process". Nevertheless, all paved sections complied with the permanent deformation specified by the Argentinean road authorities.

Cracking problems impacting pavement durability were observed decades ago in the USA., in pavements that included modified bitumen with recycled PE waste.

Periodical assessments of our experimental sections are being conducted, which include macrotexture (by the sand patch method), rut depth as well as sample extractions to conduct lab tests, so far with encouraging results, especially on the CA20 – PN/VH (Section 2).

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