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Macro Stickies Content Evaluation of Different Cellulose-Based Materials Through Image Analysis

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Abstract: In this work an evaluation of Macro Stickies was performed on thirteen different cellulose-based materials through image analysis. In particular, the materials that were evaluated consisted of different types/categories of papers/products produced by the industry, namely, molded cellulose products, unbleached kraft papers, barrier papers, one recycled paper, and a laminated paper package. The Macro Stickies Evaluation was carried out using an image analysis tool developed by our research group to perform this kind of work from now on. The results indicated that eight of the processed samples revealed low/residual contents of Macro Stickies, whereas the remaining five revealed higher amounts of Macro Stickies in their surfaces. Of the eight samples showing a low/residual Macro Stickies content, five of them belonged to the unbleached kraft papers category, with an area per mass of Macro Stickies ranging from 8.60 to 29.04 mm^2/kg. However, the lowest case did not belong to this category, but to the molded cellulose products category with a value of 6.10 mm^2/kg. Of the five samples showing higher amounts of Macro Stickies, the worst three cases were associated to one of the barrier papers, the recycled paper and the laminated paper, with an area per mass of Macro Stickies of 28,973.42, 6998.56, and 14,058.76 mm^2/kg, respectively. Macro Stickies can assume different sizes, numbers and distributions depending on the characteristics and nature of each sample, and can be a great concern in the recycling of cellulose-based materials. In this sense, the proper assessment of Macro Stickies provides valuable information for the recycling sector to classify them in the products, and to anticipate which materials might give rise to potential stickies related problems in the recycling process.

Keywords: CEPI methodology; recycling; macro stickies; cellulose-based materials; image analysis

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Academic Editor: Silvia Serranti

Received: 28 February 2025
Revised: 27 March 2025
Accepted: 9 April 2025
Published: 11 April 2025

Citation: Mendes, A.d.O.; Vieira, J.C.; Costa, V.L.D.; Pinto, P.; Soares, B.; Barata, P.; Curto, J.M.R.; Amaral, M.E.; Costa, A.P.; Fiadeiro, P.T. Macro Stickies Content Evaluation of Different Cellulose-Based Materials Through Image Analysis. *Recycling* **2025**, *10*, 69. https://doi.org/10.3390/recycling10020069

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1. Introduction

Nowadays, more than ever, high concerns and efforts are being put into the environment in the attempt to reduce/recycle waste [1–3] and attain more sustainable and green economies [4–6]. One of those attempts, and a major goal to achieve, concerns the substitution of pollutant and hazardous materials (plastics, chemicals, others) found in packaging and consumer products [7,8], by materials that are more environmentally friendly. Paper/cellulose is a very interesting and promising replacement material, and currently, one of the most preferred options. Paper/cellulose has already been used in bags,

recipients for food, and several other applications for many years, and it is expected to continue being used on an increasing variety of products [9–13]. For instance, in recent years, mono-use items such as drinking straws and coffee capsules, commonly manufactured in plastic and/or with metal components, have been replaced by equivalent products made of paper [14,15]. These changes that are being implemented in the industry and commercial companies are very positive in order to progressively stop the introduction of more plastics in the nature, oceans and freshwater sources which have a severe impact on the flora, fauna and on the human health [16–20].

However, with the increase usage of paper/cellulose materials in the everyday life, other concerns must also be addressed, namely, the recyclability of these new products. In this matter, the CEPI (Confederation of European Paper Industry) made it possible to harmonize a European laboratory test method to generate parameters enabling the assessment of the recyclability of paper and board products in standard paper and board recycling mills. Presently, the available CEPI methodology provides recommendations for cellulose-based products for recycling in standard mills (Part I), flotation deinking recycling mills, (Part II), and in the near future, Part III (specialized recycling mills) will become accessible. This methodology enables to adequately evaluate and compare different cellulosic fiber-based products in a laboratory and access efficient recycling. It is important to note that a negative evaluation does not preclude additional testing from being performed. Another important remark is that CEPI recyclability scores obtained for a given type of cellulosic fiber-based materials/products cannot be transferred to other types. Moreover, higher scores indicate better recyclability of the materials/products, whereas, a negative score only means that the evaluated sample is not suitable for this type of recyclability assessment, not meaning that the material/product is not recyclable at all [21,22]. The quantification of Macro Stickies on each sample is the final stage of this methodology, although it is not yet included in the attribution of the final score. However, despite being optional, it is an important matter within the Pulp & Paper Industry since their presence may cause paper production disturbances, such as machine breaks, defects on the paper and converting problems [23–25].

Macro Stickies are a diverse group of materials (such as residues of paint, waxes and adhesives) that, according to the CEPI methodology, are retained in a laboratory sieve with a 150 μm gap and that they can potentially adhere to adjacent objects due to their inherent adhesive characteristics (or acquired by an increase in temperature, pressure or change in pH). Furthermore, Macro Stickies can permanently adhere to other non-adhesive components of the sample, namely cellulosic fibers [26,27]. In the recycling process of cellulose-based products, the smaller the particle size, the lower its removal efficiency. Therefore, particles with a diameter of less than 2000 μm should be avoided, especially in the case of Macro Stickies [28].

For the quantification of the Macro Stickies, several approaches can be used, for instance, the visual method [29], laser triangulation [23,30], near infrared spectroscopy [23,30,31], and image analysis [23,27,32]. This latter is particularly significant because it has been established as a standard procedure followed by CEPI (Confederation of European Paper Industry) for this kind of analysis, when it is decided to perform this part of the methodology.

In order to address and evaluate the recyclability of different paper/cellulose and packaging materials provided by the Portuguese Paper Industry and from the benchmarking, our research group has implemented, in the facilities of the University of Beira Interior, the entire methodology followed by CEPI, including the part concerning the assessment of the Macro Stickies by image analysis. This article is dedicated precisely to this last part of the CEPI methodology. The performed work concerning the application of the image

analysis of the samples to be processed was based on the requirements and guidance that are thoroughly described in the normative of ISO 15360-2 [27] and TAPPI/ANSI T 277 sp-21 [33]. The following sections of this article will therefore present the materials and methods that were used in the current work, together with the most important results that were collected, and the main conclusions achieved on the comparison of thirteen cellulose-based materials/products of different categories in terms of their propension to form Macro Stickies.

2. Materials and Methods

2.1. Cellulose-Based Materials

Different cellulose-based materials provided by the paper industry and from benchmarking were considered to form the group of samples for processing through the CEPI recycling methodology, and for the analysis and quantification of the Macro Stickies (MS). Table 1 presents the different types/categories of papers/products that were considered, their identification, and also the CEPI total final scores obtained for each one of the processed samples.

Table 1. Category, identification and CEPI Total Final Scores of the samples.

Category	Sample ID	CEPI Total Final Score * (Points)
Molded Cellulose	MC1	99.9
	MC2	98.7
	MC3	99.3
Unbleached Kraft Papers	UP1	98.8
	UP2	97.6
	UP3	98.8
	UP4	98.3
	UP5	99.9
Barrier Papers	BP1	98.8
	BP2	99.8
	BP3	4.5
Other Papers	OP1	79.7
	OP2	45.6

*—CEPI Total Final Scores of the samples determined based on Version 2 (2022) [21].

As a side note, in regard to the content of volatile solids, determined according to ISO 1762 [34], all samples presented in Table 1 have fulfilled the requirement of a minimum of 50% of volatile solids required by the normatives EN 13432 [35], and EN 14995 [36].

2.2. Experimental Methodology–Macro Stickies Screening

The MS screening was performed using a Somerville–Shive Content Analyzer FRANK-PTI GmbH, Birkenau, Germany with the 150 µm slotted plate, according to ISO 15360-2 [27]. For each sample, the screening was done in duplicate using 5.0 g oven dried of the accepted coarse. In case of a high amount of retained MS (Figure 1), which might impair the visualization of MS individually, half of the accepted coarse quantity (2.5 g) was used.



Figure 1. High amount of retained Macro Stickies.

2.3. Experimental Methodology–Optical Analysis

For the MS evaluation of the laboratory samples that were processed according to the procedure described in the previous section, a two-step methodology was then applied to the samples. The first step consisted of scanning the samples to obtain images of their surfaces, and the second step consisted of processing the obtained digitized images of the scanned samples.

2.3.1. Optical Analysis–Scanning Step

In this step of the methodology, digitized images of the samples were captured using a high-resolution scanner of 256 grey levels of sensitivity or more, and a pixel resolution below 50 μm per pixel, resulting in a combined area of 0.01 mm^2 of four contiguous pixels [27]. Specifically, a Color Image Scanner Perfection V850 Pro, EPSON, London, United Kingdom was used for the digitization of the samples using a resolution of 600 DPIs without any color or image corrections during the scanning of the samples.

2.3.2. Optical Analysis–Processing Step

In this step of the methodology, a processing routine written in the MATLAB® R2024b programming language, was implemented for the digitized images of the samples. The routine begins by defining a circular area of interest with a diameter of 200 mm, equivalent to the effective diameter of the produced paper sheets. This is followed by a binarization [37,38] of the images on which the elements to be detected (Macro Stickies) are separated from the background. This routine is very similar to the one used in our previous work [39] to obtain the corresponding maps of pills of fabric samples subjected to abrasion. The main difference between both approaches is that in our previous work, the elements intended to be separated from the background consisted of three-dimensional data, whereas in this work the elements to be separated consist of two-dimensional data registered on different grey levels. Nevertheless, in both cases, the result is a map of the elements to be detected which is then used to perform the calculations of the parameters of interest. Similarly, as in our previous work, the routine used in this work also ends with a series of steps consisting of image cleaning and noise removal of the obtained maps of elements [37,38]. The scheme of Figure 2 shows the different steps of the processing methodology implemented in this work.

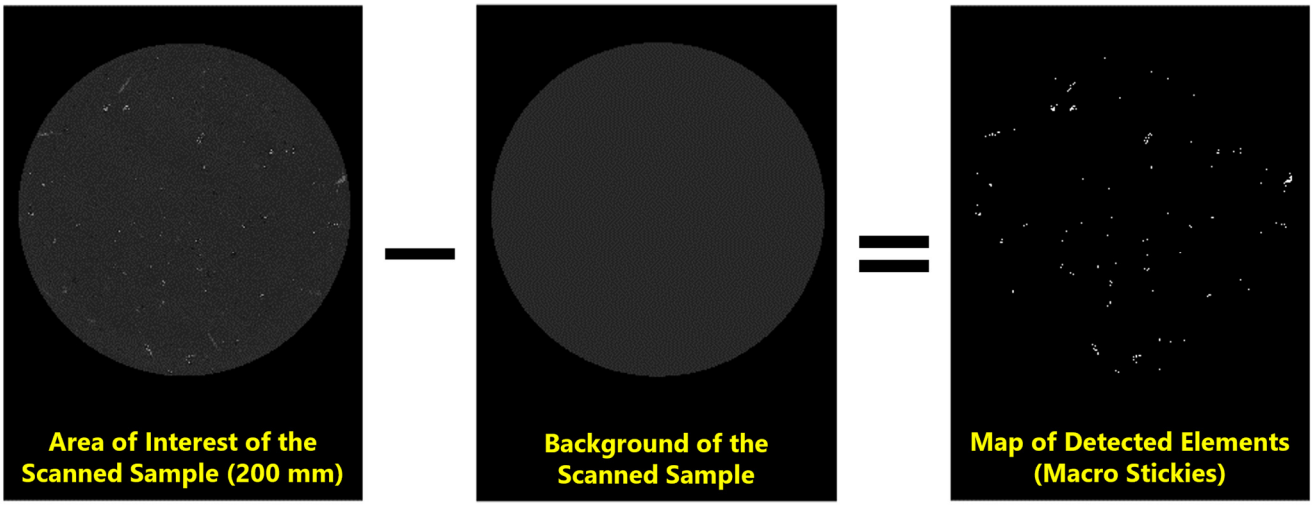


Figure 2. Scheme of the processing step methodology.

3. Results and Discussion

3.1. Global Analysis

The samples considered in the present work were subjected to the methodology described in the previous section and a global analysis of MS was then carried out. In the analysis performed, the following parameters were calculated for each one of the samples:

- Number of detected elements (units);
- Total area of detected elements (mm^2);
- Total area of detected elements per oven-dried mass of pulp (mm^2/kg).

The results obtained in this analysis for the thirteen different samples are presented in Table 2.

Table 2. Global analysis of Macro Stickies (detected elements, total area and area per mass) for the thirteen different samples studied, presented from the lowest to the highest number of detected elements on each category.

	Macro Stickies (Global Analysis)		
Sample ID	**Detected Elements (Units)**	**Total Area (mm^2)**	**Area per Mass (mm^2/kg)**
MC1	1	0.03	6.10
MC2	19	2.82	564.52
MC3	36	7.25	1450.54
UP1	2	0.04	8.60
UP2	2	0.08	16.48
UP3	3	0.08	16.12
UP4	4	0.14	27.24
UP5	4	0.15	29.04
BP1	2	0.11	22.58
BP2	5	0.13	26.16
BP3	1783	144.87	28,973.42
OP1	141	34.99	6998.56
OP2 *	678	35.15	14,058.76

*—This sample was produced considering 2.5 g of dried mass. All the others considered 5 g of dried mass.

From Tables 1 and 2, some interesting findings can be immediately highlighted. Firstly, the presented results indicate that the samples belonging to the UP category are, in general

and consistently, the ones with the lowest MS content, accordingly, showing good recyclability, which can be explained by the low additives and adhesive-like components amongst all the other tested materials. Furthermore, BP3 is the sample that exhibits the highest number of detected elements (1783), highest total area (144.87 mm^2), highest area per mass (28,973.42 mm^2/kg), and lowest CEPI score (4.5 points), whereas MC1 is the sample with the lowest number of detected elements (1), lowest total area (0.03 mm^2), lowest area per mass (6.10 mm^2/kg), and highest CEPI score (99.9 points).

It can also be seen in Tables 1 and 2 that there are five samples across categories, namely, MC2, MC3, BP3, OP1 and OP2, that show substantial differences comparatively to the other remaining samples, revealing higher amounts of MS, with a minimum of 19 detected elements for the sample MC2 and a maximum of 1783 detected elements for the sample BP3. However, the CEPI scores of the first two (MC2 and MC3) are very high, decreasing greatly for the other three (BP3, OP1 and OP2). The remaining eight samples, identified as MC1, UP1, UP2, UP3, UP4, UP5, BP1 and BP2, all present small amounts of MS, with a minimum of 1 detected element for the sample MC1 and a maximum of 5 detected elements for the sample BP2, and high CEPI scores, with a minimum of 97.6 for the sample UP2 and a maximum of 99.9 for the samples MC1 and UP5.

These findings can also be observed in Figure 3, which exhibits the Macro Stickies content versus the CEPI score obtained for each one of the thirteen samples studied.

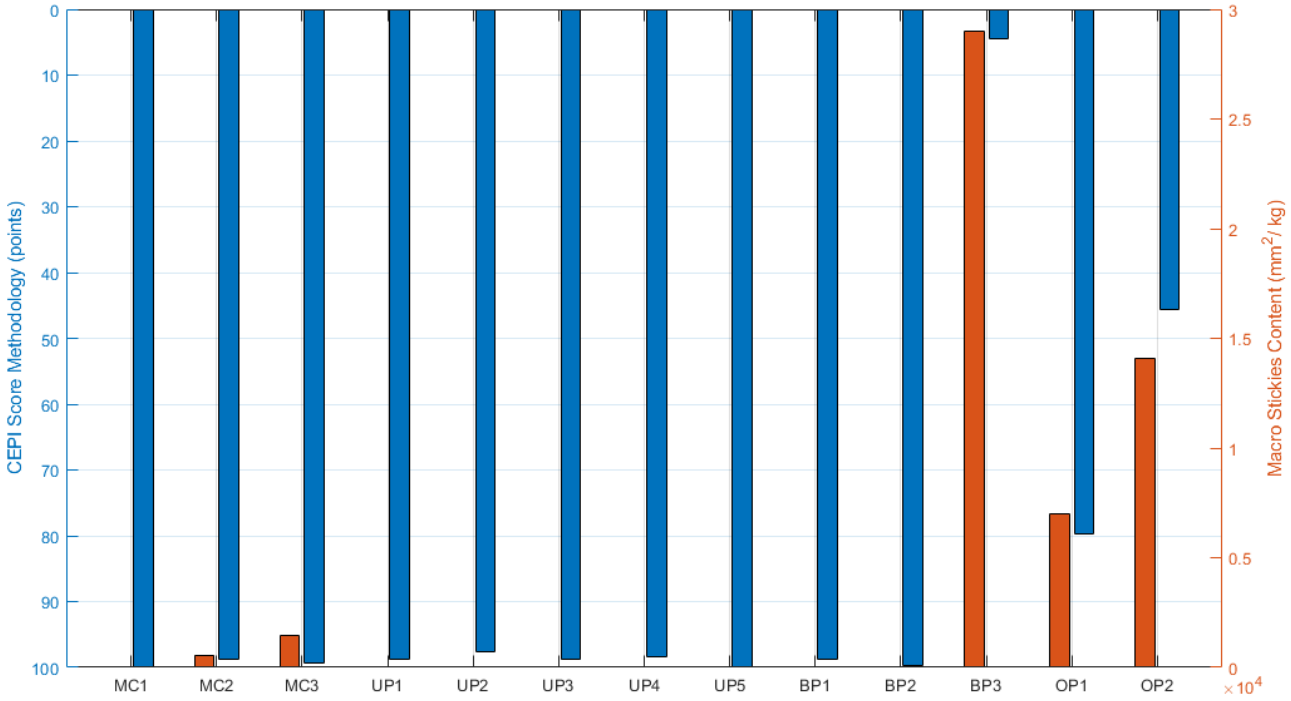


Figure 3. Macro Stickies content vs. CEPI score for the thirteen samples studied.

In particular, Figure 3 shows that the CEPI scores are high for the first ten samples shown in the graph (MC1 to BP2), even for the samples MC2 and MC3, as aforementioned. On the other hand, the last three samples shown in the graph (BP3 to OP2) all have higher MS contents, and they also exhibit lower CEPI scores, namely, 4.5 points for the sample BP3, 79.7 points for the sample OP1, and 45.6 points for the sample OP2. Nevertheless, although this tendency has been noted in the obtained results, it cannot be inferred that there is a proportional correlation between the high MS content and the material's poor recyclability, since the MS dimensions, geometry, orientation, and distribution also have an important influence on the recycling potential of the product, in accordance with the findings of Huber et al. [40].

Making an analysis within each category is also a matter of interest, and specifically, for the first group presented in Tables 1 and 2 (molded cellulose products), the three samples of the group reveal to be distinct, as it can be observed from their digitized images shown in Figure 4.

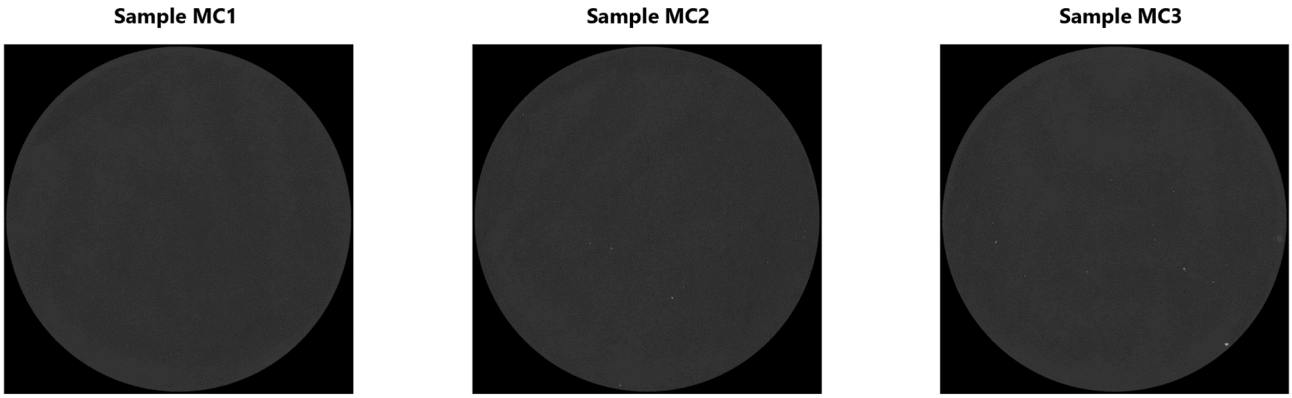


Figure 4. Digitized images of the top surface of samples MC1 to MC3 (diameter of 200 mm).

The corresponding maps of MS of these samples were also computed through application of the implemented processing methodology, and they can be observed in Figure 5, confirming that the amount of MS present on the three samples differs from a single element detected on MC1, 19 elements detected on MC2, and 36 different elements detected on MC3.

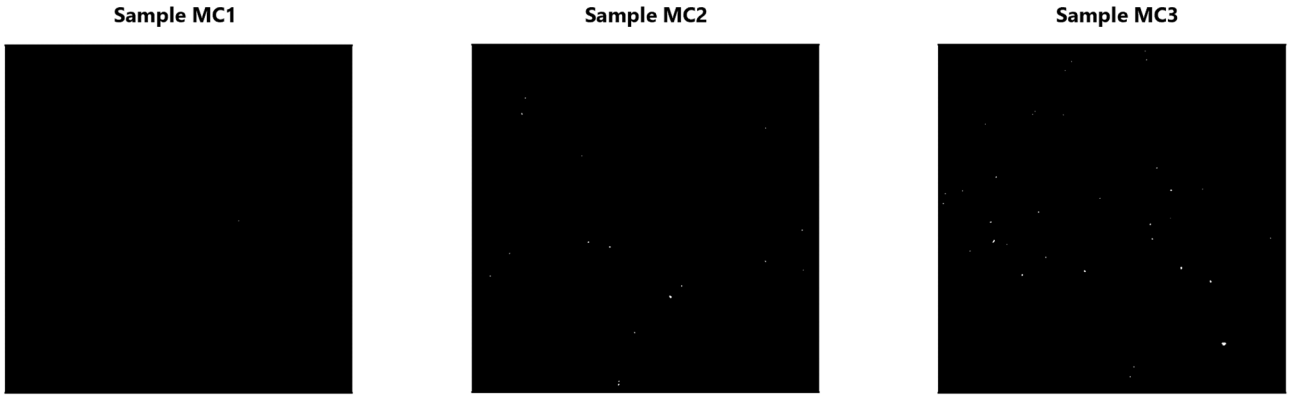


Figure 5. Maps of Macro Stickies obtained for the samples MC1 to MC3.

Moving on to the analysis of the next category of products presented in Tables 1 and 2 (Unbleached Kraft Papers), the five samples that compose the group reveal to be very similar in terms of number of detected elements, as it can be observed from their digitized images shown in Figure 6.

Using the same procedure as before, the corresponding maps of MS were computed for these five samples, UP1 to UP5, and they can be observed in Figure 7. However, it must be noted that because these five particular samples exhibit only a low/residual presence of MS on their surfaces (2 elements each detected on UP1 and UP2, 3 elements on UP3 and 4 elements detected on UP4 and UP5), the generated maps of MS correspond almost entirely to black maps, with only a few white spots signalizing the locations of the MS, which may be difficult to visualize. Yet, it is important to note that they are actually there.

The next group of products presented in Tables 1 and 2 concerns the three samples belonging to the category of barrier papers, and their digitized images and corresponding maps of MS can be observed in Figures 8 and 9, respectively.

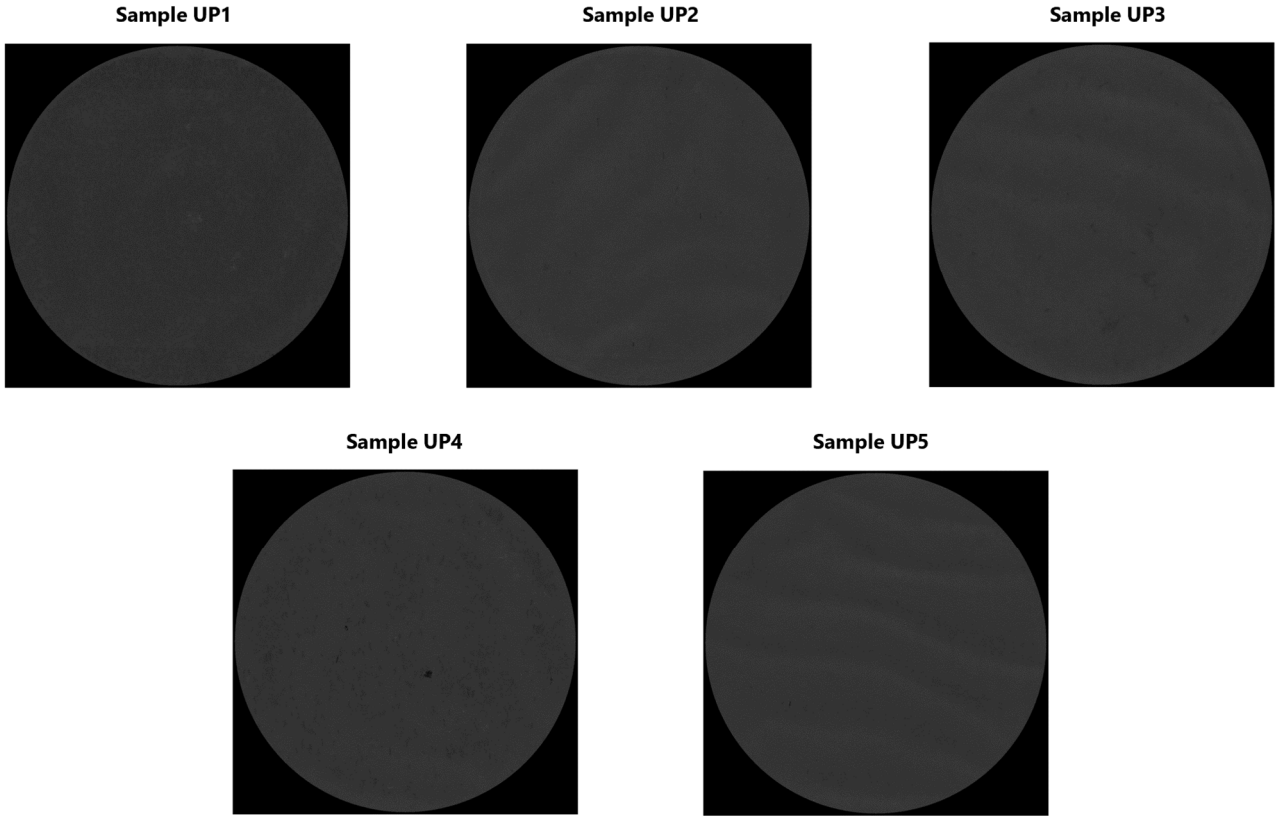


Figure 6. Digitized images of the top surface of the samples UP1 to UP5 (diameter of 200 mm).

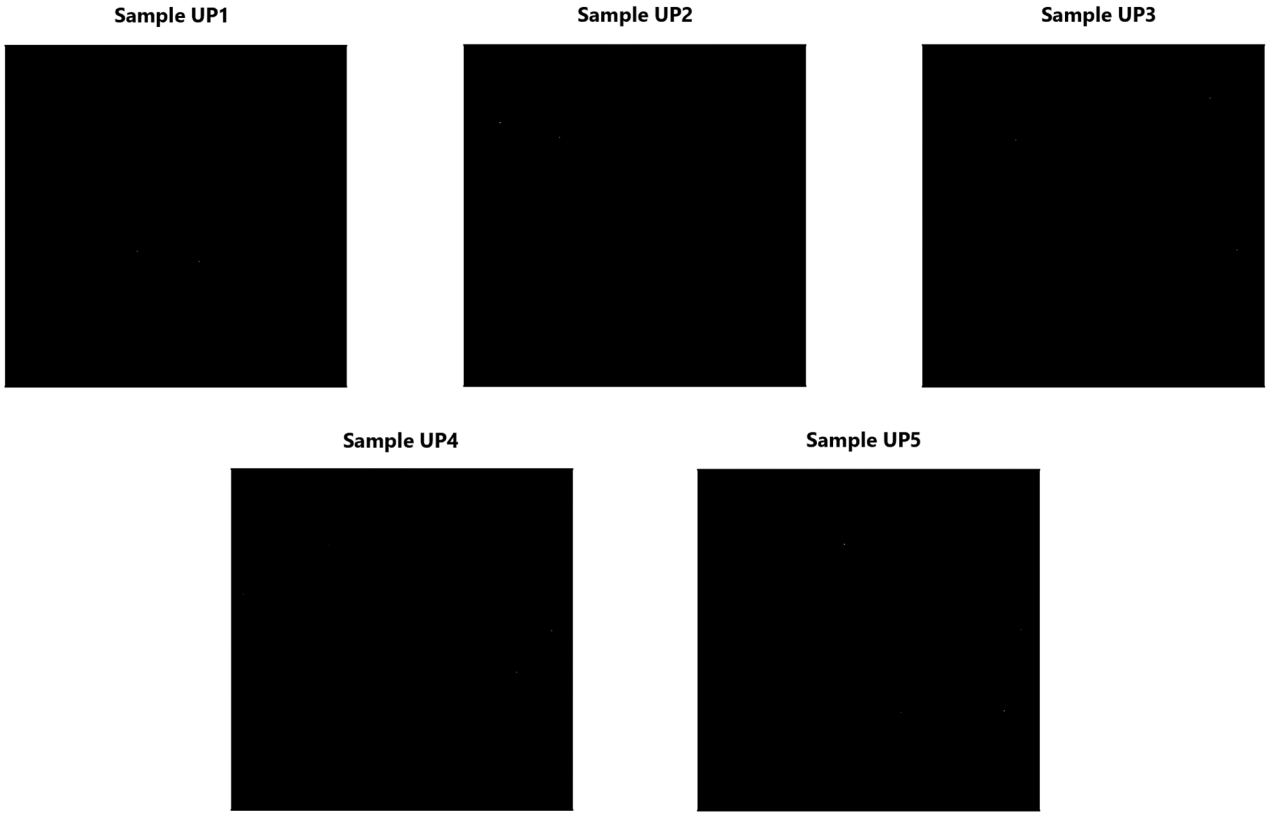


Figure 7. Maps of Macro Stickies obtained for the samples UP1 to UP5.

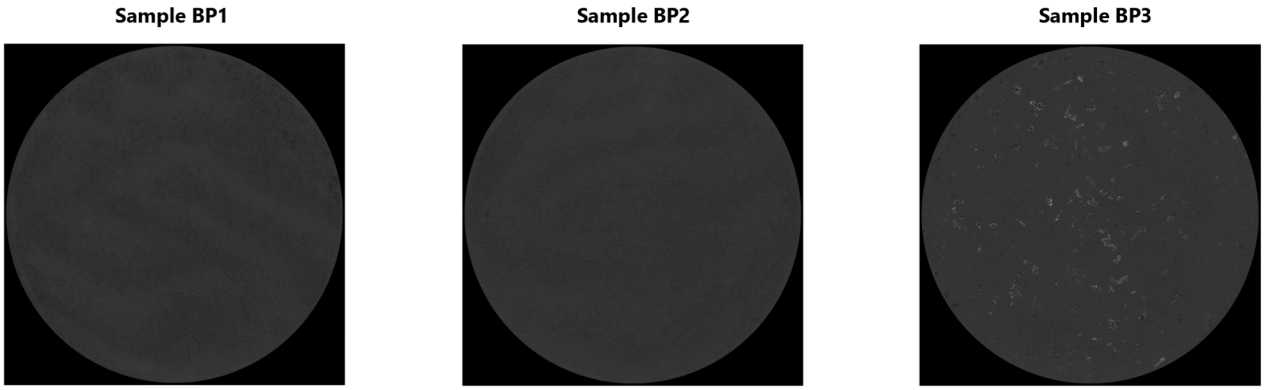


Figure 8. Digitized images of the top surface of samples BP1 to BP3 (diameter of 200 mm).

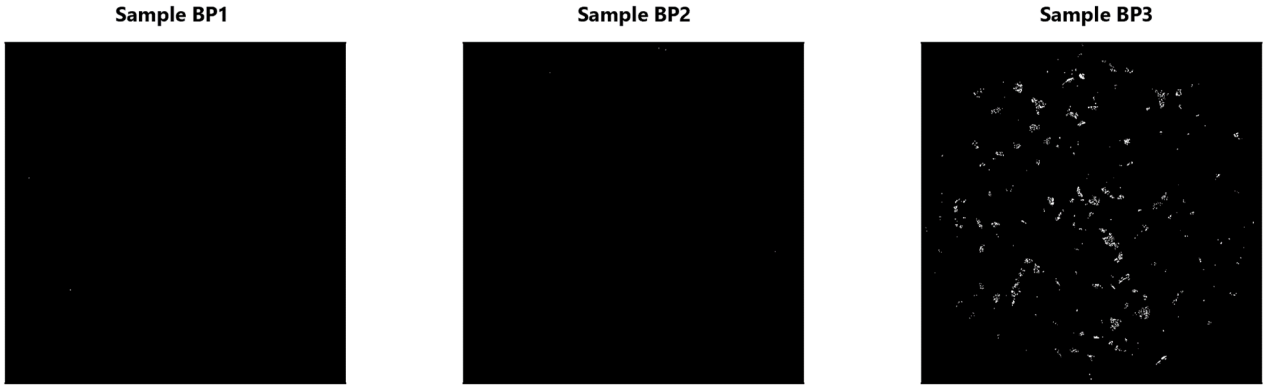


Figure 9. Maps of Macro Stickies obtained for the samples BP1 to BP3.

From the above figures, it can be seen that the first two samples BP1 and BP2 are very similar, and both present a very low amount of MS (2 and 5 for the samples BP1 and BP2, respectively). The remaining sample of this group, BP3, is completely different from the other two, presenting a significant amount of MS on its surface (1783 elements). This happened because the barrier properties of this sample were provided by a plastic film that, not being suitable for recycling, is discarded alongside attached cellulosic fibers. As a consequence, the MS content of this sample is very high in comparison with the other two samples of this category, and its CEPI score is very low, as indicated earlier.

The final group of products presented in Tables 1 and 2 concerns two samples belonging to the category of other papers, on which the first one, the sample OP1, corresponds to recycled paper, and the second one, the sample OP2, corresponds to a laminated paper. Their digitized images and corresponding maps of MS can be observed in Figures 10 and 11, respectively.

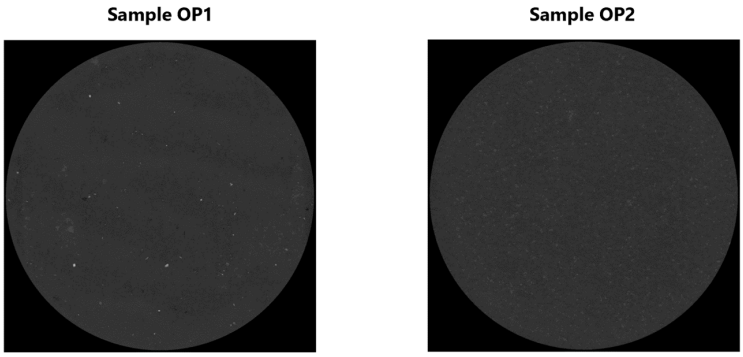


Figure 10. Digitized images of the top surface of samples OP1 and OP2 (diameter of 200 mm).

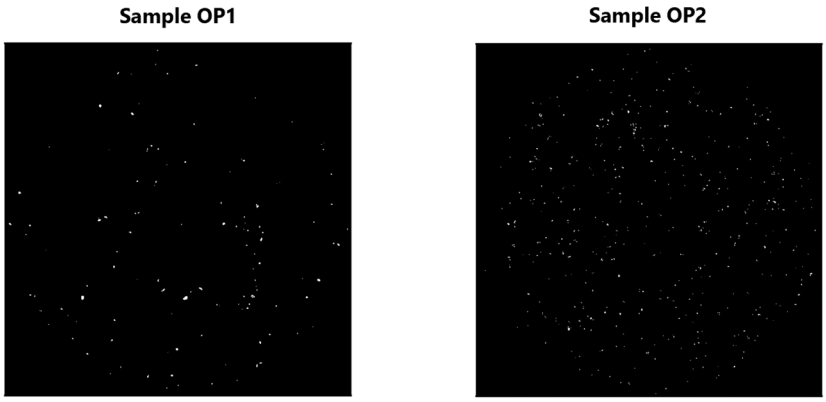


Figure 11. Maps of Macro Stickies obtained for the samples OP1 and OP2.

From Figures 10 and 11, it can be seen that the samples OP1 and OP2 both present a relatively high number of MS on their surfaces, 141 for the sample OP1, and 678 for the sample OP2, to be exact. However, the distribution and sizes of the MS are quite different on both samples. Specifically, on sample OP1, the MS reveal to have, in global, higher dimensions and a less dispersed distribution, whereas on sample OP2, they reveal to have globally lower dimensions and are located practically all over the sample. The differences in MS distribution on the sheet area may be related to the MS density, dimensions and interactions with other constituents of the sample, since they can facilitate flocculation and formation of aggregates during the sheet formation. Another important remark concerning this second sample of the group of "other papers" is that it was the only sample of the entire set being produced using 2.5 g of dried mass while all the other samples were produced using 5.0 g of dried mass. This happened due to the very high amount of material retained in the sieve during processing according to the CEPI methodology, as explained earlier in Section 2.2 of this article. Of course, all the calculations performed in Table 2 had this in consideration. It is also interesting to notice that this sample was the only one that needed extra disintegration (according to this methodology, an addition cycle of 30,000 revolutions in the disintegration step was performed in order to obtain a homogeneous pulp).

3.2. Analysis per Classes

Because the MS on the surfaces of all the considered samples in our studies are very different in terms of sizes and distributions, it is also an important matter to know exactly what their dimensions are for each case. Thus, in addition to the previously presented global analysis, a second analysis was also considered in the current work but now performing a categorization of the detected MS by classes based on their dimensions. Different approaches are possible, and based on the samples analyzed in our studies, a categorization of the MS on 8 different classes, designated by C1 to C8, was carried out according to the reference dimensions indicated in Table 3.

Table 3. Classes considered for the analysis of Macro Stickies based on their dimensions.

Class Designation	Dimensions of Macro Stickies per Class
C1	$\geq$0.01 mm^2, <0.05 mm^2
C2	$\geq$0.05 mm^2, <0.10 mm^2
C3	$\geq$0.10 mm^2, <0.20 mm^2
C4	$\geq$0.20 mm^2, <0.50 mm^2
C5	$\geq$0.50 mm^2, <1.00 mm^2
C6	$\geq$1.00 mm^2, <2.00 mm^2
C7	$\geq$2.00 mm^2, <5.00 mm^2
C8	$\geq$5.00 mm^2

The same parameters considered previously in the global analysis, namely, the number of detected elements, the total area, and the area per mass of MS are considered once again, in this second analysis. However, in this new approach each parameter is calculated for the 8 different classes independently instead of as a whole. The complete results that were obtained for the thirteen different samples in this analysis per classes are presented in Figure 12 (histograms of MS) and in Tables 4–6 (detected elements, total area, and area per mass, respectively). The histograms of Figure 12 represent the same as Table 4, however, in graphic form, making the interpretation of the results of the number of detected elements easier. The horizontal axis of the graphs denotes the eight different classes that were considered (C1 to C8), whereas the vertical axis denotes the number of detected elements, which is represented in different scales depending on each case. The majority of the graphs created are scaled from 0 to 10, but there are also four other scales that were used in the representation of the histograms, in particular, from 0 to 30, from 0 to 50, from 0 to 500, and from 0 to 1000.

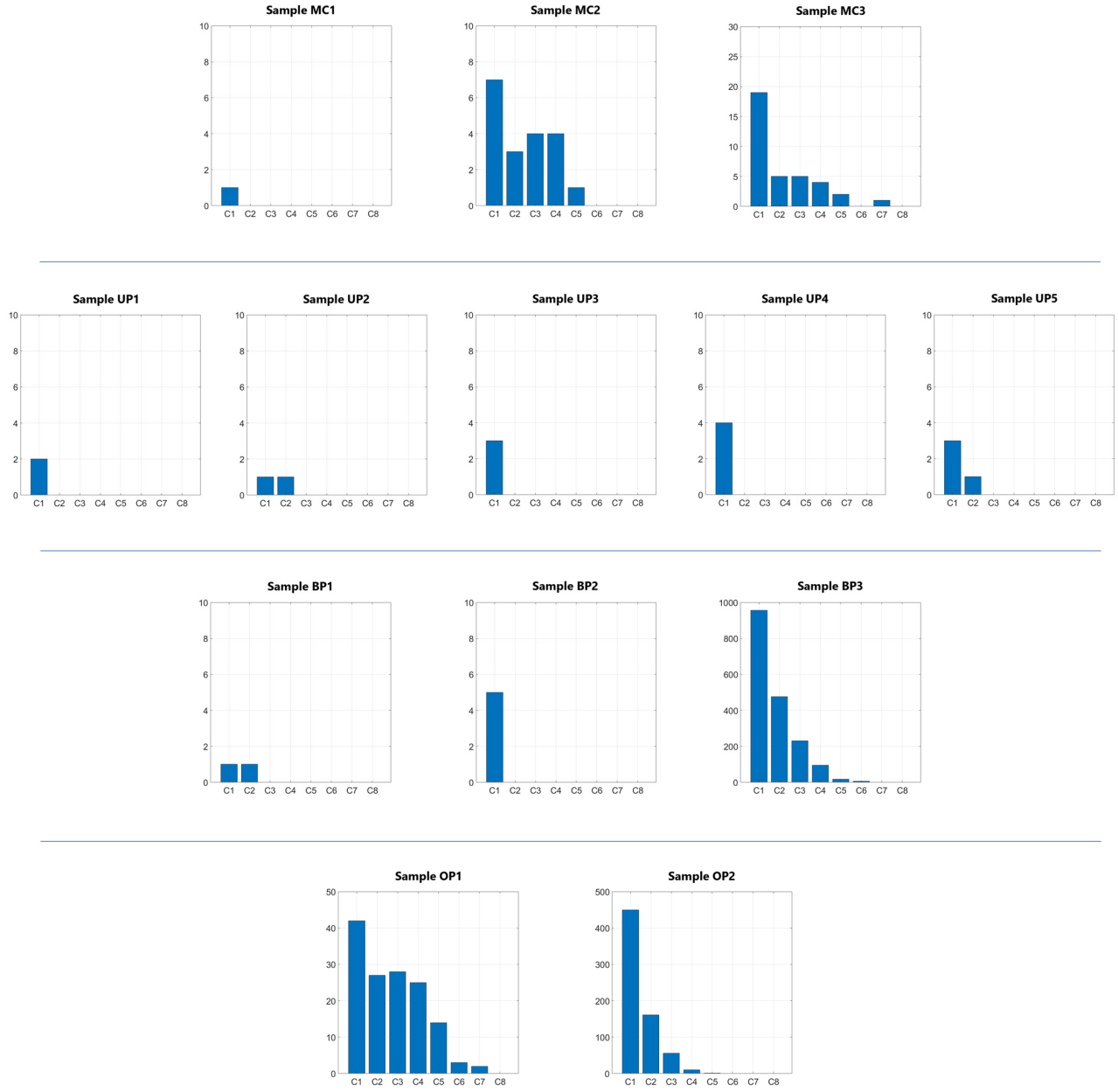


Figure 12. Histograms of Macro Stickies obtained for the thirteen analyzed samples (number of detected elements per classes).

Table 4. Analysis per classes of the number of detected Macro Stickies for the thirteen different samples studied.

Macro Stickies (Analysis per Classes mm²)–Detected Elements (Units)								
Sample ID	**C1 0.01–0.05**	**C2 0.05–0.1**	**C3 0.1–0.2**	**C4 0.2–0.5**	**C5 0.5–1.0**	**C6 1.0–2.0**	**C7 2.0–5.0**	**C8 >5.0**
MC1	1	0	0	0	0	0	0	0
MC2	7	3	4	4	1	0	0	0
MC3	19	5	5	4	2	0	1	0
UP1	2	0	0	0	0	0	0	0
UP2	1	1	0	0	0	0	0	0
UP3	3	0	0	0	0	0	0	0
UP4	4	0	0	0	0	0	0	0
UP5	3	1	0	0	0	0	0	0
BP1	1	1	0	0	0	0	0	0
BP2	5	0	0	0	0	0	0	0
BP3	957	476	231	95	17	6	1	0
OP1	42	27	28	25	14	3	2	0
OP2 *	450	161	56	10	1	0	0	0

*—This sample was produced considering 2.5 g of dried mass. All the others considered 5 g of dried mass.

Table 5. Analysis per classes of the total area of Macro Stickies for the thirteen different samples studied.

Macro Stickies (Analysis per Classes mm²)–Total Area (mm²)								
Sample ID	**C1 0.01–0.05**	**C2 0.05–0.1**	**C3 0.1–0.2**	**C4 0.2–0.5**	**C5 0.5–1.0**	**C6 1.0–2.0**	**C7 2.0–5.0**	**C8 >5.0**
MC1	0.03	0	0	0	0	0	0	0
MC2	0.18	0.16	0.49	1.19	0.81	0	0	0
MC3	0.66	0.34	0.86	1.26	1.38	0	2.75	0
UP1	0.04	0	0	0	0	0	0	0
UP2	0.02	0.06	0	0	0	0	0	0
UP3	0.08	0	0	0	0	0	0	0
UP4	0.14	0	0	0	0	0	0	0
UP5	0.09	0.06	0	0	0	0	0	0
BP1	0.04	0.07	0	0	0	0	0	0
BP2	0.13	0	0	0	0	0	0	0
BP3	33.09	33.01	31.28	27.23	10.60	7.61	2.05	0
OP1	1.31	1.85	3.98	7.67	10.61	3.64	5.93	0
OP2 *	13.17	11.07	7.42	2.96	0.53	0	0	0

*—This sample was produced considering 2.5 g of dried mass. All the others considered 5 g of dried mass.

From the analysis of the above elements (Figure 12 and Tables 4–6), with a special remark to the histograms, it can be observed that the majority of detected MS on the considered thirteen analyzed samples belong mostly to the categories with lower dimensions. Eight of the thirteen cases only show MS in C1 or in C1 and C2, whereas the other five cases show MS in other categories. In general, a decreasing tendency of MS can be observed meaning that they tend to appear in higher numbers for smaller sizes and in lower number for higher sizes. In fact, class C1 is the dominant class with the highest number of MS for all the thirteen samples studied. On the other hand, the last class C8 did not register any element for any of the samples. Another interesting remark concerning this performed categorized analysis is that it allows us to know exactly what is happening in each class of MS giving a more complete and detailed information about the samples. For instance,

taking as an example the sample with the highest total area of MS, namely, the sample BP3, it is possible to verify that it has 144.87 mm^2 of combined MS area but it is not distributed equitably through the different classes. In particular, the classes C1 and C2 contribute each one with ≈23% of the total area, C3 contributes with ≈22%, C4 with ≈19%, C5 with ≈7%, C6 with ≈5%, C7 with ≈1%, and C8 with 0%. Moreover, it can also be verified that the distribution differs between samples. For instance, for the sample MC3, it is the class C7 that has the highest contribution, for the sample MC2 it is the class C4, and for the sample OP1 it is the class C5 that contributes the most. Of course, this will depend on each individual case.

Table 6. Analysis per classes of the area per mass of Macro Stickies for the thirteen different samples studied.

	Macro Stickies (Analysis per Classes mm^2)–Area per Mass (mm^2/kg)							
Sample ID	**C1 0.01–0.05**	**C2 0.05–0.1**	**C3 0.1–0.2**	**C4 0.2–0.5**	**C5 0.5–1.0**	**C6 1.0–2.0**	**C7 2.0–5.0**	**C8 >5.0**
MC1	6.10	0	0	0	0	0	0	0
MC2	36.92	31.54	97.14	237.28	161.64	0	0	0
MC3	132.26	67.38	171.32	252.32	276.34	0	550.90	0
UP1	8.60	0	0	0	0	0	0	0
UP2	4.30	12.18	0	0	0	0	0	0
UP3	16.12	0	0	0	0	0	0	0
UP4	27.24	0	0	0	0	0	0	0
UP5	17.92	11.12	0	0	0	0	0	0
BP1	8.60	13.98	0	0	0	0	0	0
BP2	26.16	0	0	0	0	0	0	0
BP3	6617.20	6601.80	6255.18	5446.58	2120.42	1521.86	410.40	0
OP1	262.72	370.60	795.70	1534.76	2121.14	727.24	1186.40	0
OP2 *	5269.50	4427.96	2966.30	1182.80	212.20	0	0	0

*—This sample was produced considering 2.5 g of dried mass. All the others considered 5 g of dried mass.

This analysis per classes allowed us to verify that in the recycling process using the CEPI methodology, the largest quantity of MS is found in the classes with the smallest dimensions. According to Ran et al. [41] and Doshi et al. [42], the smaller MS are those that cause the biggest problems in the paper machine runnability, both in terms of reducing the drainage efficiency due to web clogging and adhesion of the paper to the drying cylinders.

4. Conclusions

In this work, the CEPI recycling methodology was applied on a set of thirteen different cellulose-based materials for the assessment of their Macro Stickies, particularly the number of detected elements, total area and area per mass, determined through image analysis.

It was found that eight samples had low/residual amounts of Macro Stickies, whereas the remaining five samples varied from a few detected elements to a considerable high amount. Samples with a low/residual Macro Stickies content were found in different categories, but it was in the UP category that most of them were found. In fact, all the samples of this group revealed low/residual Macro Stickies contents. On the other hand, samples with the highest Macro Stickies contents belonged to the categories BP and OP, the latter, composed of a recycled paper and a laminated paper. These samples, due to their composition, showed a higher number of Macro Stickies elements. However, as described in this article, the quantified Macro Stickies assumed different sizes, numbers and distributions on each case.

The assessment of Macro Stickies carried out in this work provides valuable information for the recycling sector in terms of their propension to be formed on different cellulose-based materials/products of different categories. This is particularly important because Macro stickies can be a significant challenge in the recycling of cellulose-based materials due to their small size and sticky nature, complicating their removal during the recycling process (increasing the costs associated with it), operational issues (such as clogging and reduced drainage efficiency) and impacting the quality of the final recycled products.

Author Contributions: Conceptualization, A.d.O.M. and P.T.F.; methodology, A.d.O.M., P.T.F., J.C.V. and V.L.D.C.; software, A.d.O.M. and P.T.F.; validation, A.d.O.M., P.T.F., J.C.V. and V.L.D.C., formal analysis, A.d.O.M., P.T.F., J.C.V. and V.L.D.C.; investigation, A.d.O.M., P.T.F., J.C.V., V.L.D.C., J.M.R.C., A.P.C. and M.E.A.; resources, A.d.O.M., P.T.F., J.C.V., V.L.D.C., J.M.R.C., M.E.A., A.P.C., P.P., B.S. and P.B.; data curation, A.d.O.M., P.T.F., J.C.V. and V.L.D.C.; writing—original draft preparation, A.d.O.M., P.T.F., J.C.V. and V.L.D.C.; writing—review and editing, A.d.O.M., J.C.V., V.L.D.C., J.M.R.C., M.E.A., A.P.C., P.T.F., P.P., B.S. and P.B.; visualization, A.d.O.M., J.C.V., V.L.D.C., J.M.R.C., M.E.A., A.P.C. and P.T.F.; supervision, P.T.F., A.P.C., J.M.R.C., M.E.A., P.P. and B.S.; project administration, P.T.F., A.P.C., J.M.R.C., M.E.A., P.P. and B.S.; funding acquisition, P.T.F., A.P.C., J.M.R.C., M.E.A. and P.P. All authors have read and agreed to the published version of the manuscript.

Funding: The authors are grateful for the financial support granted by the Recovery and Resilience Plan (PRR) and by the Next Generation EU European Funds to Universidade da Beira Interior, through the Green Agenda for Business Innovation "From Fossil to Forest–Sustainable packaging and products to replace fossil plastic" (Project no. 8 with the application C644920945-00000036). The authors are also very grateful for the support granted by the Research Unit of Fiber Materials and Environmental Technologies (FibEnTech-UBI), through the Project reference UIDB/00195/2020, funded by the Fundação para a Ciência e a Tecnologia, IP/MCTES through national funds (PIDDAC) and DOI: https://doi.org/10.54499/UIDB/00195/2020.

Data Availability Statement: The original contributions presented in this study are included in the article.

Acknowledgments: The authors acknowledge the materials, access to equipment and installations, and all the general support given by The Navigator Company, the Forest and Paper Research Institute (RAIZ), and the Optical Center, the Research Center of Paper Science and Technology, the Department of Physics, and the Department of Chemistry of the Universidade da Beira Interior.

Conflicts of Interest: Author Paulo Barata was employed by the The Navigator Company. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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