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RESIN8©: A Micro-Plastic Assessment and Product Circularity When Used in CMU's and Concrete Pavers

Luis G. Loria-Salazar[1,*], German Gomez-Sandoval[2]

[1]University of Costa Rica/Mat-Tech Engineering and Material Science, San Jose, Costa Rica.
[2]Grupo PEDREGAL, San Antonio, Belen, Heredia, Costa Rica.

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***Corresponding author:** Luis G. Loria-Salazar, University of Costa Rica/Mat-Tech Engineering and Material Science, San Jose, Costa Rica.
Email: luis.loriasalazar@ucr.ac.cr

Abstract

Contamination by plastic waste is becoming one of the largest world problems. The use of this material as an additive or filler for construction materials is becoming widely used to reduce the global contamination. In order to help out with this crisis, the Centre for Regenerative Design and Collaboration (CRDC) in partnership with PEDREGAL©, a construction materials company and builder from Costa Rica developed a patented and unique solution for the plastic waste crisis called RESIN8. It consists of an extruded mix of 80% recycled plastic (from various origins) and 20% mineral materials (mostly lime and wooden ash). This innovative material has been successfully used in the production of concrete masonry blocks and pavers. A question has been raised regarding the potential release of micro-plastics during the service life of RESIN8© modified CMUs and pavers and about their recyclability at the end of their service life. Therefore, a circular economy analysis was performed to assess the potential recycling of these products after their service life. Also, a full-scale accelerated pavement testing (APT) was performed to assess the micro-plastic release potential of RESIN8 modified pavers after a very abrasive wheel loading process. This parameter was found as low as 0.094%.

Keywords

Micro-plastics, Concrete-pavers, Recycle, Circularity, Pavement

1. Introduction

In 2018, the Centre for Regenerative Design and Collaboration (CRDC) in partnership with PEDREGAL©, a construction materials company and builder from Costa Rica developed a patented and unique solution for the plastic waste crisis called Preconditioned Resin Aggregate (PRA©). Under commercial name of RESIN8, it consists of an extruded mix of 80% recycled plastic (from various origins) and 20% mineral materials (mostly lime and wooden ash). The lime is mainly used as an anti-septic filler in order to remove any contamination that the plastic might contain. Other than wooden ash, it can be also used fly, sugar cane, coffer or plastic ashes. The extrusion process consists of mixing the indicated materials at a temperature between 190°C to 200°C for light density plastics and to a maximum of 230°C for high-density plastics such as PVC. After the mix, the material is cooled down in water, having a sort-of-ribbon shape, and finally, it is crushed in a milling machine to reduce it to a "sand-shape" material. The production equipment is set to a maximum temperature of 240°C since high-density plastics like PVC release chlorides products or other toxic gases above 260°C.

RESIN8© has been successfully used as a substitute of sand in masonry blocks, pavers and more recently, into Hot-Mix Asphalt (HMA).

Concrete Masonry Units (CMUs) and Interlocking blocks—pavers have been produced with various percentages of RESIN8© with an excellent performance, normally in a range varying from 2% to 10% of the volume of aggregates. When pavers are used as a pavement upper layer, various distresses might occur: permanent deformation—vertical displacement-, horizontal displacement and rotation. This paper does not seek to assess the structural strength of neither CMUs nor when pavers are used as an upper layer of a pavement but look for determining the potential of micro-plastic production when they are subjected to wheel loading that is a highly abrasive process.

Another important point is to evaluate the circularity of construction elements that contains RESIN8© under the light of conceptual research efforts in this field. Geissdoerfer, Savaget, Bocken, and Jan Hultink [1] define the Circular Economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. Pan, Du, Huang, Liu, and Chang [2] indicate that the waste-to-energy (WTE) supply chain has been aggressively constructed in different industrial parks around the world. And the principles of building WTE supply chain are based upon the "5R practices", those are reduction, reuse, recycling, recovery (energy), and reclamation (land). The authors recommend to effectively implementing the WTE supply chain, policy mechanisms should be able to tackle multiple barriers from the aspects of regulation, institution, finance and technology at once. Licona David [3] evaluated the environmental and economic impact of usage of recycle materials to produce structural and non-structural concrete in Cataluña. In her study, the production of 1 m^3 of conventional concrete was taken into account, to be compared with 1 m^3 of structural concrete with 25% recycled aggregates and 1 m^3 of non-structural concrete with 50% recycled aggregates. In the three alternatives, the greatest impact on the categories was the cement process; the following processes with the greatest impact were natural aggregates and recycled aggregates, due to their process.

The generation of micro-plastic is among the various concerns about the use of recycled plastics as a filler or additive for construction materials. According to the National Oceanic and Atmospheric Administration (NOAA) of the United States Government, micro plastics are small plastic pieces less than five millimeters long which can be harmful to our ocean and aquatic life. Also, NOAA's document stated that Micro-plastics come from a variety of sources, including from larger plastic debris that degrades into smaller and smaller pieces. In addition, microbeads, a type of micro-plastic, are very tiny pieces of manufactured polyethylene plastic that are added as exfoliants to health and beauty products, such as some cleansers and toothpastes. These tiny particles easily pass through water filtration systems and end up in the ocean and Great Lakes, posing a potential threat to aquatic life [4].

Therefore, there is a need of evaluating the performance of RESIN8© used as CMU's and pavers concrete mix filler under real in-situ conditions. It is particularly important to determine the paver's micro-plastics production by the abrasive process of tire wearing. To this end, an Accelerated Pavement Testing (APT) experiment was carried out by means of a Dynatest Heavy Vehicle Simulator (HVS) Mark VI at the PaveLab of the National Laboratory of Materials and Structural Models of the University of Costa Rica (LanammeUCR). This paper includes several information from the report LM-PI-UIIT-108-R1 from LanammeUCR [5].

The APT experiment performed at the PaveLab of LanammeUCR look to evaluate the mass loss of the pavers subjected to the abrasive effect of real traffic conditions.

The objectives of this research paper were the following:

- To briefly study RESIN8© from the circular economy view,
- To assess micro-plastic production in an accelerated pavement testing of test tracks constructed with normal pavers and RESIN8-modified ones.

2. RESIN8© Circular Economy Assessment

From the circular economy (CE) point of view, RESIN8© pavers and CMUs are very recyclable materials at the end of their service life. Mihelcic et al. defined in 2003 the current concept of circular economy as it is shown in Figure 1 [6]. Its message is that the inner circles demand less resources and energy and are more economic as well. The time the value in the resources spends within the inner circles should be maximized.

According to the CE elements for sustainable development mentioned by Korhonen et al. (2018) [7], it can be stated that RESIN8© is a win-win product from the sustainable perspective, accomplishing goals for its three elements: environment, economics and social. From the environmental perspective, RESIN8© reduces the virgin material and the energy input, reduces wastes and emissions, and the resources in production-consumption systems—such as CMU's and pavers- are used many times, not only one.

Regarding the economic win, RESIN8© reduced the raw material and energy costs, at the end of the product life it can be reuse several times, the use of costly scarce resources is minimized, and of course; it raise up the image, responsible and green market potential. In addition, value leaks and losses are reduced, the waste management cost is reduced as well, there is a reduction in emissions control costs, and; reduced costs from environmental legislation, taxation and insurance. Finally, new responsible business image attracts investment. In the case of social win, RESIN8© generates new employment opportunities through new uses of the value embedded in resources, increases the sense of community, cooperation and participation, and; user groups share the function and service of a physical product instead of individuals owning and consuming the physical product.

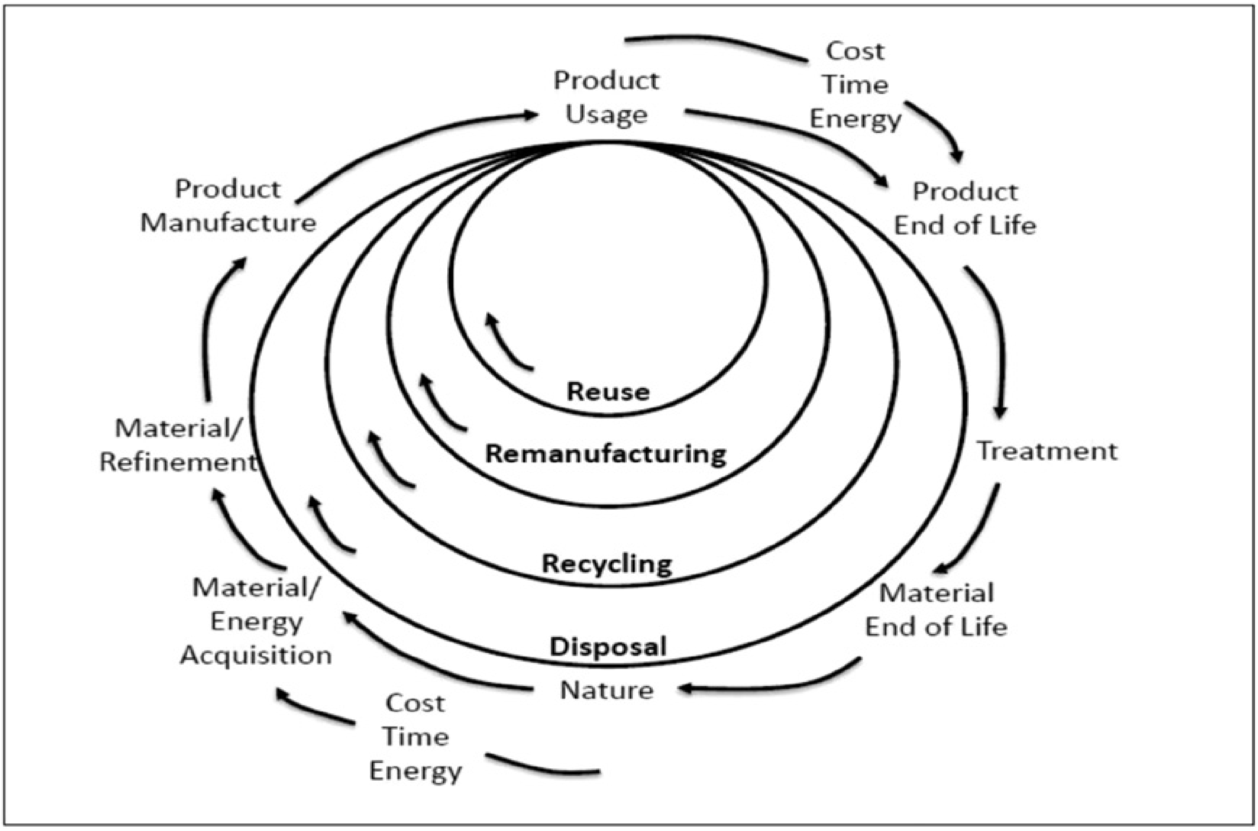

Figure 1. Classical CE concept by Michelcic et al.

3. Material Characterization

The sands used in the experiment are described in the following table and figure (Table 1 and Figure 2).

Table 1. Sieve analysis by ASTM D75, C117 Y C136

Sand type	AR-01 -Holland-	AR-02 Guapiles, Costa Rica	AR-03 Chirripo, Costa Rica
Sieve		**% Passing**	
9.50 mm (3/8”)	100	100	100
6.35 mm (1/4”)	100	99	100
4.75 mm (N° 4)	99	97	97
2.36 mm (N° 8)	88	88	90
1.18 mm (N° 16)	71	72	77
0.60 mm (N° 30)	40	42	47
0.300 mm (N° 50)	6	17	20
0.150 mm (N°100)	0,2	6	7
0.075 mm (N° 200)	0,1	2.2	3.2
Nominal aggregate size (mm)	4.75 (N° 4)	4.75 (N° 4)	2.36 (N° 8)

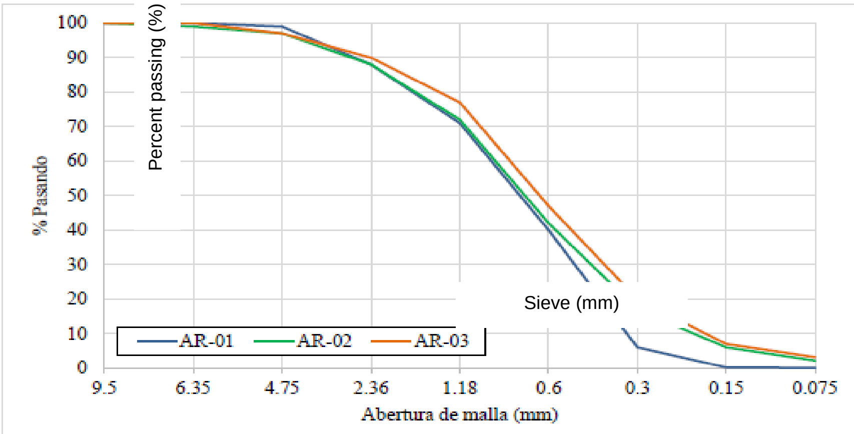

Figure 2. Sand sieve analysis.

The sands characterization is summarized as follows: 1) the coarser one is the AR-1; 2) the finer one is the AR-3; and, 3) all the sands meet the recommendations for nominal maximum aggregate size since are smaller than 9.52 mm; 4) all came from a grinding process; and 5) the percentage passing the 0.075 mm (N° 200) sieve for all the sand is below 10%.

A8 pavers (80 mm thick) were used in the experiment containing a 10% RESIN8© per volume of aggregate. Pavers characterization is shown in the following table (Table 2). The test methods used to characterize the pavers are the ASTM C140 and the Costa Rica´s INTE C94 and INTE C51.

Table 2. A8 Paver characterization.

Test		Results
Absorption (%)		5.0
Compressive strength (MPa)		55
Dimensions (mm)	Length	198 ± 2.0
	Width	98 ± 2.0
	Thickness	80 ± 3.0 (A8)
Weigh (kg)		3.50 (A8-1)

4. APT Experimental Design

HVS trafficking was applied to four pavement structures with the aforementioned three different sands and the A8 paver. The pavement structure consisted on the paver layer, a Portland Cement Concrete (PCC) slab, a granular subbase and a natural subgrade. Neither water saturation nor temperature control was applied during the experiment. The paver sand joints had an approximately thickness of 2 mm. The sand base under the paver was 2 cm thick. The following figure shows the studied pavement structure (Figure 3).

Loading began in August 2018. A 20 cm thick Portland cement concrete (PCC) slab was built in order to aisle the effect of the underneath pavement layers on the upper paver layer performance. The PCC's slab compressive strength was 25.5 MPa (250 kg/cm2). The PCC layer was laid on a 30 cm granular subbase that was on top of a 100 cm clayey soil. The objective of constructing the PCC layer was to work as a rigid -non-deformable- platform to allow the sand and the pavers taking all the tire pressure. The granular subbase was placed at a maximum density of 2,217 kg/m3 with an optimum moisture content of 8.6%. The subbase material had a CBR of 95%. Finally, the subgrade material was constructed for a maximum density of 1,056 kg/m3 with an optimum moisture content of 52% and CBR of 6.6%.

4.1 Test Set-up

The average speed selected should be adjusted for each test. The first loading applications generate—as it is expected quick initial deformations in the pavement structure due to a particle accommodation process and post-compaction of the sand. The same process occurs at real in-service pavements once are subjected to traffic. This is the reason because deformation measurements are made on a higher frequency at the experiment initiation and the initial deformation rate could be properly determined. The selected load to be applied was 60 kN which is equivalent to 4.71 Equivalent Single

Axle Loads (ESALs). An ESAL correspond to a single load of 40 kN applied on a single axel dual tire configuration.

The number of load repetitions was selected in 250,000-bidirectional passes. Loading speed was chosen at 4 km/hr. This test configuration allows for 10,000 load repetitions per day.

The next figures (Figure 4 and Figure 5) show the test tracks and the Dynatest HVS Mark IV used in the experiment.

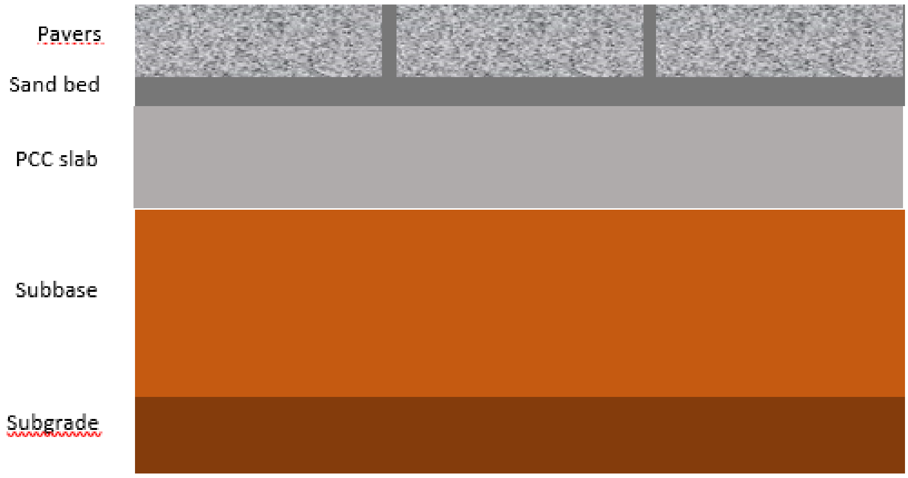

Figure 3. Pavement structure.

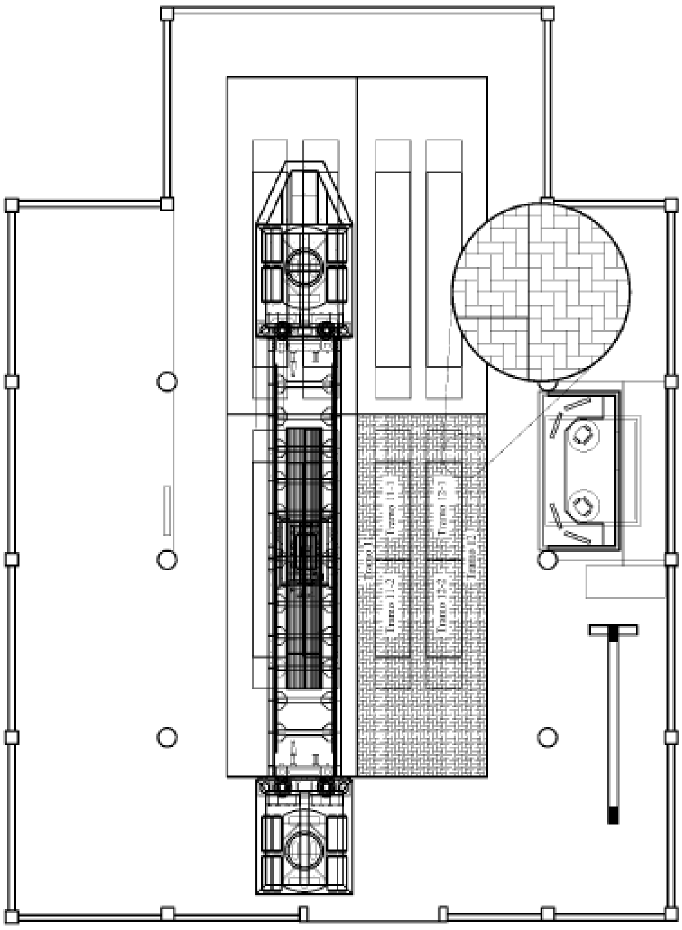

Figure 4. Test tracks.

Figure 5. HVS along the test sections.

5. Test Results

Paver samples were taken from the trafficked (T) and non-trafficked (NT) test tracks in order to compare their mass loss and relate it to the micro-plastic released potential. The mass measured from the recover pavers before and after trafficking, is shown in Table 3. The “lost” columns indicate the mass reduction in the pavers recovered after the APT experiment.

Table 3. Mass and Height Loss after APT experiment

Sand Code		**AR-01**	**AR-02**	**AR-01**	**AR-03**	**Pattern**	**AR-01**	**AR-02**	**AR-01**	**AR-03**
Sand Source		**Holland**	**Guapiles**	**Holland**	**Chirripo**	**Pavers**	**Holland**	**Guapiles**	**Holland**	**Chirripo**
Tread	Replicate	GU	LM	H-GU	H-LM	Non-used	Lost GU	Lost LM	Lost H-GU	Lost H-LM
Full (g)	1	3,724	3,594	3,715	3,526	3,768	44	174	53	242
	2	3,672	3,620	3,740	3,746	3,782	110	162	42	36
	3	3,628	3,630	3,775	3,670	3,728	100	98	-47	58
	4	3,690	3,662	3,572	3,516	3,810	120	148	238	294
	5	3,500	3,598	3,714	3,782	3,746	246	148	32	-36
Partial (g)	1	3,724	3,566	3,686	3,584	3,796	72	230	110	212
	2	3,518	3,618	3,719	3,628	3,610	92	-8	-109	-18
	3	3,748	3,662	3,627	3,566	3,640	-108	-22	13	74
	4	3,674	3,576	3,642	3,676	3,764	90	188	122	88
	5	3,712	3,678	3,721	3,614	3,714	2	36	-7	100
Average (g)		**3,659,0**	**3,620,4**	**3,691,1**	**3,630,8**	**3,735,8**	**76.8**	**115.4**	**44.7**	**105.0**
Standard Deviation		**86.1**	**38.0**	**60.5**	**88.5**	**65.6**	**90.3**	**86.2**	**96.4**	**110.1**
Thickness	mm	80.0	80.0	80.0	80.0	80.0	**Average height loss (mm) due to wheel abrasion:**			
Weight	grs/mm	45.7	45.3	46.1	45.4	46.7	**1.88**			
Height Lost	mm	1.68	2.55	0.97	2.31	-				

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Full-tread corresponds to pavers where completely cover by the wheel load while the partial-tread ones just a smaller area was subjected to trafficking.

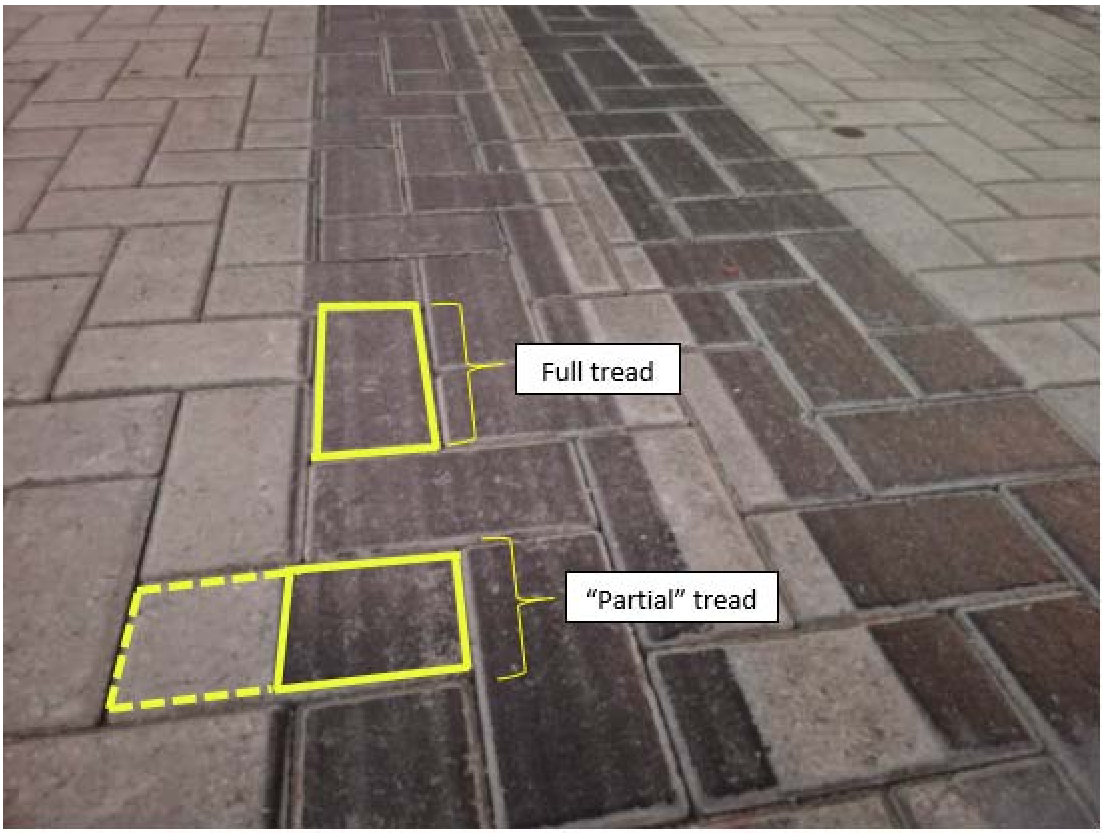

Figure 6. "Full" and "half" treads patterns.

According to Table 3, the average height loss of the pavers was 1.88 mm.

6. Micro-plastic Release Potential

Hereinafter, some calculations will be presented in order to determine the paver's micro-plastic release potential. According to Knapton et al. [8], the life-cycle analysis periods used for pavements are generally 20 to 30 years. Therefore, an average life period of 25 years is selected for the following calculations.

For the A8 paver 10% of RESIN8 was used, therefore, each paver contains 76.9 g of RESIN8 and 80% of that is recycled plastic. Then, each A8 paver has 61.5 g of recycled plastic.

If the maximum abrasion of the paver in 25 years is 1.88 mm, it corresponds to (1.88/80)*100 = 2.35% of the A8 paver volume. Therefore, every 25 years (2.35%) (61.5) = 1.44 g of plastic lost back to the environment. Therefore, 1.44 g / 25 yr = 0,058 g/yr of plastic lost per paver.

If 1.0 square meter of pavers has 50 units, we have (0.058 g/yr) (50) = 2.9 g/m2 of plastic lost each year.

If each paver square meter has 50 units, therefore it contains: (50 units/m2) (61.5g) = 3,075 g/m2 of recycled plastic.

Finally, the micro-plastic release potential of RESIN8© pavers is:

Micro-plastic release potential (MpRP) = $\frac{Plastic\ lost\ each\ year}{Plastic\ amount\ in\ 1\ sq.meter\ of\ paver} x100 =$

$$MpRP = \frac{2.9\ g/m^2}{3{,}075\ g/m^2} x100 = 0.094\%$$

Therefore, only 0.094% of the recycled plastic used to construct the pavers will be potentially converted into micro-plastics that is much better than have this material producing contamination and pollution around the world.

7. Conclusion

A circularity analysis was made to describe the re-use possibilities at the end of the service life of RESIN8© CMUs and pavers. Also, an APT experiment was performed to assess the micro-plastic release potential of pavers modified with 10% of RESIN8. From the CE review, it was assessed that RESIN8© CMUs and pavers are safe for being recyclable at the end of the useful life of the products, therefore, crushing and reutilization is expected that the entire plastic component will be effectively recycled. The micro-plastic release potential (MpRP) was determined and it was found to be as low as 0.094%. This very small amount helps to reduce the doubts regarding some possible harmful effects of use RESIN8 as a filler in construction materials during its service life. The performed APT experiment represents the most abrasive condition possible, a road use; and the micro-plastic release was very low, but moreover, it can be concluded that the release of micro-plastics would be negligible in non-abrasive conditions such as others construction elements. Micro-plastic release potential is negligible in the case of CMUs that are usually covered by a sand-cement mortar. In cases where CMUs are exposed, they normally are not subjected to any recurrent abrasive process; therefore, their MPRP is also considered negligible.

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