

Experimental pervious pavement parking areas in the North of Spain

Aires de stationnement expérimentales en pavés poreux dans le Nord de l'Espagne

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RÉSUMÉ

Les inondations et la pollution diffuse sont devenues des problèmes urbains majeurs, affectant la vie quotidienne dans les villes. Les pavés perméables peuvent atténuer ces problèmes, en les utilisant dans de grandes zones urbaines pour des aires de parking. Soixante-huit places de stationnement ont été construites sur trois aires de stationnement expérimentaux dans le nord de l'Espagne en combinant quatre surfaces perméables (pavés en béton autobloquants, asphalte poreux, béton poreux à base de polymère modifié et de l'herbe renforcée avec des cellules en plastique et en béton) et trois sous-couches (granulats calcaire, granulats recyclés et laitiers d'aciéries de conversion) avec et sans géotextiles. Le pH, L'oxygène Dissous (OD), la conductivité électrique (CE), les Matières en Suspension (MES), la turbidité et des Hydrocarbures Totaux (HCT) ont été analysés afin de comparer le comportement général des différentes combinaisons de surfaces perméables et de sous-couches. La perméabilité et le comportement d'infiltration ont été mesurées sur le terrain et dans le laboratoire, en utilisant le perméamètre LCS, et les infiltromètres Cantabriques portable et fixe. Les surfaces en asphalte poreux et les sous-couches en granulats calcaires ont montré le meilleur comportement, tout en soulignant l'importance des opérations de maintenance.

ABSTRACT

Flooding and diffuse pollution have become great urban problems, affecting daily life in cities. Pervious pavements can reduce these problems, and can occupy large urban areas by their use in car parks. Sixty-eight parking bays were constructed in three experimental parking areas in the north of Spain combining four pervious surfaces (interlocking concrete blocks pavement, porous asphalt, polymer modified porous concrete and reinforced grass with plastic and concrete cells) and three sub-bases (limestone aggregates, recycled aggregates and Basic Oxygen Furnace slag (BOF-slag)) with and without geotextiles. Dissolved Oxygen (DO), pH, Electric Conductivity (EC), Total Suspended Solids (TSS), Turbidity and Total Petroleum Hydrocarbons (TPH) were analyzed to compare the general behaviour of the different combinations of pervious surfaces and sub-bases. Permeability and infiltration behaviour were measured under both field and laboratory conditions, using the LCS permeameter, Cantabrian Portable (CP) and Cantabrian Fixed (CF) Infiltrimeters. Porous asphalt surfaces combined with sub-bases made of limestone aggregate showed the best behaviour, and also highlighted the importance of maintenance.

KEYWORDS

Infiltration, Pervious pavements, Rainwater harvesting, SUDS, Water quality

1 INTRODUCTION

Global population growth and its tendency to concentrate in urban areas is increasing pressure on the natural environment (Eigenbrod et al., 2011). Future levels of global urbanization are expected to rise from 50% in 2009 to 70% in 2050 and in developed countries these levels will rise from 75% to 86% (United Nations, 2011). Sealing of the natural soil due to this growth in urban zones disrupts the natural water cycle by increasing runoff peak flows (90% of the rainfall volume for a storm in urban areas versus 25% of the rainfall volume in forested watersheds), reducing time to peak, even for short duration and low rainfall intensity events (Shang and Wilson, 2009), and increasing the urban heat island effect (Haselbach et al., 2011). Climate change has intensified flooding problems (Ntelekos et al., 2010) by modifying the patterns of rainfall around the world. Significant increases in extreme rainfall intensities and duration are expected in some regions (Christensen and Christensen, 2003) whilst long periods of drought have been predicted for others. These possible scenarios leads to increasing vulnerability of cities to flooding and drought (Karamouz et al., 2011) where population density rises and conventional drainage becomes insufficient to manage future water flows and diffuse pollution (Swan, 2010).

There is broad agreement of the necessity to increase permeable surfaces in urban areas to reduce runoff peak flows (Dietz, 2007). In this context pervious pavements (PPS) have important advantages, not only in the reduction of runoff by decreasing impermeable areas (Rushton, 2001), but also in the reduction of pollutants (Coupe et al, 2003), recharge of aquifers (Ferguson, 2011), erosion control (Wright, 2008) and increased urban amenity (Ellis et al., 2004). The main applications of PPS in urban areas are car parks for light traffic where PPS have the potential to occupy large urban areas (Shu et al., 2011), access roads for residential streets, parking areas and roads for recreational facilities such as golf courses and bike lanes, amongst others (Scholz and Grabowiecki, 2009).

There are many field studies of the efficiency of PPS such as Collins et al. (2008) in the USA, Pratt et al. (1995) in the UK, Lucke and Beecham (2011) in Australia, Pagotto et al. (2000) in France, and Acioli et al. (2005) in Brazil, amongst others. In spite of the fact that the results are slightly different depending on the climatic conditions of the region where the car park is located, important benefits in terms of runoff reduction, water quality and amenity were demonstrated in all of them.

The aim of this paper is focused on a general analysis of the water quality and pavement functionality in three experimental parking areas ("La Guía", "Parque Tecnológico" and "Las Llamas") located in Asturias and Cantabria, in the north of Spain. The Construction Technology Applied Research Group (GITECO) of the University of Cantabria in collaboration with the Sustainable Drainage Applied Research Group at Coventry University has introduced PPS technology to Spain, and created the Sustainable Urban Drainage System laboratory (SUDSlab). The PPS were constructed with four different surfaces (interlocking concrete block pavement, porous asphalt, polymer modified porous concrete and grass reinforced with plastic cells) with and without geotextile, and with two different sub-bases (limestone aggregates and Basic Oxygen Furnace slag (BOF-slag)). The influence of geotextile was shown in terms of biodegradation of hydrocarbons. The impacts on water quality of BOF-slag used in the sub-base were compared with the usual sub-base of limestone aggregate.

2 METHODOLOGY

2.1 Location and climatic characteristics

Of the three experimental parking areas, "La Guía" and "Parque Tecnológico" are located in the city of Gijón (Asturias) and "Las Llamas" is located on the campus of the University of Cantabria in Santander (Cantabria), all three on the north coast of Spain. According to the Köppen-Geiger climatic classification (Essenwanger, 2001), Asturias and Cantabria have temperate climates without a dry season and with temperate-warm summers, corresponding to a Cfb climate. The average annual temperature is 15°C in this part of the country with average temperatures of 10°C during the winter and 20°C during the summer. Santander has the fourth highest annual average precipitation in Spain with 1,136 mm and Gijón is similar, always over 1,000 mm per annum. These regions of Spain also have the highest average number of days with precipitation above 1 mm, with 125-150 days per year (AEMET, 2011).

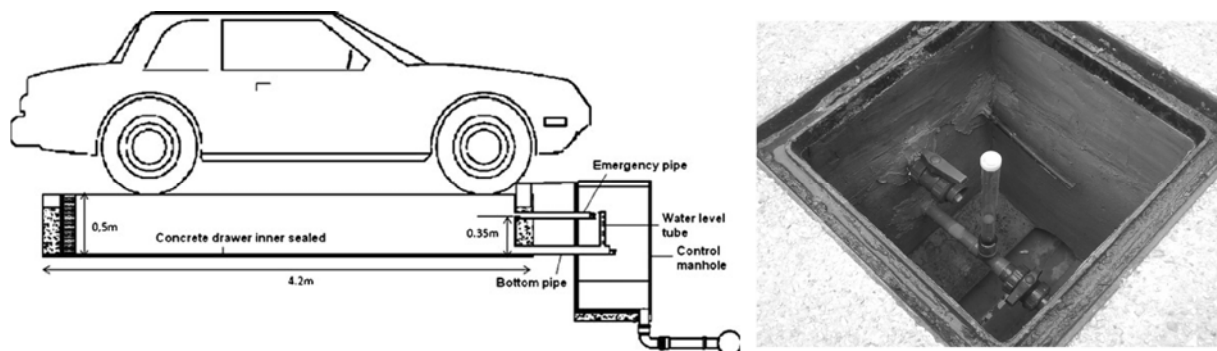


Figure 1. (Left) Generalised scheme of the PPS parking bay for all experimental parking areas and (right) the control manhole.

2.2 Experimental parking areas

The “La Guía” car park was constructed in 2005, being the first full-scale trial of a PPS carried out in Spain, with 15 experimental parking bays (Bayon et al., 2005). It is also part of a bigger parking area of 22,000 m² in total with 798 parking bays of reinforced grass with Atlantis plastic cells. It is close to the “La Guía” Sport Centre Hall and the football stadium of “El Molinón” in Gijón (Asturias). The experimental bays designed and monitored in this car park consist of three different pervious pavements: 6 bays with interlocking concrete block pavement (ICBP), 6 bays with porous asphalt (PA-12; Bustos and Pérez, 2007) and 3 bays of reinforced grass with Atlantis plastic cells; these latter represent the rest of the bays in the parking area. Clean limestone was used as the sub-base in the 3 bays with ICBP and the 3 bays with PA-12 surface courses, whilst recycled aggregates were used in the other 3 bays with ICBP and PA-12. The objective was to assess the best combination of pervious surface and sub-base. All experimental bays were 5 m long, 2.50 m wide and had 0% slope (see Figure 1 and Table 1). The ICBP and PA-12 surfaces had an extra layer of draining plastic cells (Atlantis) without fill and under sealed added in order to allow effluent to drain towards the control manhole as shown in Figure 1.

The “Parque Tecnológico” car park was constructed in 2010 and was composed of 8 bays with two different surfaces (4 bays of ICBP and 4 bays of PA-12), all with a BOF-slag sub-base. The objective here was to study the influence of this sub-base incorporated into different PPS. All bays were 4.2 m long and 2.4 m wide (see Table 1) with a cross section as shown in Figure 1.

The “Las Llamas” car park, had 45 experimental bays, and was one of the largest monitored experimental car parks with PPS in the world when built in 2008. Five different surfaces were installed in combination with either two different geotextiles or without geotextile at all, to compare water quality and quantity behaviour and assess the importance of the presence of geotextiles. Of the parking bays designed and monitored in this car park, 19 consisted of ICBP (ten with Aquaflo concrete blocks (Hanson-Formpave) and nine ICBP bays of Bloques Monserrat concrete blocks), nine bays of PA-12, nine bays of polymer modified porous concrete (PMPC), six bays of reinforced grass with concrete cells, and finally, two bays of reinforced grass with plastic cells. All the experimental bays were 4.2 m long and 2.4 m wide (see Table 1).

2.3 Monitoring methodology

The monitoring methodology in all the experimental parking areas was divided into two: water quality (particularly focused on retention capacity and biodegradation of hydrocarbons in association with the geotextile) and pavement functionality (related to water infiltration capacity and storage properties) as well as amenity (possible structural damage and visual aspects).

2.3.1 Water quality monitoring

The following parameters were monitored: pH, Dissolved Oxygen (DO), Electric Conductivity (EC),

Total Suspended Solids (TSS), Turbidity and Total Petroleum Hydrocarbons (TPH). These parameters were chosen to comply with the general regulatory compliance of water in Spain. Samples of the effluent were taken from each of the control manholes (Figure 1). DO, pH and EC values were taken in situ using multi-parameter probes (Hach HQ 40D) in each parking bay. The remaining parameters were measured in the laboratory using a turbidimeter (Hach 2100 P Turbidimeter) and the Horiba OCMA-310 absorption infrared oil detector using S-316 as the solvent for TPH analysis. TSS was measured using a Sartorius Filtering ramp, glass microfiber filters, Rocker 400 Vacuum pump, desiccators and laboratory oven. Finally, portable IAQRAE and QRAE+ instruments were used to measure O₂ and CO₂ concentrations as well as temperature and humidity inside the pavement in order to assess the development of hydrocarbon biodegrading communities in the geotextile layer (Coupe et al., 2003; Bayon et al., 2005; Gomez-Ullate et al., 2010; Newman et al., 2011).

Table 1. Parking bay sections of each parking area.

	Layer	ICBP (Aquaflow)	ICBP (Montserrat)	PA-12	PMPC	Concrete cells	Plastic cells
"La Guía" (Gijón) 798 bays (15 monitored) 2005	Surface	—	100mm	100mm (2 layers of 50mm)	—	—	80mm
	Base	—	Clean limestone aggregate (50-70mm)		—	—	Clean limestone aggregate (50- 70mm)
	Geotextile	—	Terratest TMA 125	Geotextile (Amopave)	—	—	—
	Sub-base	—	Recycled aggregates (3 bays)	Recycled aggregates (3 bays)	—	—	Blast furnace slag with a low infiltration rate
Clean limestone without fines (3 bays)			Clean limestone without fines (3 bays)				
"Las Llamas" (Santander) 45 bays (45 monitored) 2008	Surface	80mm	100mm	80mm	80mm	90mm	80mm
	Base	Clean limestone aggregates (50-70mm)					
	Geotextile	Inbitex (4bays)	Polyfelt TS30 (4bays)	Polyfelt TS30 (4bays)	Polyfelt TS30 (4bays)	Polyfelt TS30 (2bays)	Polyfelt TS30 (2bays)
		One-Way (4bays)	Danofelt PY150 (4bays)	Danofelt PY150 (4bays)	Danofelt PY150 (4bays)	Danofelt PY150 (2bays)	
		Without geotextile (2bays)	Without geotextile (1bay)	Without geotextile (1bay)	Without geotextil e (bay1)	Without geotextile (2bays)	
Sub-base	Clean limestone (350-370mm)						
"Parque Tecnológico" (Gijón) bays (8 monitored) 2010	Surface	—	100mm (4bays)	80mm (4bays)	—	—	—
	Base and geotextile	—	50 mm of clean limestone aggregates (4-8 mm)	70 mm of clean limestone aggregates (4-8 mm)	—	—	—
	Sub-base	350 mm of BOF-Slag					

2.3.2 Pavement functionality

To assess the pavement functionality of the car park, field and laboratory tests of permeability and infiltration capacity were undertaken. Visual inspection of the surface was carried out to check for possible damage. An LCS permeameter and Cantabria Portable (CP) Infiltrometer were used in the field to measure permeability and infiltration behaviour respectively (Rodríguez-Hernández et al., 2009). A Cantabrian Fixed (CF) Infiltrometer was also used to measure the infiltration behaviour of each pervious surface in the SUDS laboratory at the University of Cantabria (González-Angullo et al., 2008; Rodríguez-Hernández et al., 2012; Sañudo-Fontaneda et al., 2013) (Figure 2).

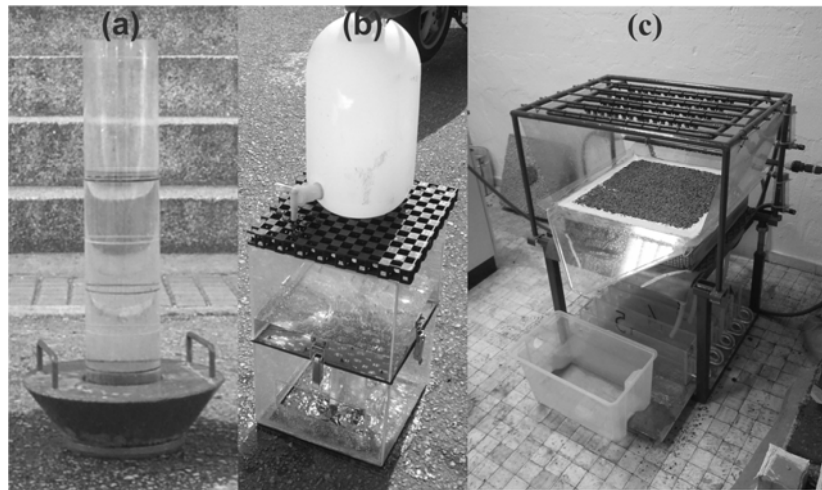


Figure 2. Field and laboratory devices used to analyze pavement functionality: (a) LCS permeameter. (b) CP Infiltrometer. (c) CF Infiltrometer.

3 RESULTS AND DISCUSSION

3.1 Water quality

The PA-12 and PMPC surfaces registered the highest biological activity, represented by high values of O_2 consumption and CO_2 production within the PPS, up to six times higher than the values registered for ICBP surfaces. It is thought that the low values obtained from the ICBP surfaces were due to the open spaces between blocks allowing loss of gases into the overlying atmosphere, but this does not mean that there is no or low biological activity in the structure. It was found that the parking bays made of grass reinforced with plastic cells had high biological activity due to their organic character.

Monitoring of pH found that surfaces of PMPC registered the highest average values ($pH = 8.25$), whilst the lowest average values were obtained from the grass reinforced with plastic cells ($pH = 7.75$). All pervious surfaces with limestone aggregates in the sub-base were alkaline, between 7.75 and 8.25. Samples taken from parking bays with BOF-slag sub-bases had pHs of up to 12, due to the highly alkaline nature of the material used in the sub-base (Figure 3).

No clear differences were observed between parking bays with sub-bases made of limestone aggregates and BOF-slag in terms of DO with values at 5.5mg/L on average, above the lower limit of 4mg/L required for good quality water according to Spanish legislation (Figure 3).

In the long term, it was found that values of TPH settled at low values in the majority of cases, close to the detection limit of the HORIBA instrument (0.1 mg/L). However, soon after construction initial values of TPH were above 0.4 mg/L in all cases, gradually decreasing to between 0.1 and 0.2 mg/L, apart from "Parque Tecnológico" where the values remained at 1.2 mg/L. More hydrocarbons were retained associated with PA-12 than with the ICBP surfaces. However, the PA surfaces appeared to introduce pollution initially due to the bonding emulsion used in asphalt pavements (Figure 3).

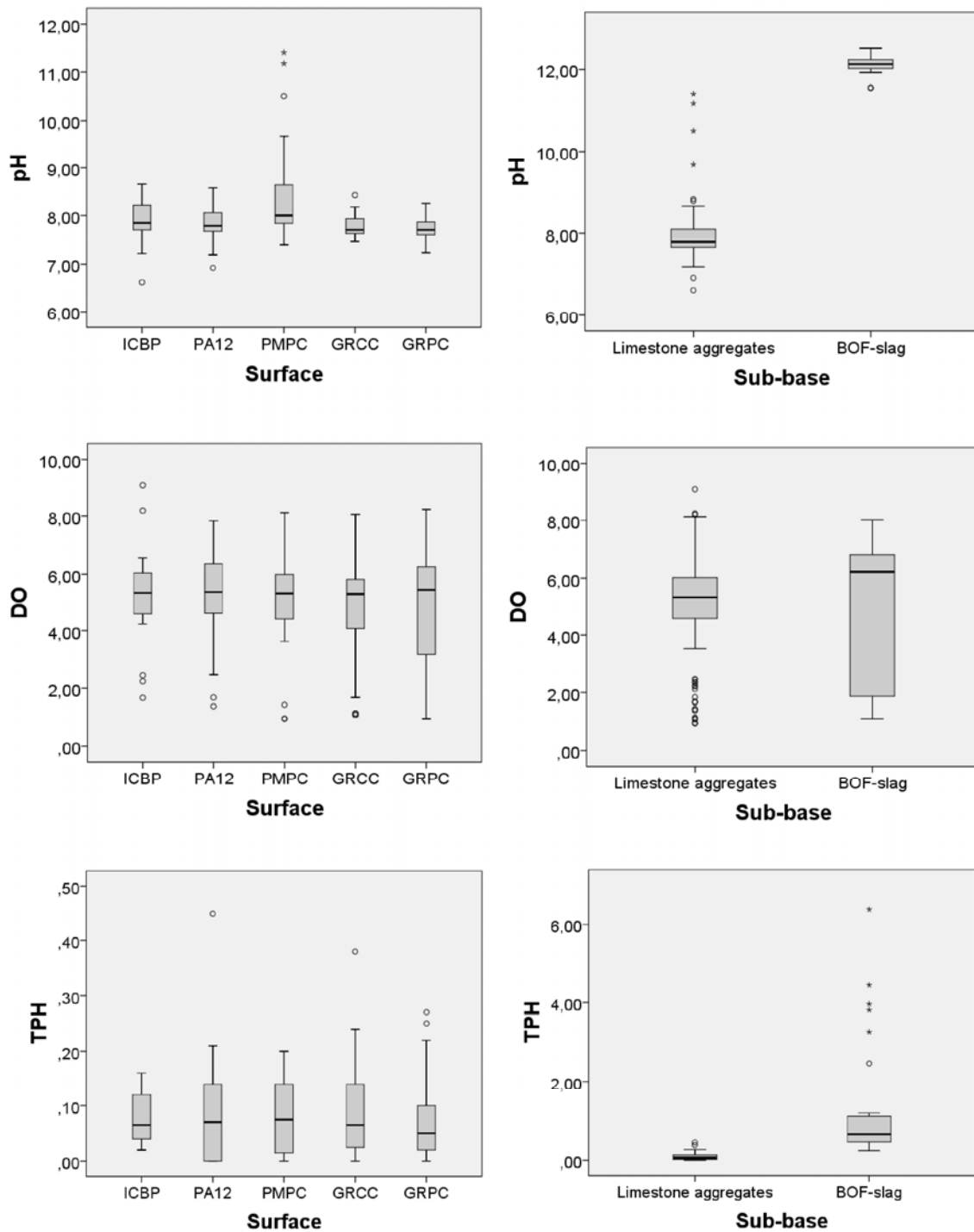


Figure 3. Boxplot of pH, DO and TPH values obtained in all parking areas.

TSS values were below 20mg/L from most bays, satisfying the regulations existing in Europe. Only those parking bays without geotextiles were above this value (50-60mg/L).

Values of turbidity in all cases using a geotextile layer were below 16NTU; otherwise, without geotextile, values obtained increased to 55NTU.

EC was low, between 100 μ S/cm for ICBP, PA-12 and PMPC surface courses and up to 200 μ S/cm for grass reinforced with plastic cells, in parking bays with sub-bases of limestone aggregates. However, those parking bays without geotextile registered higher values of EC, above 300 μ S/cm. BOF-slag bays had higher still EC values, of between 3000 μ S/cm and 4000 μ S/cm (Figure 4).

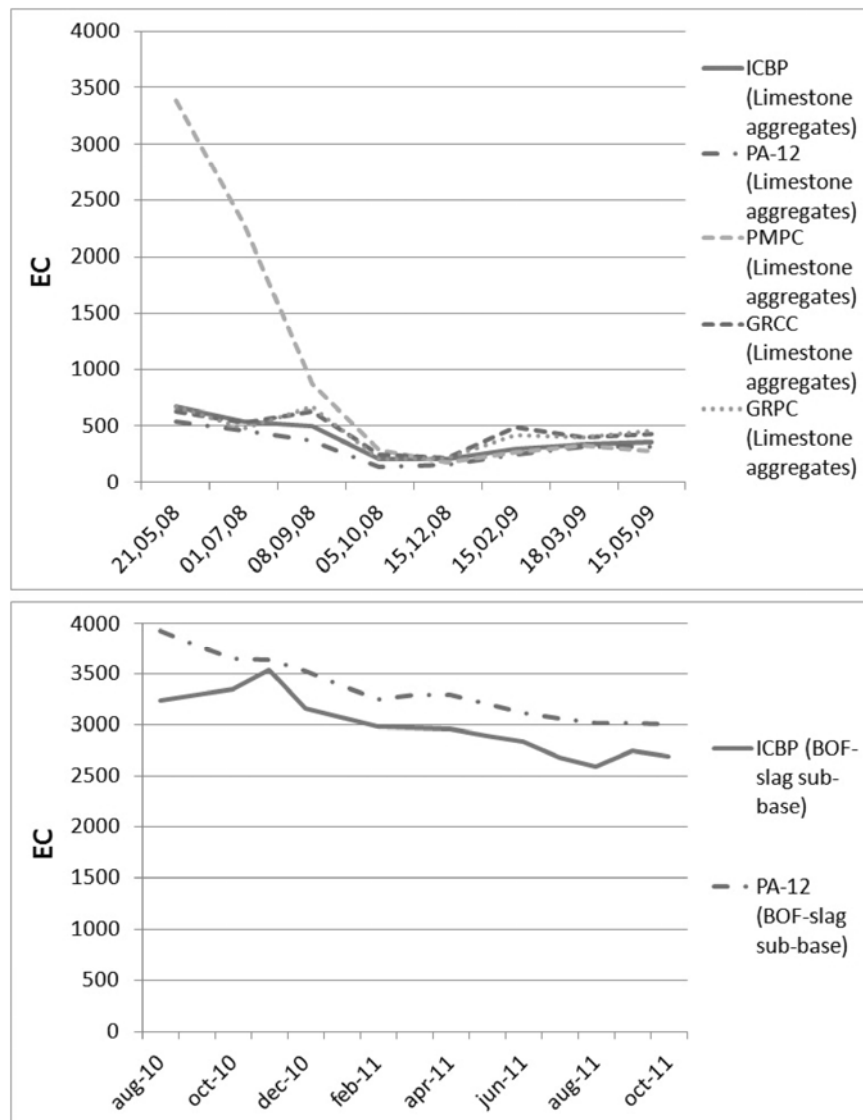


Figure 4. Development of the EC values during a year in “Las Llamas” and “Parque Tecnológico” parking areas, respectively.

Summarizing all the results, it was found that pervious surfaces such as PA-12 and PMPC were the most efficient in reducing TPH. The lowest pH values were obtained from grass surfaces reinforced with plastic cells. The lowest EC values were registered in ICBP, PA12 and PMPC surfaces which may reflect lower dissolved contaminant concentrations.

The use of geotextiles in parking bays reduces values of EC by at least a third in comparison with those without geotextile taking account of all types of surface and sub-base. In the case of DO, the presence of a geotextile reduced DO by 0.5mg/L in ICBP surfaces and increased it by 0.5mg/L in PA-12 and PMPC. The presence of geotextile substantially reduced both TSS and turbidity values (between 1.33 times in the case of PMPC and 2 times in the case of ICBP), but particularly PA-12 (by 4 times) and plastic cells (by 5 times). Geotextile has a particularly important role in the biodegradation of hydrocarbons, this is demonstrated by the highest values of O₂ consumption and CO₂ production and the greatest reduction in TPH being registered from those parking bays which included a geotextile in their structure in comparison with those bays without geotextiles (4 times in the case of PA-12 and PMPC, and 3 times in the case of ICBP).

Finally, BOF-slag substantially influenced pH values, increasing them from an average of 8 up to 12, whilst EC values were ten times higher in comparison with the usual limestone aggregates. No other noticeable differences were registered for any of the other parameters.

3.2 Pavement functionality

Field tests undertaken using the LCS permeameter and the CP Infiltrometer in parking areas in Gijón and Santander showed that the ICBP, PA-12 and PMPC surfaces had the best permeability as shown in Table 2. The CP Infiltrometer also showed that there was no generation of surface runoff under rainfall intensities of 5 minutes duration, corresponding to ten years (78 mm/h), fifty years (115 mm/h) and one hundred years (142 mm/h) in Gijón (Asturias) and ten years (98 mm/h), fifty years (155 mm/h) and one hundred years (178 mm/h) in Santander (Cantabria) over the ICBP and PA-12 surfaces. However, the reinforced grass with plastic cells did generate a small amount of surface runoff (see Table 2).

Table 2. Average permeability measurements obtained with the LCS permeameter and height of inundation values obtained with the CP Infiltrometer.

Pervious Surface	Site	LCS		CP Infiltrometer (cm)		
		Time (s)	Permeability (m/s)	T=10 year	T=50 year	T=100 year
ICBP	"La Guía" Gijón	4	0.0625	0	0	0
PA-12		21	0.0119	0	0	0
Plastic cells		151	0.0017	0.6	0.6	1.0
ICBP	"Las Llamas" Santander	—	—	—	—	—
PA-12		21	0.0119	0	0	0
PMPC		19	0.0132	0	0	0
Plastic cells		—	—	0.45	0.5	1.1
ICBP	"Parque Tecnológico" Gijón	5	0.0500	—	—	—
PA-12		21	0.0119	—	—	—

Additionally, for all the parking bays in both Gijón and Santander, substantial depths of storage water were measured in the sub-base, always close to maximum volumes throughout the year which is easily explained due to the climatic conditions of the north coast of Spain as discussed under section 2.1 above.

In terms of amenity, the most worn pavement surfaces were those made of the plastic cells. Although these parking areas were only used by light traffic in all cases, high occupancy, especially in "Las Llamas" and "Parque Tecnológico", contributed to the degradation of the plastic which had less structural strength than those made of concrete or asphalt. CP Infiltrometer tests undertaken in "La Guía" parking area five years after its construction showed an increase of at least 1-2 cm in water depth associated with PA-12 and PMPC surfaces due to clogging, which reduced permeability dramatically and hence their infiltration capacity. This situation worsened year on year due to lack of maintenance. In fact, currently, some of the infiltrometry measurements of PA-12 and PMPC surfaces in "Las Llamas" using the CP Infiltrometer were close to 3 cm which means that these bays are almost impervious.

Maintenance is one of the most important variables which influences the infiltration capability of pervious surfaces. It can increase infiltration rates by up to 10% for ICBP surfaces and slightly lower for porous surfaces PA-12 and PMPC. Laboratory tests of the same surfaces as have been used in the three parking areas described here have been carried out by González-Angullo et al., 2008; Rodríguez-Hernández et al., 2012; and Sañudo-Fontaneda et al., 2012. Sediments were used to clog the surface and dramatically reduced the infiltration capacity of ICBP surfaces (60%) with steeper surface slopes (>5%) whilst the infiltration capacity of porous surfaces (PA-12 and PMPC) slightly decreased (-10%) with a surface slope of 10%. Therefore, PA-12 and PMPC surfaces were better in terms of infiltration when the surface was clogged. In the case of the low slopes used in these three parking areas, infiltration capacity values decreased by up to 5% in all cases.

4 CONCLUSIONS

This paper shows the results of seven years monitoring of 68 PPS parking bays in three different experimental areas in Gijón and Santander in the North coast of Spain: “La Guía”, “Las Llamas” and “Parque Tecnológico” car parks.

The surface utilising PA-12 was the best in terms of its water quality function according to the parameters analyzed in this paper, however, it was found that the efficacy of both ICBP and PMPC surfaces was very similar to PA-12.

Parking bays constructed with PA-12 and reinforced grass with plastic cells had high biological activity related to the biodegradation process of hydrocarbons, reflected in high values of O₂ consumption and CO₂ production, the evidence being the low TPH values obtained in water samples.

The positive influence of the geotextile is shown by values obtained for DO, TSS and turbidity with and without geotextile, and particularly the increase in biological activity of the microorganisms biodegrading the hydrocarbons in association with the presence of geotextile.

Limestone aggregates used in the sub-base performed better than the BOF-slag in all water quality parameters studied, especially pH, EC, TSS and turbidity. Water storage in those parking bays constructed using geotextile utilising all the types of sub-base and surface such as ICBP, PA-12 and PMPC satisfy all the restrictions imposed by existing regulations in Spain for water to be used for environmental, recreational, industrial, agricultural and residential purposes.

Regular maintenance influences the recovery of infiltration capacity for all surfaces used in all parking areas, especially those utilising ICBP.

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- ‘Development of systems for rainwater catchment and storage through the use of pervious pavements to assess its non-potable uses as resource of low-enthalpy geothermal energy (REV)’ [BIA2009-08272].

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