1 *Article*

In-situ study of road marking durability using glass microbeads and antiskid aggregates as drop-on materials

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Abstract: Road markings play an important role in road safety because they provide significant information to drivers about the road. For that reason, they must be replaced when they are not correctly perceived by road users. To analyse which are the main factors that affect road marking perception over time, a test section was designed in a two-lane rural highway, running actual traffic over 18 different types of markings fabricated with different combinations of drop-on materials. Chromatic coordinates, luminance and retroreflectivity of each sample were measured during 18 months in order to study their evolution over time. The results obtained show different behaviours depending on the aggregates and application method used. An increment of the durability has been observed with the use of different layers and mixtures of glass microbeads with different sizes.

Keywords: road markings; glass microbeads; drop-on materials; retroreflectivity; skid resistance; road safety

1. Introduction

Until now, four main engineering treatments have generally been carried out in order to improve road safety: (i) highway updating; (ii) road signing refurbishment; (iii) repainting of road markings; and (iv) pavement resurfacing. Updating the horizontal or vertical signage is the most affordable option and, in addition to this, road safety increases up to 35% [1].

Road markings provide continuous information to road users about roadway alignment and vehicle positioning [2]. Whether lines or pictograms, both should transmit an understandable message for any user. In rural highways, where the traffic average speed is high, it is especially important that this kind of signs is clear and understandable [3].

Road marking should meet certain standards of durability, resistance and visibility [4]. The service threshold is established according to drivers' safety needs and traffic requirements, and for that reason it is requested [5]:

- Defining road marking's essential features for that they achieve their function, from the users' point of view.
- Setting the minimum acceptable value for these features, according to traffic circumstances and the intended objectives.

To ensure a good road marking quality, it is very important to make a proper selection of the materials to be used, for which we should consider economic, environmental, application and use or location criteria. But amongst all them, their specific characteristics and suitability for use must be principally considered; road marking must fulfil some requirements of durability, skid resistance and visibility [6].

45   Daytime visibility is achieved through visual contrast between road marking and pavement
46   [3,4]. Nighttime visibility is reached by using glass microbeads embedded in the paint surface, so the
47   drivers can receive a proper amount of reflected light, providing them an adequate road visibility at
48   night and increasing their safety [7]. The correct retroreflection value is attained through the
49   combination of good quality microbeads and base material (white painting) in a correct dosage.
50   Microbeads efficiency must be assessed for their different compositions and densities in the painting
51   embedment [8]. Previous studies show that microbeads must be embedded from 1/3 to 2/3 of their
52   diameter to optimise light retroreflection [7].

53   Furthermore, road markings must ensure safety for any road user that drives on them. For this
54   reason, it is also necessary to provide them with antiskid properties (skid resistance) [9].

55   Road marking should be replaced when their colour, retroreflectivity or skid resistance
56   measurements drop below a certain value established by regulations [10]. The evolution of these
57   properties (daytime and nighttime visibility, skid resistance and durability) depends on the quality
58   of the products used, their resistance against traffic conditions, application system, connection
59   between the paint coating and the pavement, base material, traffic volume, etc. [9].

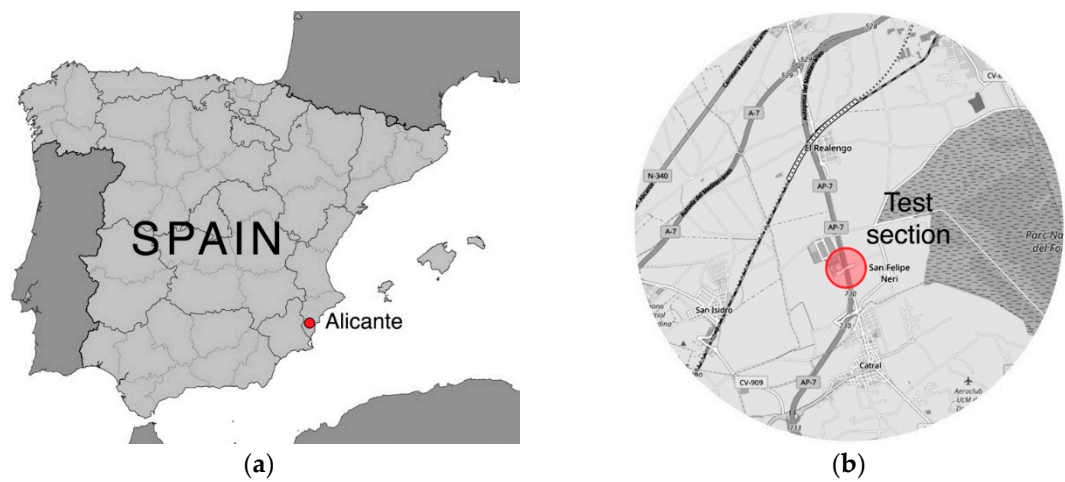
60   Another aspect that has a vital importance for the behaviour of drivers is how they perceive road
61   safety because of the road markings. On one hand, depending on the situation, this perception makes
62   the users feel more comfortable and protected, but on the other hand it is more likely that if they do
63   not feel like this, they will react impulsively increasing the risk of having an accident on road. It is a
64   delicate issue that must be studied and considered thoroughly by the responsible of every road
65   marking project [11].

66   This paper is focused on obtaining the best composition for road markings by using different
67   combinations of drop-on materials and postmix application systems: glass microbeads, transparent
68   and non-transparent antiskid aggregates, mixed in different proportions with the same base material,
69   and applied in one or two layers, in order to determine which key aspects should be considered in
70   order to improve visibility distance and skid resistance of road markings, both crucial factors for road
71   safety.

2. Experimental program

2.1. Test section

74   For this piece of research, an in-situ test section was set on the CV-904 rural two-lane highway
75   from Crevillente to Catral, located at the existing intersection on 4+400 kilometric point (KP), in the
76   municipality of Catral, province of Alicante, Spain (see Figure 1). There is virtually no traffic
77   diversion in this junction because this section is only connected with minor rural paths, so it
78   guarantees a continuous traffic flow along the testing samples (transversal stripes). In addition, speed
79   reduction of passing vehicles is negligible, preventing skid marks that could pollute the samples,
80   altering the wearing process. Furthermore, placing the test section in a crossing makes easier to create
81   a third virtual traffic lane to divert the traffic while making or measuring the samples. The tests were
82   performed under actual traffic and weather conditions, which provide more accurate results than
83   those obtained in laboratory simulations.

(**a**)   (**b**)

84   **Figure 1.** Test section location: (**a**) in Spain; (**b**) at CV-904 two-lane highway (Crevillente-Almoradí).

85   In the technical datasheet of the traffic count station ID 904020, located at the CV-904 highway,
86   covering traffic flow from 1+300 KP to 7+000 KP [12], we can observe that traffic volume is balanced
87   between the two lanes, approximately 50% in direction to Catral (ascending) and 50% in direction to
88   Crevillente (descending).
89   Table 1 shows that that traffic flow is regular over time, with Annual Average Daily Traffic
90   (AADT) values around 4,000 vehicles/day, and a decreasing percentage of trucks (P_T).

91   **Table 1.** AADT and P_T (2009-2013), traffic count station ID 904020.

$AADT_{2009}$	$P_{T,2009}$	$AADT_{2010}$	$P_{T,2010}$	$AADT_{2011}$	$P_{T,2011}$	$AADT_{2012}$	$P_{T,2012}$	$AADT_{2013}$	$P_{T,2013}$
4,055	-	4,507	6.0%	4,276	4.9%	4,406	3.6%	3,734	3.4%

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93   We also notice (see Table 2) that the average traffic flow rates during working days are greater
94   than on weekends, what means that it is a rural road with a predominant mobility function. Annual
95   Average Daily Truck Traffic (AADTT) remains stable throughout the year, being less intense on
96   weekends as well.

97   **Table 2.** Traffic flow rates in 2013, traffic count station ID 904020.

Month	Average day			Working days			Saturdays			Sundays		
	AADT	AADTT	P_T	AADT	AADTT	P_T	AADT	AADTT	P_T	AADT	AADTT	P_T
May	3,897	134	3.4%	4,144	169	4.1%	3,555	64	1.8%	3,007	29	1.0%
November	7,144	280	3.9%	7,659	356	4.6%	6,566	124	1.9%	5,146	58	1.1%

98   *2.2. Materials and application systems*

99   We have analysed different compositions of road marking materials and application systems in
100   order to study their damage over time.

101   2.2.1.   Base material

102   Base material used in all testing samples is white styrene acrylic painting. Technical
103   specifications are described in Table 3.

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105   **Table 3.** White styrene acrylic painting specifications.

Parameter	Standard	Value and unit
Consistency	UNE 48076	86 ± 10 KU
Relative density	EN ISO 2811	1.59 ± 0.02 g/cm^3
Drying time	UNE 135202	15 minutes
Colour	EN ISO 11664-1	(x,y) inside the polygon specified by regulations
Solids content	EN 12802	$\beta = 0.89 \pm 0.02$ – LF7 class
Coating powder	UNE 135213	72 ± 2 %
Bleed resistance	EN 1871	Rc = 0.96 ± 0.01
Bleed stability	EN 1871	$\beta \leq 0.05$ – BR2 class
Stability in full container	UNE 48083	Consistency variation ≤ 5 KU. Without skins, neither clots, nor solid traces
UV ageing	EN 1871	$\Delta\beta \leq 0.05$ - type UV1. (x,y) inside the polygon, without alterations
Storage stability	EN 1871	8
Alkali resistance	EN 1871	Non-skin effect

106   2.2.2.   Glass microbeads

107   We used four different types of glass microbeads, with different grading and surface treatment:
108   (i) Echostar 5 (125 - 710 μm); (ii) Echostar 20 (1180 - 125 μm); (iii) Duolux 125 H1 (425 – 850 μm); and
109   (iv) Ultralux (600 - 850 μm). Technical information provided by their manufacturers is shown from
110   Table 4 to Table 8, according to EN 1423 [13] and EN 1424/A1 [14] European Standards.

111   **Table 4.** Echostar 5 glass microbeads specifications.

Attribute	Specification		
Sphericity (% good quality beads)	≥80% manual method (microscope) (EN 1423 & Annex D from EN 1423)		
	Sieve (microns)	Min	Max
	1000	0	2
Grading	710	0	10
(according to ISO 2591-1	600	5	40
sieve according to series	355	40	80
R 40/3 from ISO 565)	212	70	100
	125	95	100
	Bottom	100	100
Refractive index	Type A ≥ 1.5 (EN 1423 & Annex A from EN 1423)		
Colour	According to EN 1423 & EN 1424		
Physicochemical resistance (H_2O, HCl, $CaCl_2$, Na_2S)	According to EN 1423		
Surface treatment	SBP (Aromatic solvent-based paints) SBP ECO (Non-aromatic solvent-based paints)		
CE-marking	Certifying agencies		
	LCPC / ESE (France)	BENOR (Belgium)	COPRO (Schönborn)	AENOR (Spain)

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Table 5. Echostar 20 glass microbeads specifications.

Attribute	Specification		
Sphericity (% good quality beads)	≥80% manual method (microscope) (EN 1423 & Annex D from EN 1423)		
Grading (according to ISO 2591-1 sieve according to series R 40/3 from ISO 565)	Sieve (microns)	Min	Max
	1400	0	2
	1180	0	10
	1000	5	20
	850	10	30
	600	20	60
	355	50	90
	212	70	100
	125	95	100
	Bottom	100	100
Refractive index	Type A ≥ 1.5 (EN 1423 & Annex A from EN 1423)		
Colour	According to EN 1423 & EN 1424		
Physicochemical resistance (H_2O, HCl, $CaCl_2$, Na_2S)	According to EN 1423		
Surface treatment	SBP (Aromatic solvent-based paints)		
CE-marking	Certifying agencies		
	LCPC / ESE (France)	BENOR (Belgium)	COPRO (Schönborn)	AENOR (Spain)

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Table 6. Duolux 125 H1 glass microbeads specifications.

Attribute	Specification		
Sphericity (% good quality beads)	91%		
Grading (EN 1423)	Sieve (microns)	% Retained	% Passed
	1000	0-2	98-100
	850	0-10	90-100
	600	60-75	25-40
	425	95-100	0-5
Refractive index	Type A ≥ 1.5 (EN 1423 & Annex A from EN 1423)		
Colour	According to EN 1423 & EN 1424		
Surface treatment	Adhesion Coating		
Certification number	0913-CPD-2007/002		

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Table 7. Duolux 121 H1 glass microbeads specifications.

Attribute	Specification		
Sphericity (% good quality beads)	91%		
Grading (EN 1423)	Sieve (microns)	% Retained	% Passed
	1400	0-2	98-100
	1180	0-10	90-100
	1000	5-15	85-95
	820	10-30	70-90
	600	20-50	50-80
	425	40-80	20-60
	250	80-100	0-20
	180	90-100	0-10
	125	95-100	0-5
Refractive index	$\geq 1,54$		
Colour	According to EN 1423 & EN 1424		
Surface treatment	Adhesion Coating		
Certification number	0913-CPD-2007/002		

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Table 8. Ultralux glass microbeads specifications.

Attribute	Specification		
Sphericity (% good quality beads)	91%		
Grading (EN 1423)	Sieve (microns)	% Retained	% Passed
	1000	0-2	98-100
	850	0-10	90-100
	710	85-95	5-15
	600	95-100	0-5
Refraction index	$\geq 1,5$		
Colour	According to EN 1423 & EN 1424		
Surface treatment	Adhesion Coating		
Certification number	0913-CPD-2007/002		

120   2.2.3.   Antiskid aggregates

121   We have used white marble sand (Macael 400) as non-transparent antiskid aggregate and
122   sodium-calcium glass particles (Glass 600) as transparent antiskid aggregate. Macael 400 aggregate
123   properties are described in Table 9.
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Table 9. Macael 400 white marble sand specifications.

		Lower limit	Upper limit
Physical & Mechanical features	Water absorption	0.16%	
	Apparent density	2.72 gr/cm^3	
	Knoop's micro-hardness	140.4 Kg/mm^2	
	Shock resistance	45 cm	
	Wear resistance	0.36 m/m	
	Compression strength	803.9 kg/cm^2	
	Bending strength	211.9 Kg/cm^2	
Chemical Analysis	CO_2	43.55%	
	CaO	55.19%	
	MgO	0.02%	
	FeO / Fe_2O_3	0.21%	
	Al_2O_3	0.00%	
	Na_2O	0.01%	
	SiO_2	0.19%	
	K_2O	0.00%	
	SO_3	0.00%	
	Insoluble waste	0.26%	
	Total	99.43%	
	Calcite ($CaCO_3$)	98.55%	
Sieve analysis (ISO 3310.1:2016 [15])	**Retained above**	**Lower limit**	**Upper limit**
	0.001 mm	0.0%	0.0%
	0.01 mm	1.1%	3.3%
	0.05 mm	15.0%	18.6%
	0.2 mm	33.1%	40.5%
	0.4 mm	25.9%	28.5%
	0.5 mm	5.4%	7.2%
	0.6 mm	4.9%	7.3%
	0.7 mm	3.4%	6.2%
	0.8 mm	0.0%	0.6%
	1 mm	0.0%	0.0%

126

127   Transparent antiskid Glass 600 calcium and sodium granules have irregular shapes and sharp
128   edges to be mixed with glass microbeads, in order to generate roughness. Technical specifications are
129   shown in Table 10.

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Table 10. Glass 600 granules specifications.

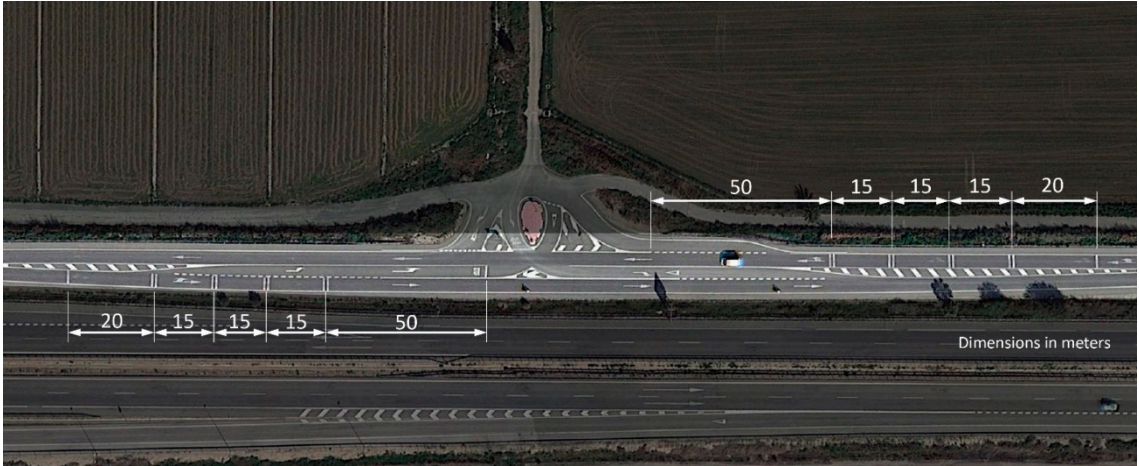
Physical & Mechanical features	Colour	Transparent
	Hardness	6/7 Mohs
	Apparent density	2.60 g/cm³
	Impurities:	Non-magnetic metals: < 5 g/Tn
		Magnetic metals: 0 g/Tn (However it is acceptable one particle smaller than 0.05 g in each delivery)
		Infusible: < 25 g/Tn
Chemical analysis	SiO_2	70.00-74.00%
	Na_2O	12.00-1400%
	CaO	7.00-11.00%
	MgO	3.00-5.00%
	Al_2O_3	0.50-2.00%
	FeO/Fe_2O_3	<0.3%
	K_2O	0.20-1.00%
Sieve analysis (ISO 3310.1:2016)	**Sieve size (mm)**	**Quantity (%)**
	< 0.3	10.0 Max
	> 0.6	5.0 Max

132   2.2.4.   Application systems

133   Two different types of application systems were used in this study:

134   (1) "Monolayer" or single layer system (AS1): it is the traditional system of application. First, the
135   base material is sprayed and immediately after, mixture of drop-on material is projected (it can
136   be just glass microbeads or a mixture of microbeads with transparent or non-transparent
137   antiskid aggregates).
138   (2) "Bilayer" or double layer system (AS2): the first step is to create a complete AS1 layer, as
139   explained before; once it is dry, another identical layer is applied over the previous one.

140   *2.3. Test section design and sample fabrication*

141   Following the indications of the Spanish regulations on road surface marking design, included
142   in the Ministerial Order FOM/3053/2008 [16], we sketched the placement of the testing samples on
143   the pavement with chalk and adhesive tape. As shown in Figure 2, stripes were painted in pairs
144   (except the first one, that is just one stripe), spaced 15 m between groups, except for the single stripe,
145   that is 20 m apart. The last stripe is 50 m away from the intersection, considered as a conflict point.

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147   **Figure 2.** Test section general layout.

148   There are 9 stripes per traffic direction. In addition, every stripe is divided into 2 testing samples
149   covering half of the lane, so that both are treaded by a tyre at the same time, totalizing 18 testing
150   samples with different combinations of road marking materials (see Table 11). The scheme was
151   repeated in the opposite direction, obtaining a total of 36 testing samples, labelled as shown in Figure
152   3. As AADT is similar in both directions, it is possible to compare and contrast the results obtained
153   from each testing sample.

154   **Table 11.** Test samples composition and application system.

Group	Testing Sample	Glass microbeads	Particle size (µm)	% Drop-on material			Applic. System
				Microbeads	Macael 400	Glass 600	
G1	S1	Echostar 5	125-710	100	-	-	AS1
	S2	Echostar 20	125-1180	100	-	-	AS1
	S3	Duolux 125 H1	425-850	100	-	-	AS1
	S4	Duolux 121 H1	125-1180	100	-	-	AS1
	S5	Ultralux	600-850	100	-	-	AS1
G2	S6	Echostar 5	125-710	80	20	-	AS1
	S7	Echostar 20	125-1180	80	20	-	AS1
	S8	Duolux 125 H1	425-850	80	20	-	AS1
	S9	Duolux 121 H1	125-1180	80	20	-	AS1
	S10	Ultralux	600-850	80	20	-	AS1
G3	S11	Echostar 5	125-710	80	-	20	AS1
	S12	Echostar 20	125-1180	80	-	20	AS1
	S13	Duolux 125 H1	425-850	80	-	20	AS1
	S14	Duolux 121 H1	125-1180	80	-	20	AS1
	S15	Ultralux	600-850	80	-	20	AS1
G4	S16	Ultralux	600-850	100	-	-	AS2
	S17	Ultralux	600-850	80	20	-	AS2
	S18	Ultralux	600-850	80	-	20	AS2

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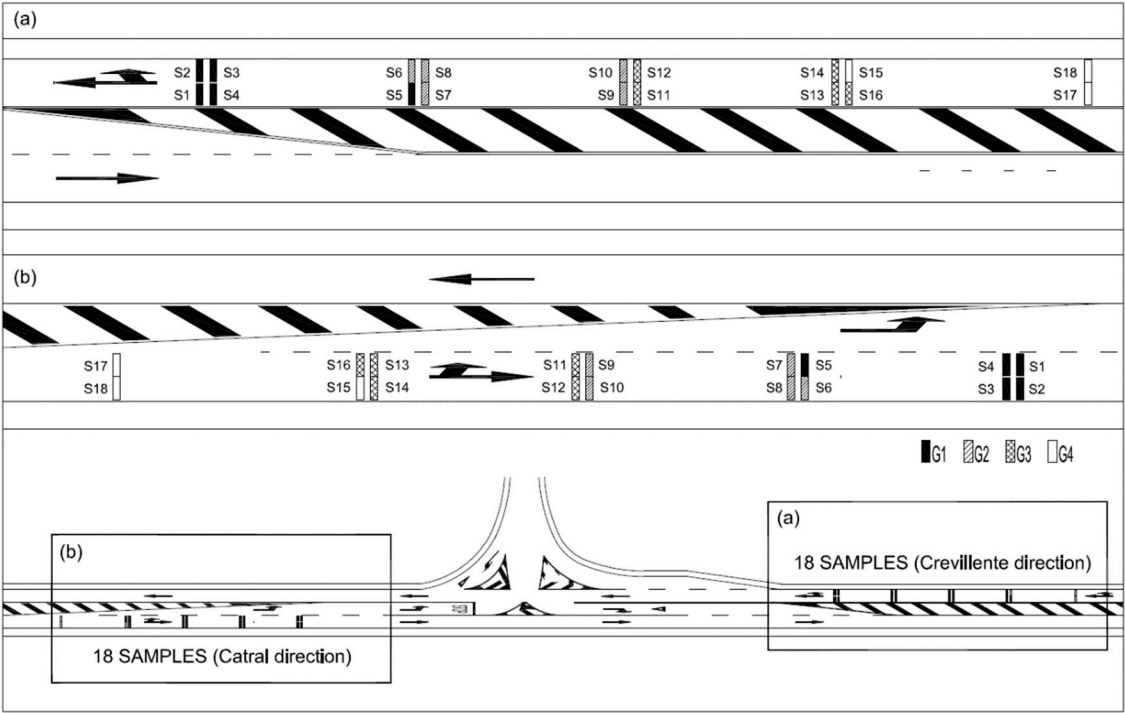
Figure 3. Testing samples labelling: (**a**) Crevillente direction; (**b**) Catral direction.

While fabricating each of in-situ testing samples, we obtained specimens in a 15x30 cm metal plate placed on the pavement while painting to examine them under a laboratory microscope. Figure 4 shows the sample fabrication process.
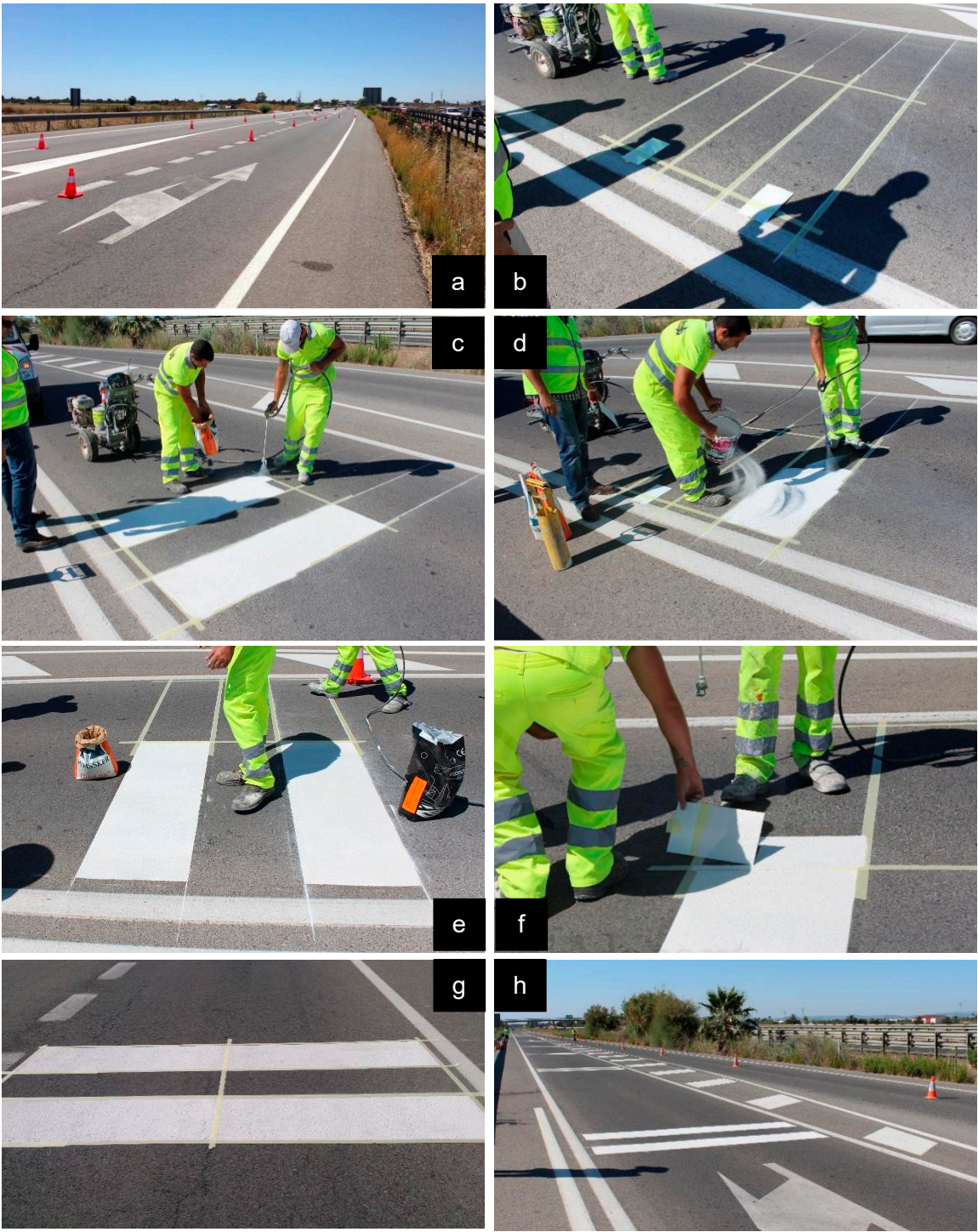
Figure 4. Sample fabrication process: (**a**) traffic diversion; (**b**) sample sketching with chalk and adhesive tape; (**c**) spraying of base material; (**d**) application of drop-on material; (**e**) in-situ test sample finished; (**f**) laboratory specimen fabrication; (**g**) transversal stripe completed; (**h**) finished test section, ready to be opened to traffic.

2.4. Tests performed

We have tested the fundamental parameters of the in-situ testing samples: (i) luminance factor β and colour (chromatic coordinates X,Y) for daytime visibility, using a Spectro-Guide 45/0 gloss spectrophotometer; (ii) retroreflective luminance coefficient (retroreflectivity) in dry (R_L) and wet conditions (R_W) for nighttime visibility, using a ZRM 6013 retroreflectometer; and (iii) skid resistance coefficient (SRT) using the TRRL pendulum. All the tests were performed inside the wheel path area.

173   As standards require, each factor was measured a minimum of three times in every testing sample
174   per driving direction, and subsequently the average value is calculated. Therefore, for each kind of
175   mixture tested (S1 to S18), at least six values for each parameter and period of time assessed were
176   determined.
177   For the durability study, we have measured those parameters at different times: just produced,
178   after 1 month, 6 months, 12 months and 18 months, for a quantitative and qualitative analysis
179   supported by data charts, pictures of in-situ testing samples and laboratory specimens using a Leica
180   EZ4D microscope. The weather conditions during data collection are shown in Figure 5.

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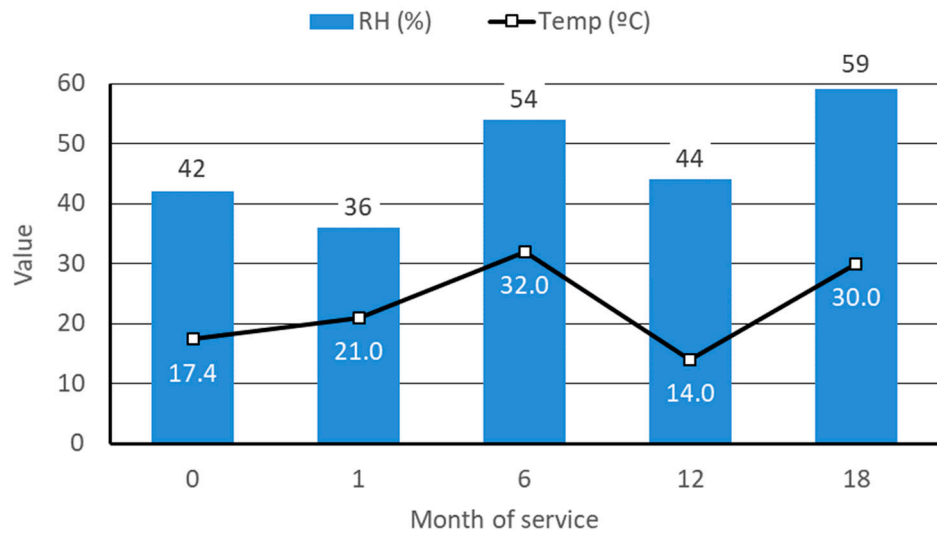
182   **Figure 5.** Surface temperature and relative humidity (RH) measured in the test section during data
183   collection.

3. Results and discussion

3.1. Daytime visibility

186   Figure 6 shows the average results of the chromatic coordinates (X,Y) measured on the 18 in-situ
187   testing samples over time. The results obtained are all inside the colour polygon defined by its
188   vertices for the white permanent colour, hence this parameter is not a limiting condition according
189   to the aspects studied in this paper.

Acceptance Criteria: Inside the Polygon

✕ Chromatic Coordinates X,Y of the 18 testing samples over time

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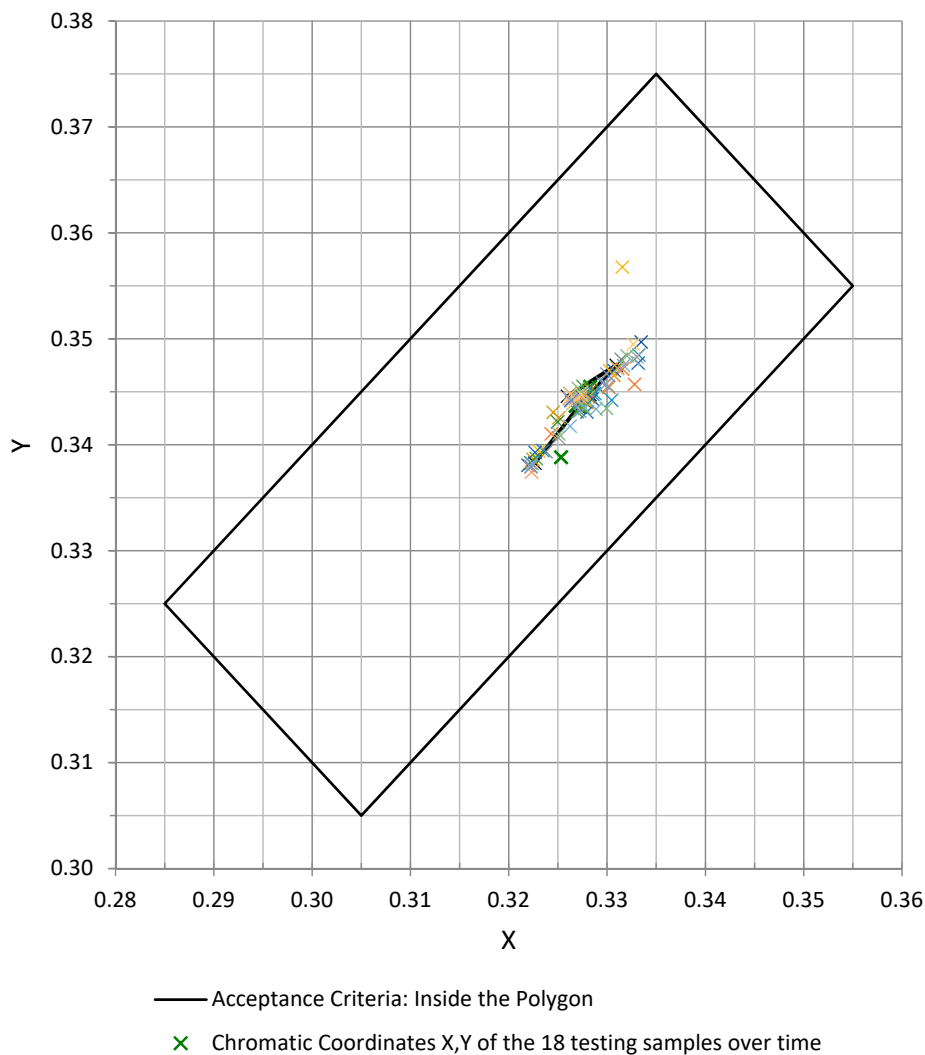
191   **Figure 6.** Chromatic coordinates (X,Y) of the 18 testing samples during the 18-month testing period.

192   The luminance factor evolution over time is shown in the Figure 7. An analysis of the collected
193   data shows that between the sample groups with AS1 application system (monolayer), the best
194   performance is obtained by the group G1 samples, that only use glass microbeads as drop-on
195   material, followed by group G3, which samples contain glass microbeads (80%) and glass 600 (20%)
196   and the last one is G2, that has a mixture of glass beads and non-transparent antiskid aggregates as
197   drop-on materials. We should underline that group G4 (bilayer) results follow a similar trend, but
198   getting better outcomes than the equivalent AS1 group with the same kind of drop-on aggregates.
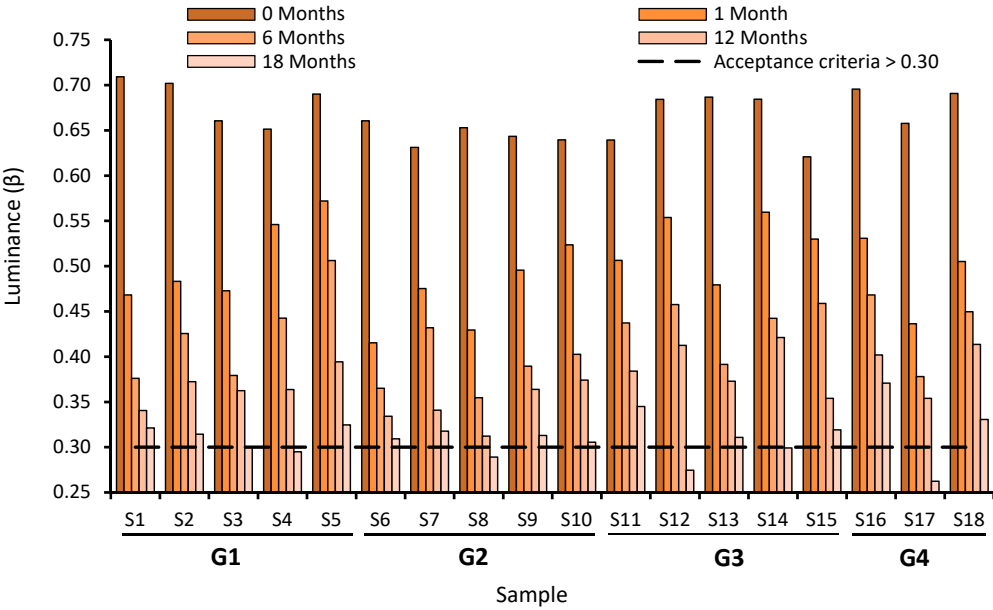
Figure 7. Evolution of the average luminance factor β in the 18 testing samples.

From the qualitative analysis of the in-situ pictures taken from every testing sample over time, we notice that larger glass microbeads become detached first, leaving craters which are filled by dust, dirt and rubber from tyres, making the road markings darker and losing its luminance factor, as observed in Figure 8a. However, we realize that glass microbeads with an adhesive coating (as in sample S4) are detached with more difficulty, even if they are in bigger sizes. Therefore, a lesser number of craters are created, and the luminance stays better over time, as seen in Figure 8b.
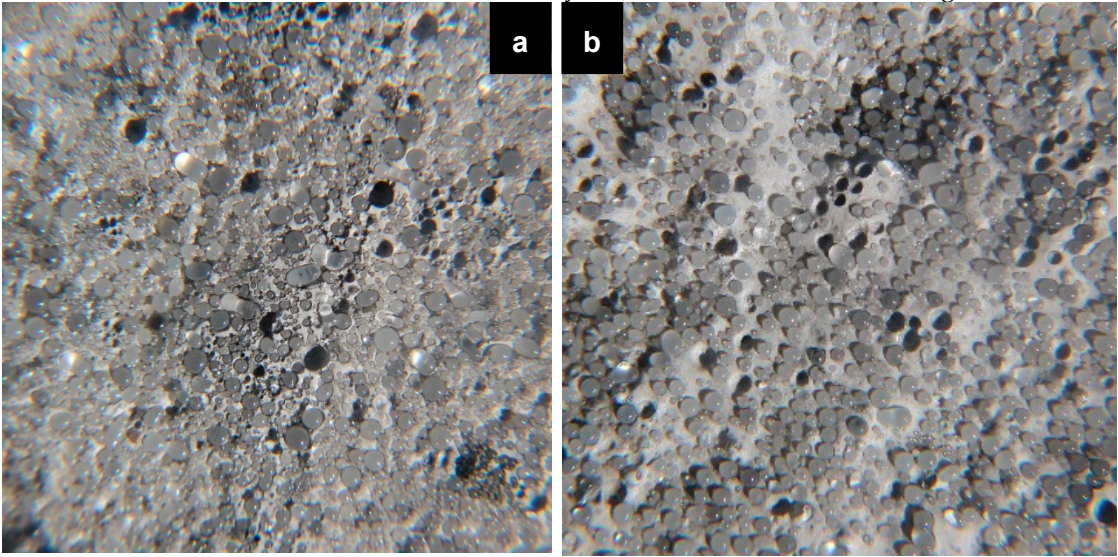
Figure 8. In-situ surface detail after 1 month of service: (**a**) S2 sample; (**b**) S4 sample.

Regarding G2 and G3, apart from the craters caused by the detached microbeads, the antiskid aggregates retain dust and rubber particles, which also contributes to reduce luminance (Figure 9).

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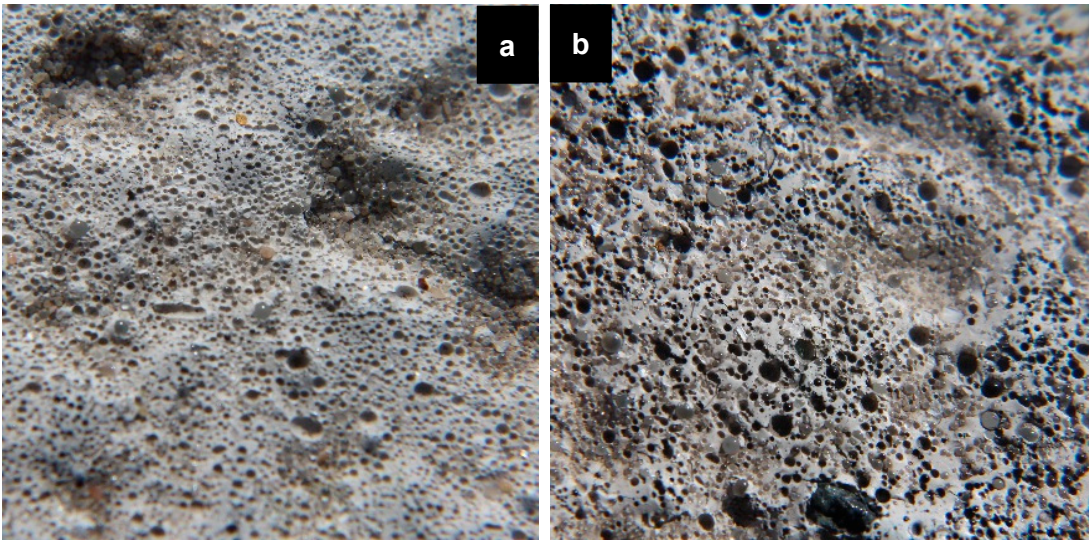
212   **Figure 9.** In-situ surface detail after 12 months of service: (**a**) S8 sample; (**b**) S13 sample.

213   From the global analysis of the luminance factor in all the 18 testing samples, we notice that they
214 fulfil the minimum acceptance standard of $\beta = 0.30$ established by the Spanish regulations [17, 18],
215 being some testing samples slightly under this value in at 18 months age, as in S12 and S17, but could
216 be still acceptable. That is why we consider the luminance factor β is not the main limiting factor for
217 durability.

218   *3.2. Nighttime visibility*

219   Figure 10 shows the evolution of the retroreflectivity in dry conditions, R_L. Samples from groups
220 G2 and G3 reached lower R_L values than those from G1, which only has glass microbeads as drop-on
221 material.

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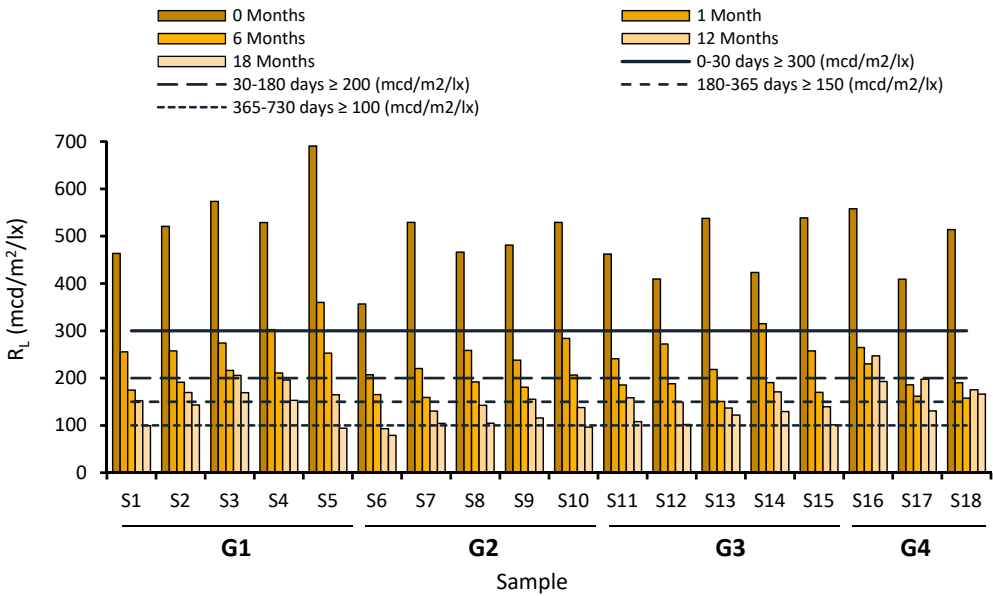
223   **Figure 10.** Evolution of R_L on test samples during the first 18 months of service.

224   From the qualitative analysis of the pictures taken in laboratory, we realized that in G2 the non-
225 transparent antiskid particles were taking up spaces that could be covered with glass microbeads.
226 Consequently, these opaque particles do not let the light go through them. Moreover, they cast
227 shadows to the glass microbeads placed just behind them (Figure 11). That is the reason why this
228 sample group has a considerable loss of retroreflectivity compared to G1.

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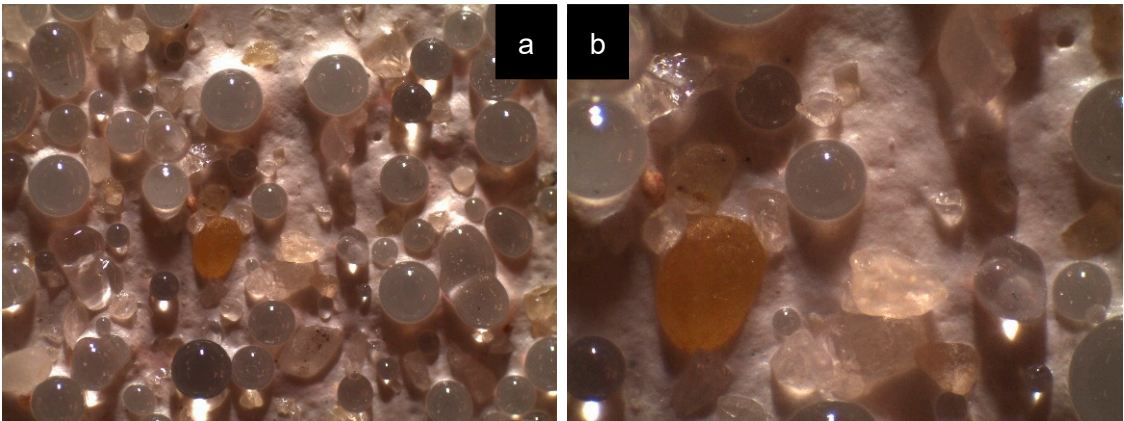
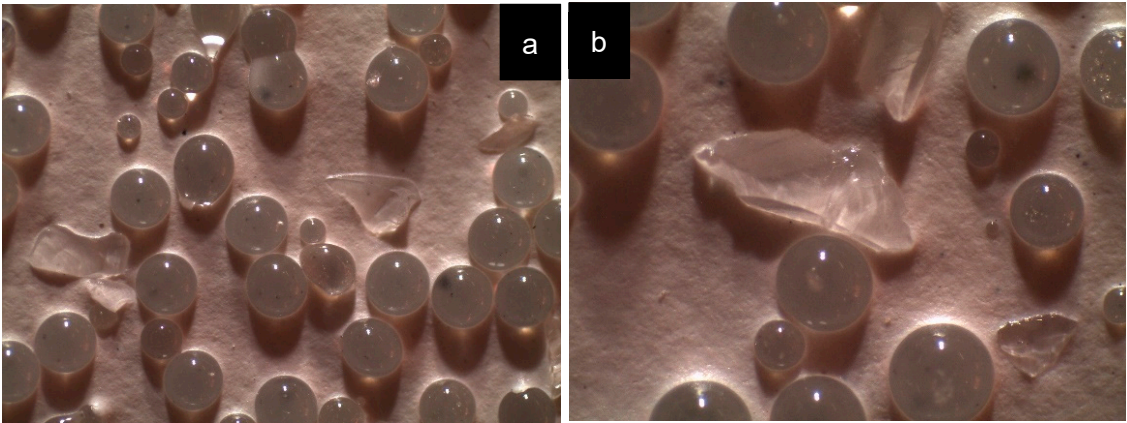

230   **Figure 11.** Microscope detail of S9 sample: (**a**) x16 magnifications; (**b**) x35 magnifications.

231   Something similar happens with G3 samples. As they have mixed glass beads plus transparent
232   antiskid aggregates, the last ones let part of the light go through them and be retroreflected (Figure
233   12). That is why G3 samples obtain better results than in G2 but not as good as in G1.

234

235   **Figure 12.** Microscope detail of S15 sample: (**a**) x16 magnifications; (**b**) x35 magnifications.

236   Following the acceptance criteria [17, 18], we find that from the eighteenth month, some G2
237   testing samples have a R_L value below Spanish standard requirements (100 mcd/m²/lx). For G3,
238   testing samples S13 and S14 are those whose perform best along the different tests, achieving the best
239   results during service life.
240   From both qualitative and quantitative analysis, we can conclude that initial retroreflectivity
241   results improve when microbeads used have a greater size. On the other hand, the smaller the glass
242   beads are, the more they embed in the base material, getting less retroreflectivity at first. However,
243   as they detach with more difficulty, retroreflectivity is preserved better along time, extending road
244   marking service life. The samples fabricated with medium-sized glass microbeads (425-850 μm)
245   obtained good results initially and over time. Another important aspect to consider is that glass
246   microbeads with an adhesive coating are detached from the paint with more difficulty, extending
247   road marking performance.
248   In the G4 testing samples group, a retroreflection increase is observed after twelve months of
249   service. This behaviour could be explained because the upper paint layer is progressively worn out
250   by traffic, revealing the microbeads embedded in the lower layer (Figure 13), improving
251   retroreflectivity. This process starts from the sixth month of service and extends the service life of
252   bilayer road markings, reducing retroreflectivity decay over time.

253

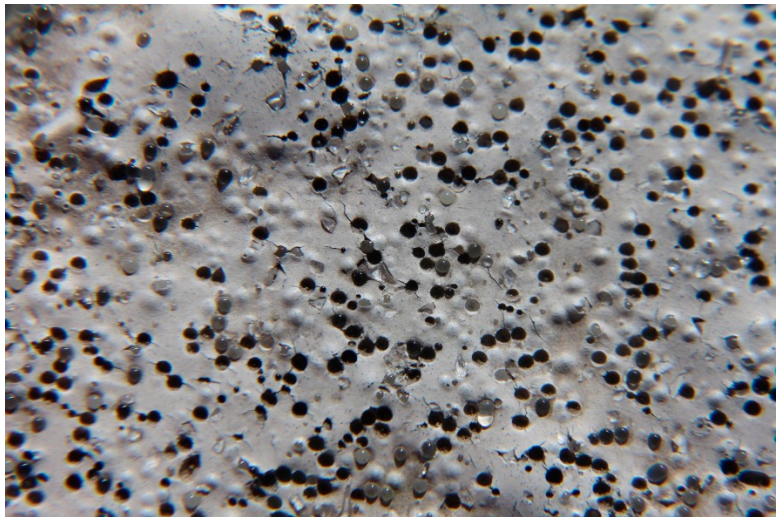



Figure 13. S18 sample in-situ detail after 12 months of service. Emergence of glass microbeads from the bottom layer is observed.

256   Figure 14 shows retroreflectivity evolution over time in wet conditions. From this figure, it can
257   be confirmed that from six months old, none of the G1, G2 and G3 testing samples reach the minimum
258   value required by Spanish regulations [17, 18]. We also notice that samples with bigger microbeads
259   get better R_W results than those with smaller ones, because they protrude over the water surface.
260   Furthermore, as bigger microbeads are detached easier, R_W drops quickly over time, as seen on Figure
261   14.

262

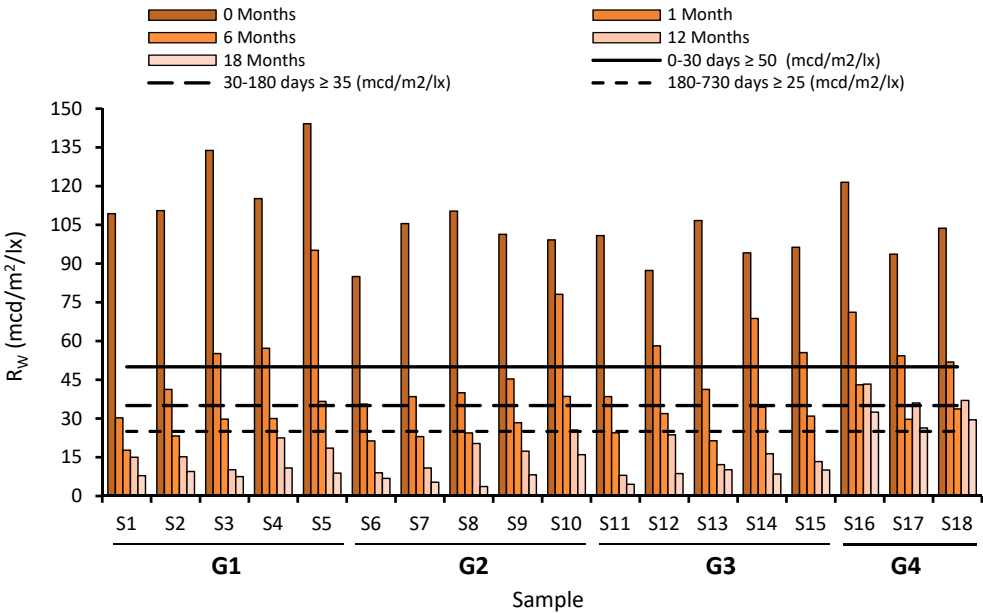



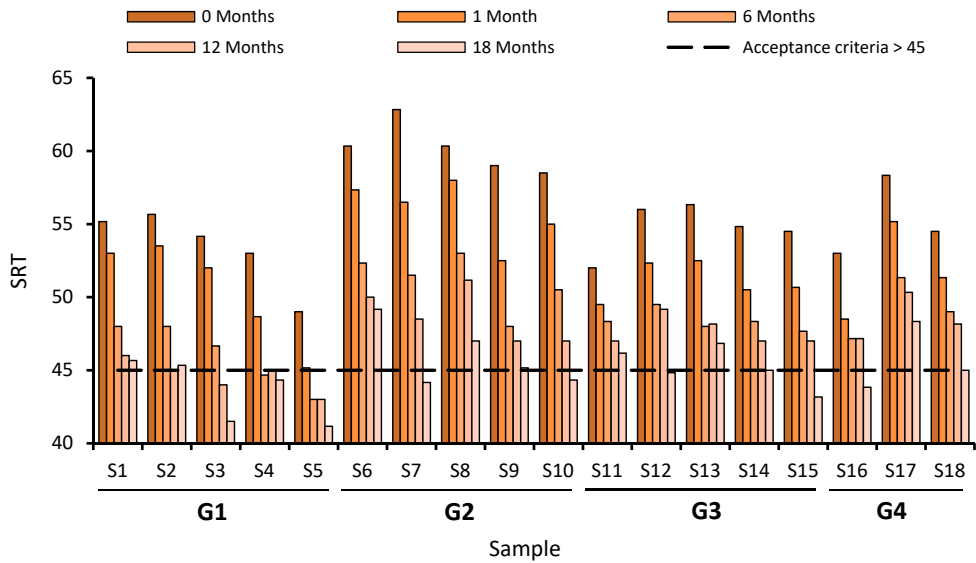
Figure 14. Evolution of R_W on test samples during the first 18 months of service.

264   As happened with R_L values, R_W increase from the sixth to the twelfth month is observed in G4
265   samples, due to the same reason explained before. This effect makes that these 3 samples achieve the
266   minimum R_W values established by the Spanish regulations [17, 18].

267   *3.3. Skid resistance*

268   Figure 15 shows skid resistance results of the 18 testing samples over time. Results were the
269   opposite of those obtained for β, R_L and R_W. So, the best group for SRT value is G2, followed by G3

270   and finally G1. Therefore, non-transparent aggregates have better roughness results than transparent
271   ones.

272

273   **Figure 15.** SRT evolution on test samples during the first 18 months of service.

274   For G4, testing samples follow same the trend that those testing samples that have the same
275   drop-on materials but are applied using AS1 system. Sample S17 shows the best results in this group,
276   followed by S18 and S16.

4. Conclusions

278   All sample groups reach the luminance factor acceptance requirements over time. Thus,
279   luminance is not the most determining factor in order to choose the optimum combination of
280   materials for road marking selection amongst all the samples studied. The craters left on the base
281   material by the detached drop-on aggregates are filled with dust and rubber particles, darkening the
282   road markings and making them lose luminance and therefore daytime visibility over time.
283   Regarding the chromatic coordinates, all the testing samples analysed are inside the polygon
284   that defines permanent white colour during the 18-month testing period. As happens as the
285   luminance factor, colour is not determinant to find the optimum drop-on mixture.
286   Retroreflectivity of road marking samples made of just microglass beads as drop-on material is
287   greater than those which have a mixture of microbeads and transparent antiskid aggregates, and
288   these ones obtain better results than those made with opaque antiskid aggregates.
289   Macael 400 particles take the space that could have be covered by glass microbeads and blocking
290   the incident light, what reduces R_L values in G2 samples. Glass 600 particles also fill that space,
291   reducing R_L value; however, as they are transparent, they let that part of the light goes through them,
292   obtaining slightly better R_L values in the G3 sample group.
293   As the size and quality (less impurities and defective beads) of microbeads increase, better initial
294   R_L values are obtained. On the other hand, largest microbeads are detached from the painting easier
295   and faster than the smaller ones, because the first ones are poorly embedded in the base material,
296   losing retroreflection capacity over time. Moreover, microcraters left by missing beads are posteriorly
297   filled by dirt, dust and rubber from tyres, causing also extra luminance loss. Microbeads' surface
298   coating gives them extra adhesion to remain embedded in the base material, getting really good
299   results, even in the largest diameters. Best R_W values are obtained with the largest microbead sizes,
300   because their upper part remains above the water and continues providing some retroreflection
301   capacity.

Bilayer road markings (G4 samples) results follow the trend of their equivalent monolayer sample. It should be pointed out that what we achieve with this application system is to decrease the wearing of road markings from the first month and to keep constant retroreflectivity values from the sixth month to the end of the testing period, even recovering this feature from the sixth to the twelfth month of service because of the emergence of the bottom layer after the wearing of the upper layer.

The relation between skid resistance is opposite to daytime and nighttime visibility: road markings having better SRT results (G2 sample group) obtain lower values of luminance and retroreflectivity. That is because rougher mixtures capture a greater amount of dirt and rubber particles, darkening the markings surface.

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