RECYCLABILITY CRITERIA FOR PAPER BASED PACKAGING PRODUCTS

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Paper for recycling is an important raw material for the European paper industry. Especially for packaging papers, the recov+ered paper utilisation rate is very high. As these packaging products are usually returned into the paper recycling loop, a method based on a standard stock preparation line for packaging products was developed to assess on a laboratory scale the recyclability of packaging products. For the evaluation of the process efficiency and quality of the achieved pulp after recycling, coarse reject, flake content, macrosticky area below 2,000 µm and optical homogeneity were tested for packaging products of different categories. The recyclability test shows very high deviation of the results between and within the different product categories due to the product design, which is mostly affected by the purpose of the packaging product.

Keywords: paper for recycling, paper recycling, recyclability, packaging products, macrostickies

INTRODUCTION

The use of recycled fibres in the paper industry has grown significantly in the last twenty years, both for economic and environmental reasons. Nowadays, in Europe the paper used for recycling represents, with an utilization of 47.5 million tons in 2013, more than 50% of the raw material utilized in the paper industry.[1] The utilisation rate of paper for recycling in the production of packaging products is even higher, corresponding to 75.1%.[2] Currently, in many European countries, the amount of paper based packaging products overcome that of graphic products in the collection system. In recent years, the increasing use of recycled fibres has been supported by more and more efficient collection systems.[3] Nevertheless, it was observed that the increased amount of collected paper resulted in a reduction of the quality of the paper for recycling.[4,5]

In the packaging area, corrugated boxes and folding boxboards have the largest share among paper based product categories and are normally quite easy to recycle in standard paper mills.[6] However, the negative impacts of specific materials such as adhesives applications may generate macrostickies during stock preparation and are often underestimated by product designers.[7,8] Furthermore, the presence of additives and multi-layer materials generate higher rejects in the recycling process and need several adjustments in order to increase fibre yield. Innovation in paper based packaging products aims to replace at least parts of the plastic present on the market. In the near future, even more diversified paper based packaging products are expected on the market. Most likely, they will be laminated with new biopolymers, have new functional barriers capable of replacing multi-layer material and intelligent functionalities.[9] Nevertheless, all these developments will in principle maintain a good recyclability behaviour of the product in order to avoid spoiling the well-established paper recycling loop. This is actually one of the most relevant sustainability aspects of the paper value chain.

In the present work, the criteria of a new laboratory method to assess the recyclability of paper based packaging products in standard paper mills are described. The method has been recently developed in a European project, called EcoPaperLoop, and used to assess the recyclability of paper based products present on the market of five European countries. The results obtained for different product categories are shown and discussed with the intention of creating a suitable packaging scorecard to classify recyclability by a single number, to allow scientific comparisons among products as well as to facilitate developments of proper scientifically based eco-design criteria for packaging products.

EXPERIMENTAL

Materials

Products used to test packaging recyclability were collected from five different countries, normally from packaging producers and occasionally directly from the market. The products were classified into six most common categories as listed below:

- Corrugated boxes
- Folding boxboard
- Sacks
- Bags with handles
- Moulded products
- Liquid packages.

Corrugated boxes included packaging products of all sizes, made of papers for corrugated board. In the category of folding boxboard, which also includes solid board, two sub-categories were actually present, on the one hand, folding boxboard products for frozen food and on the other hand folding boxboard for other applications. However, in this paper the results for folding boxboard products are presented together. Similarly, two subcategories of sacks were tested. One category includes sacks of all sizes made of pure paper and the other category includes sacks of all sizes containing plastic layers, which and are classified as composite material. Liquid packages are also made of composite material consisting very often of board, plastic and aluminium layers. Moulded products are well-known from egg cartons, but meanwhile they have become also very common as cushioning material for electronic and other products, typically with the purpose of replacing plastic materials.

Recyclability method

All categories mentioned above were tested following the EcoPaperLoop Method 1.[10] The procedure flow chart of the assessment of packaging product recyclability is presented in Figure 1. In this method, 480 g oven-dry packaging product is disintegrated in a low consistency pulper. The dry content of the packaging product, as well as the proportion of the adherend (part of the product containing adhesives), has to be determined in advance before pulping. If only a part of a packaging product is used the adherend ratio, meaning the percentage of the adherend from the packaging product related to the mass of the packaging product, has to be calculated. The appropriate amount of adherend and non-adherend product has to be cut to palm size for the further steps of the method. To generate a fibre suspension, the prepared packaging product is disintegrated under low consistency conditions. According to the dry content of the product, a calculated amount of fresh water must be added to the pulper to reach a stock consistency of 4%. After a disintegration time of five minutes, the entire sample is transferred to the coarse screening step. Over a 10 mm hole screen, large non-paper material and difficult to disintegrate paper parts are separated from the suspension. After a first draining, 12 L fresh water is filled into the device to wash the sample again. In case free fibres are still attached to the reject on the screen or to the surface of the device, some more water can be sprayed to drain the fibres through the screen. The objective is to obtain a nearly fibre free reject, nevertheless, excessive washing might dilute the suspension too much and the low stock consistency might be problematic for the following tests. Therefore, to find a good compromise, it is recommended to use 2-5 L fresh water for this step. The achieved reject has to be determined gravimetrically afterwards. Using the coarse reject value, the yield is calculated to determine the amount of usable solid stock material, which passes the coarse screening step.

To guarantee a sufficient and homogenous sampling for further investigations, the accept of the coarse screening step is gently mixed by hand first and then the sample is transferred into a distributor and diluted to a stock consistency of approximately 1%. From the homogenised fibre suspension, the ash content is measured to obtain the inorganic content of the solid stock material after incineration at 525 °C.[11] By using the ash content and the yield calculated beforehand, the fibre yield can be calculated to obtain the fibre content of the solid stock material, which passes the coarse screening step. Afterwards, using the Zellcheming Leaflet ZM V/18/62,[12] the homogenised fibre suspension is screened over a hole plate of 0.7 mm to determine the flake content. In contrast to the Zellcheming method, non-paper components like small plastic parts are also examined as part of the flake content. For the evaluation, five samples of 2 g oven-dry material each have to be classified for 5 min using the Brecht-Holl screening device with 100 double strokes per minute. Alternatively, a Haindl Classifier could be used with a water volume flow of 3.33 L/min or 0.2 m³/h.

The macrosticky potential after disintegration and screening is measured according to INGEDE Method 4.[13] To determine the macrosticky area per kg of the packaging material, 10 g oven-dry sample material is screened over a 100 µm slotted plate. By using the Haindl device, the sample is screened for five minutes with 480 double strokes per minute. The reject on the screening plate is then transferred to a paper filter following INGEDE Method 4 for staining and visualizing the stickies. Before image analysis applied for sticky measurement according to INGEDE Method 4, a microscopic inspection of the samples is necessary. White particles or plastics, which are definitely not stickies, must be detected and removed or painted over in black so they are not visible any more for the macrosticky image analysis system.

From the accept of the macrosticky measurement, handsheets with a grammage of 60 g/m² are prepared according to ISO 5269-2.[14] They are used to inspect visually the optical homogeneity of the pulp looking at the presence of dirt specks from non-fibre components and neglecting coloured fibres.

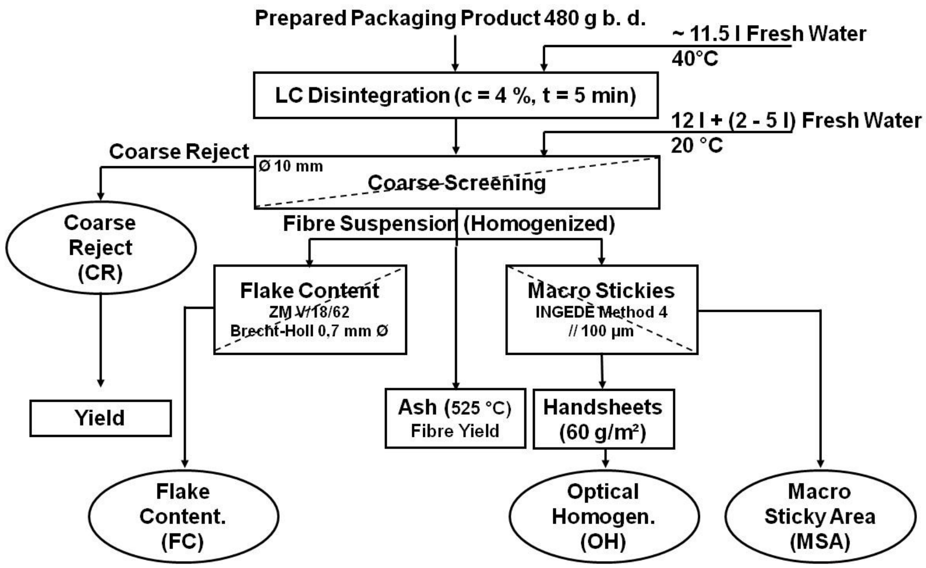

Figure 1: Flow chart of the procedure for the assessment of packaging material recyclability[10]

RESULTS AND DISCUSSION

Packaging products have to fulfil various recyclability requirements to ensure improved recycling cycles in standard paper recycling loops. In principle, they need to have a high fibre content, good disintegration behaviour and low amount of tacky particles in the final screened pulp. Thus, a low content of non-paper product material is necessary to ensure low waste rejects in the paper recycling process and a low flake content is desirable to minimise the energy demand during processing and sheet faults, to improve optical properties and to guarantee good runnability of the paper machine. It is also important that adhesives used generate macrostickies with suitable fragmentation behaviour to allow their mechanical removability during screening of the pulp suspension.

Since the structure of paper mill installations can be quite different, the work was focused on the development of a laboratory test simulating the industrial standard of paper mills, which still represents the majority of the plants present in Europe.

The parameters mentioned above in the experimental section are considered the most relevant ones in the current standard paper recycling mill technology. They are defined as follows:

- Coarse Reject - Amount of non-paper product material of the packaging product rejected by coarse screening with 10 mm holes.
- Flakes - Fibre bundles not fully disintegrated and small impurities of the packaging product rejected by screening with 0.7 mm holes.
- Macrostickies - Substances derived mostly from adhesive applications rejected after fine screening on a 100 µm slot plate.
- Optical Homogeneity - Inhomogeneity of handsheets prepared from the fibre accept after fine screening with 100 µm slots.

Coarse reject and the flake content were evaluated to investigate the parameters affecting the process efficiency of the stock preparation, whereas the quality of the obtained pulp is described by the macrosticky area and the optical homogeneity of handsheets from fine screening accepts. An overview of all packaging product categories regarding the quantitative test results with average and mean values of the coarse reject, flake content and macrosticky area is given in Table 1.

Ash content and fibre yield, although relevant, were seen at the moment less crucial as currently paper mills technology in the packaging sector tends to include also ashes in the new product and therefore they do not constitute a significant loss of material. However, if the trend of increasing ash contents will continue or additional process steps (e.g. deinking) will become more common in the packaging sector, these parameters will gain importance.

Table 1
Average and median values of recyclability parameters evaluated according to EcoPaperLoop Method 1 for different product categories (Results by October 29th 2014)

	Tested products	Coarse reject in %		Flake content in %		Macrosticky area < 2,000 µm in mm^2/kg	
	Total	Average value	Median value	Average value	Median value	Average value	Median value
Corrugated boxes	26	4.0	0.2	8	4.5	2,632	1,858
Folding boxboard	37	1.0	0	3.6	3.2	5,540	8804
Bags	16	15.7	8.0	10.8	3.4	24,755	15,796
Moulded products	17	2.8	0	11.0	3.2	860	581
Sacks – pure paper	17	16.3	0	20.0	21.1	2,254	648
Sacks – composite	21	45.8	33.4	15.1	17.4	6,555	3,587
Liquid packaging	18	48.8	44.0	18.5	17.6	1,349	1,277

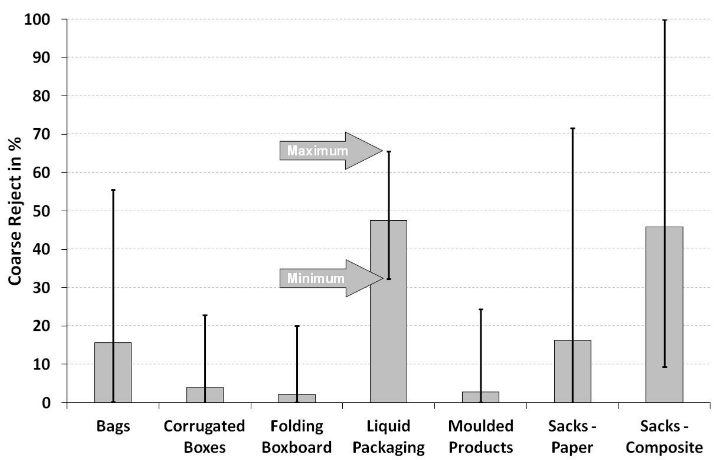

Figure 2: Average values of coarse reject from different product categories after recyclability test (Vertical lines show the minimum and maximum values of each category)

Coarse reject

For evaluation of the coarse reject, large and difficult to disintegrate paper parts as well as large non-paper materials are determined gravimetrically after coarse screening. Figure 2 shows (solid columns) the coarse reject values for every category. The vertical lines of each column indicate the maximum and minimum values and correspond therefore to the range obtained for each corresponding category. The figure points out that among the considered product categories, as well as within each product category, high differences in the amount of coarse reject were obtained.

Folding boxboards showed a very good recycling behaviour. Just one of the 37 tested products had a coarse reject above 10%, which is shown as the maximum value for folding boxboard in Figure 2. This product was a folding boxboard for frozen food with a PET film. The average coarse reject of folding boxboard was very low corresponding to 1%, besides more than 50% of the products in this category showed no coarse reject, which is indicated by a median value of 0% (Table 1).

Like folding boxboards moulded products had almost no coarse rejects. Just one product had a value over 20% and as it can be seen in Table 1 and Figure 2. The average of all products in this category was only 2.8%. Besides, over half of the products had no coarse reject. In this category, most of the tested products did not contain non-paper materials, therefore the main reason for the limited disintegration and coarse screening rejects was then probably due to the use of strength or sizing agents, which cause a very strong interfibre bonding preventing the repulping of the product.

A different disintegration behaviour was seen for bags. As shown in Table 1 and Figure 2, the average coarse reject of 15.7% and also the median value of 8.0% were higher compared to the previously mentioned products; 25% of the bags had a coarse reject over 20% and two of them even over 50%. This was due to the fact that on the one hand some of the bags had handles, which either were not made of paper, or were reinforced. On the other hand, they could have been treated with additives for the functionality of the product that had to fulfil diverse strength criteria if they had to be used for example as carrier bags for heavy consumer goods. This impeded the disintegration behaviour of the bags and resulted in a higher coarse reject.

Depending on the purpose of the sacks, the amount of coarse reject differed significantly. Noticeable were the high deviations between average and median values in these categories (Table 1). Sacks made of pure paper had an average coarse reject amount of 16.3%. In this group, 30% of the sacks had a coarse reject above 20% and most of them even over 50%. Nevertheless, half of the tested products had no coarse reject and due to this fact the median value of this category was 0%. Also, for sacks containing composite material, there was a high deviation of coarse rejects observed within this product category. The difference between average and median value was in the same range as for sacks made of pure paper, but on a higher level. The coarse reject average value of composite sacks was almost 46% and 40% of the tested products showed a coarse reject ratio above 50%. The median value reached a really high level with 33.4%. The large deviations of the results within these two categories, especially for sacks made of pure paper, were due to the fact that in these categories sacks of all sizes and for all purposes were tested. They were only differentiated on their material basis – pure paper or composite materials. Some of the sacks with a high coarse reject ratio were used for example as cement bags. They had to ensure barrier properties and, to endure extreme weights, they needed to have a robust external layer to protect the product inside. Therefore, the packaging papers were sized in mass or on the surface with wet strength additives or antiskid agents; multi-layer materials were also used. These additives complicate the defibration and increase the coarse reject amount. Sacks with a low coarse reject were used for example as bags for rolls, in these cases only thin papers were needed because they did not need to fulfil such ambitious criteria like the cement sacks. However, due to the additives used and the presence of composites like plastic, sacks with composite material had a more difficult disintegration behaviour as compared to sacks made of paper.

The disintegration behaviour of liquid packaging was in general similar to that of sacks made of composite material. However, the level of coarse reject was even higher with an average of almost 50%, as shown in Figure 2. Due to their purpose, all liquid packaging products consist, next to board, of composites like polyethylene or aluminium to reach specific barrier properties. These components impeded the disintegration behaviour and were measured together with the remaining fibres at the composites and not disintegrated fibre bundles as coarse reject after disintegration and screening. However, it has to be mentioned once again that the method we used allows simulating only the recyclability behaviour of packaging materials in a standard paper mill, which for composite materials such as liquid packages and other composite products typically results in an increased amount of coarse reject. For such products, there exist specific stock preparation plants, which are specialised in the recycling of liquid packaging products or composite sacks. Under appropriate conditions, they allow to separate aluminium and plastic for further reutilisation in other industries. This latter option, however, requires the separate collection of these products or their sorting out from other waste streams.

Corrugated boxes showed a low average coarse reject of 4%. The minimum value was 0%, but as it can also be noted in Figure 2, one of the products had a coarse reject of 36%. Using the example of corrugated boxes, the distinction between the individual product categories regarding coarse reject is shown in detail in Figure 3. Only three out of 26 corrugated packaging products had a coarse reject above 10%. One of the products was a packaging box for dangerous goods and was therefore treated with specific additives. The other two were heavy-duty corrugated board packaging – the edge of one was reinforced with an adhesive strip of glass fibre and the other one with metal cramps. The other corrugated boxes were not specially treated and had no significant amount of non-paper product material or difficult to disintegrate paper parts, so that they did not affect negatively the process efficiency of a stock preparation.

Flake content

Using this new method with the flake content, both fibre bundles and impurities like small plastic parts were measured after screening. The average flake content for each product category is presented in Figure 4. Furthermore, the maximum and the minimum achieved results are shown as vertical lines at each column for each category. The average flake content was lower than 20% in each product category, nevertheless, few products showed values up to more than 50%.

The average flake value from corrugated boxes was 8.0% ranging from 1% up to almost 35%. However, only very few samples showed values higher than 10%, which led to a low average value (Figure 4). Most of the products had really good disintegration behaviour and the recycling of these products would not have a negative impact on sheet faults and optical properties. Like for corrugated boxes, the disintegration behaviour of the tested folding boxboard products was not restricted. The flake contents were low with an average of 3.6% and the product with the highest flake content reached only 16%. As shown in Table 1, the average flake content of 10.8% in the bags category was higher than for corrugated boxes and folding boxboard products, nevertheless, the median value was in the same range. Only three of 16 tested products had a flake content over 20%. Therefore, nearly all bags had good disintegration behaviour.

The recycling of moulded products also had no negative impact on the process efficiency regarding the flake content. The slightly higher average value of 11% resulted from two of the 17 tested products, which had a flake content over 50%. Only one more product had a flake content over 10%, so that the median value of all products was at the same level as for the categories mentioned before (Table 1).

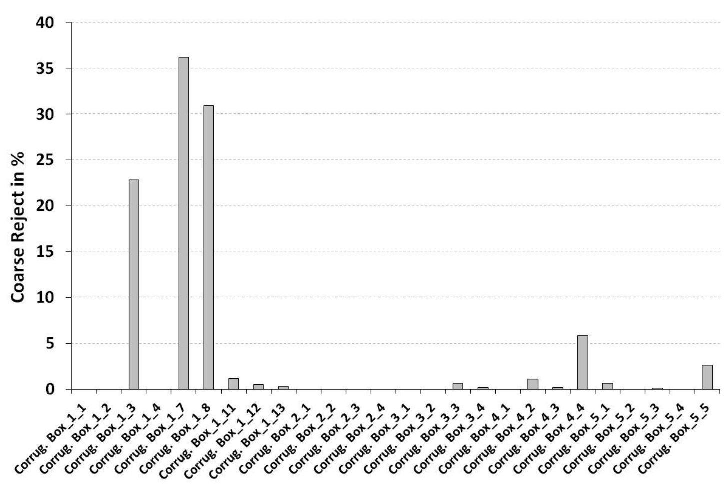

Figure 3: Coarse reject from corrugated boxes after recyclability test

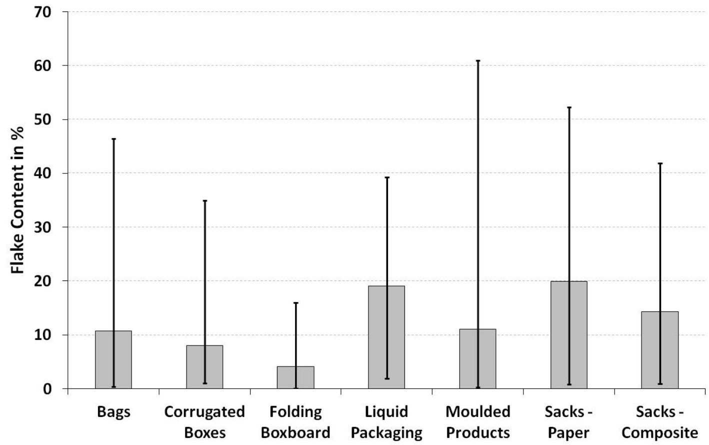

Figure 4: Average values of flake content from different product categories after recyclability test (Vertical lines in each column show the minimum and maximum values)

A higher average and median amount of flakes was instead observed in the sacks and liquid packaging categories. Although in both subcategories of sacks products, where nearly no flake content was found, more than half of the tested paper based sacks had a flake content over 20% and one sack made of pure paper even had a flake content over 50%. Besides, five of 21 sacks produced with composite material had a flake content over 20%. The average and median value was slightly lower for composite sacks than for sacks made of paper, nevertheless higher than for most product categories mentioned before. Especially for sacks for special purposes, which needed special properties like high strengths, virgin fibres were used during production. In this case, kraft pulp may be used to achieve benefits like increasing strength properties from the long fibres, though this affects the disintegration behaviour and the flake content. Nonetheless, the achieved pulp is valuable and it should be mentioned that after all in a stock preparation plant of a standard paper mill, the high flake content after disintegration requires only additional energy input to deflake those fibre bundles.

Macrosticky area

In a stock preparation plant, a high removal efficiency of macrostickies can only be achieved if the adhesive applications disintegrate into particles of large size. The smaller the particles, the lower is their removal efficiency. For the paper making process, especially macrostickies below 2,000 µm equivalent diameter should be avoided. Macrostickies could result on the one hand from adhesive applications on the packaging product or they could be introduced by the paper or board from the previous papermaking process with incomplete sticky removal from the paper for recycling. In this project the products were tested mainly without final sealing, so the macrostickies mainly resuled from the original paper or board or from the adhesive applications of the pre-manufactured industry box. The average macrosticky areas below 2,000 µm of each category are presented in Figure 5. The vertical lines of each column indicate the maximum and minimum values and correspond therefore to the range obtained for each corresponding category.

The majority of the moulded products were made of paper for recycling and except for one product no adhesive applications were added to the products. The measured macrosticky area below 2,000 µm equivalent circle diameter was never above 3,500 mm²/kg product, resulting therefore from the paper used for recycling. A high deviation of the macrosticky area between the other product categories can also be noted in Figure 5. Nearly every corrugated box had a macrosticky area below 4,000 mm²/kg product and just one had a macrosticky area over 10,000 mm²/kg product for the stickies below 2,000 µm. The macrostickies were mainly introduced from the paper used for recycling, because most of the products were tested without final sealing and almost no labels or further adhesive applications were added to the corrugated boxes.

Liquid packaging products were made of primary fibres, so the macrosticky content resulted only from the used adhesives. In this case, the macrosticky area was for all liquid products below 5,000 mm²/kg product. As far as folding boxboard products are concerned, the macrostickies could result both from paper for recycling and from the used adhesive, nevertheless in this category only one product had a very high macrosticky area (81,000 mm²/kg product) in comparison with all the other results. The majority of the products had a macrosticky area below 5,000 mm²/kg product and 50% of the products even had a macrosticky area below 1,000 mm²/kg product, as shown in Table 1. Both categories of sacks showed a few products with a macrosticky area over 10,000 mm²/kg product. Nevertheless, half of the sacks made of pure paper had a macrosticky area below 650 mm²/kg product. Sacks with composite material always resulted, for macrostickies below 2,000 µm diameter, in higher average (6,555 mm²/kg) and mean (3,587 mm²/kg) values, compared to sacks made of pure paper (2,254 and 648 mm²/kg product). This might be based on the fact that commonly more adhesives are used for paper and board with composites than for gluing the pure paper sacks. Because most of the tested products in both categories were made of virgin fibres, the macrostickies originate mainly from the used adhesives.

It is noticeable that altogether the highest amount of macrostickies is observed in the category of bags. The average is about 25,000 mm²/kg product and over 50% of the products had a macrosticky area over 16,000 mm²/kg product. In Figure 6 the results of the macrosticky area below 2,000 for this category are illustrated in detail. Three of the 16 tested bags had a macrosticky area even higher than 50,000 mm²/kg product. These results originate partially from the paper for recycling used in the products, but mainly from the used adhesives due to the design of the shopping bags. High macrosticky areas were already assumed in the preparation step for the recyclability tests, where the bags had the highest adherend ratio of all products. Often almost the entire surface was glued at the bottom in order to hold the forces acting on a filled bag.

Optical homogeneity evaluation

To investigate the quality of the pulp, the optical homogeneity of the handsheets obtained after fine screening was evaluated. There exists actually no quantitative measurement. To investigate the inhomogeneities, visual impressions of the handsheets were categorized into three groups:

- No visible inhomogeneities on the handsheets = very good
- Some visible inhomogeneities on the handsheets = good
- Plenty of visible inhomogeneities on the handsheets = tolerable.

It should be noted that only inhomogeneities from non-fibre material were taken into account and not from coloured fibres. Summarizing the achieved impressions of the produced handsheets, no visible inhomogeneities were observed for most of the tested products after fine screening. Only a few special laminated samples obtained the poorest test result – "tolerable".

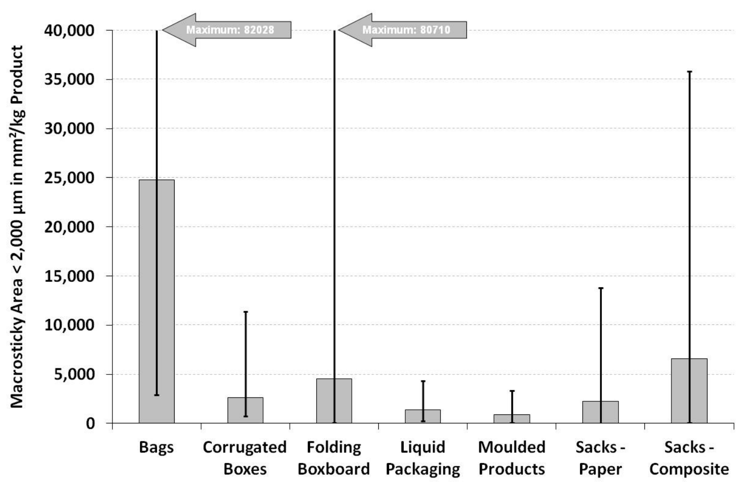

Figure 5: Average values of macrosticky area < 2,000 µm from different product categories after recyclability test (Vertical lines in each column show the minimum and maximum values)

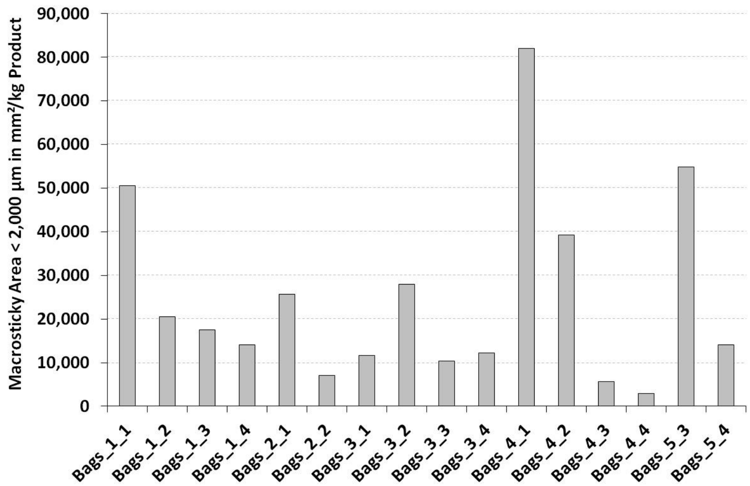

Figure 6: Macrosticky area < 2,000 µm from bags after recyclability test

CONCLUSION

One of the major target of the paper industry is to improve the quality of paper for recycling, thus ensuring future raw material availability and a better sustainability of the whole paper value chain. With the constantly increasing use of paper for recycling, it is more and more necessary to enhance the recycling behaviour of post-consumer packaging products, which represent a high proportion of secondary raw material used by the industry. The developed laboratory recyclability method for packaging products reflects the stock preparation of a standard paper mill in combination with already existing methods. The measurement of coarse rejects, flake content and macrostickies allowed us to achieve a better understanding of constrains concerning packaging products during the paper recycling process.

Within the eight paper based product categories and subcategories tested, a high variation of the analysed parameters was observed. Similarly, the results differed even within the same category. The different results obtained among categories are often associated with the functionality that has to be fulfilled by the packaging products, which requires different barriers or designs. Nevertheless, the overall recyclability tests show that composite packaging products, such as sacks with composite materials and liquid packaging, generate the highest amount of coarse rejects, followed by bags. All the other product categories have a low amount of coarse reject, except a few products within each category due to additives like wet-strength agents. Other parameters, like flake content and optical homogeneity of the handsheets after fine screening, are more balanced for all categories. Except for a few relevant exceptions, the macrosticky content in almost all categories is at an acceptable level. Only the shopping bags show for nearly all the products within this category a much higher amount of macrostickies. Additional work is currently in progress to finalise the database for the construction of a suitable score card for paper based packaging products. We expect the stakeholders of the paper value chain to use the present results benchmarking their products in order to promote a more scientific approach when claiming the recyclability in the paper end-of-life stream.

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