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Sorting plastic packages with 3D relief codes

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ABSTRACT: The European Circular Economy Action Plan strives to use more recycled plastics in Fast Moving Consumer Goods and hence contribute to the more sustainable use of plastics. Mechanical recycling of well-designed, food packages can yield highly pure recycled plastics that in principle could be used to produce new food packages, but unfortunately EFSA rulings demand that the recycling feedstock is composed of guaranteed high levels of food packaging only. As this guarantee cannot be given for sorted products from EPR schemes, the circular economy stifles. It is therefore crucial to develop sorting techniques that can discriminate between previous food-use and non-food-use of wasted plastic packages. A new sorting technology is proposed that is based on a 2D print technique used for anti-counterfeiting, with curved patterns of dots, not visible by the naked eye. The patterns of dots can be recognized by reflection of light with RGB cameras and specific developed software. The technique is translated to 3D with dots in relief in the packaging material. The aim is to find dots of such a size that they are hardly visible to the naked eye, but flawlessly readable for cameras. At first, patterns with dots with a diameter of 0.5 mm and a depth of 100 micron were studied. The patterns of dots are taken up in moulds of injection moulded and thermoformed packaging of in total 6 PP and 3 PET items like cups, trays, lids, for food packaging with different characteristics like transparent, coloured, and different surface qualities, produced on various machines. Additionally, a dynamic test was executed with a tailor-made sorting machine with different conveyor belt speeds and lighting strengths. The sorting yield was over 90% with no false positive showing that 3D relief dots can be used for this purpose. Thermoforming requires more control of the production process to obtain well-readable relief codes than injection moulding. A procedure is developed to take up a 3D relief code in packaging items. In next steps sorting will be tested based on realistic waste processing scenarios.

Keyword: Sorting of plastic packaging, markers, recycling, 3D relief code

1. INTRODUCTION

The European Circular Economy Action Plan [1] strives to reuse and recycle more plastic packaging. The Commission will propose mandatory requirements for recycled content and waste reduction measures for Fast Moving Consumer Goods such as packaging.

The use of recycled plastics in food contact materials is strictly regulated in European directives; EC 282/2008, under the umbrella legislation EC 1935/2004. Recycling companies can file a request for a positive opinion of their process-feedstock combination at the European Food Safety Authority (EFSA). To limit potential hazards with incidental contamination, EFSA set threshold values for the share of non-food-packages allowed to be present in recycling feedstock, which is at least 95% for PET bottles and 99% for HDPE bottles. Most positive opinions were given to companies recycling PET beverage bottles and one to a company recycling HDPE milk bottles in a closed collection system. No recycling company has received a formal approval, yet, from the European Commission. EC 282/2008 is currently under revision because the risk assessment EFSA executes is based on a triple worst case approach and too conservative effectively hindering the progress towards a more circular economy [2].

Within the current legal context, recycling companies have to prove and guarantee that their feedstock is almost exclusively composed of food packages. Producing high quality recycled plastics also requires that the recycling company can discriminate between different qualities (grades) of plastics from the same polymer class, with different melt flow indexes. Current sorting techniques are sorting on the level of main polymers like PE, PP, PET, etc. but cannot distinguish between various types or grades of a polymer class, for instance for PE, between HDPE, MDPE, LDPE and LLDPE. Near-infrared (NIR) is the current standard technology in plastic sorting. It uses the frequency range of 600 to 2500 nm of common light sources [3,4]. The light is shone onto the plastic items, from which the polymers absorb specific frequencies and reflect that modulated radiation back into spectrophotometer, which can accurately identify the main type of polymer within microseconds. The technique is used for sorting packages on fast moving conveyor belts. Software determines a contour of an item and its position on the conveyor belt and will determine if this item needs to be blown out by the air nozzles. Within sorting facilities that use a cascade of NIR sorting machines only the most common polymer types are sorted; PE, PP, PET and PS.
Sorting packaging waste with NIR machines does not give detailed information about the grade of plastic that is sorted, nor about its previous use. NIR is also used to sort flakes of plastic. There are more sorting techniques of material available like elutriation, wind-sifting, optical colour recognition, static electro charge, X-ray fluorescence and magnetic density separation [4], to mention some, but they all sort on base of simple characteristics of the materials and are not able to make a distinction between food and non-food used materials yet.

Companies are searching for ways to be able to recycle the material of the packaging they use themselves back again to a new packaging item and are investigating possibilities to be able to circularly recycle the packaging material they used previously. From plastics used in Europe 39.6% of 50.7 million tons is used in 2020 for packaging, in total 20 million tons [5]. Food accounts for about 2/3 of this amount, but there are hardly clear figures to underline this. In the Netherlands 520.000 tons of plastic is used for packaging yearly [6].
Sorting on the level of packaging can be a solution to overcome uncertainties about grades, additives and previous use. Several techniques are promising to recognize packaging from waste streams: sorting on base of digital marking and by using camera's with recognition software with Artificial Intelligence (AI). In the HolyGrail project [7] the use of tracers and digital marking are used. By adding elemental tracers to the polymer, the material can be recognized with X-ray fluorescence equipment. With digital marking patterns are taken up in

the print (2D) or in relief in the material (3D) as tested with two different techniques: Digimarc and CurvCode. The patterns can be recognized by reflection of light of the dots and the use of conventional cameras and specific software. In the HolyGrail project it was concluded that digital marking techniques are more promising than the use of tracers [8]. For using digital marking technique the packages have to be changed. The patterns have to be taken up in the print, or in the material in relief. For plastic packaging or items without print or large labels or sleeves, the patterns have to be taken up in the mould to reproduce the code.
Digimarc is using unique codes per SKU by which it is possible to add specific information to the sorted item. The Digimarc codes have a dimension of ca. 2.2 x 2.2 cm and are taken up all over the packaging to ensure they can be scanned even if they are crushed and dirty. The Digimarc technique can be used in every stage of the lifecycle of the packaging, like scanning the packs on the paying desk of a supermarket, for consumer engagement, and also for waste sorting. Every packaging has u unique code which means that for waste sorting a big database of codes is needed and this will set requirements to the sorting equipment and process. The CurvCode is using codes per type of material. The codes are only used for sorting packaging items for recycling. The number of codes in the database is limited. For every type of material a different code for food as for non-food is used.

A technique in which the packaging does not have to be changed and that possibly also can be used for sorting is based on recognition of images scanned with RGB camera's with use of Artificial Intelligence. For face recognition patterns can be used as a matrix because every face has the same structure. With packaging a common pattern cannot be used. Software must be trained to recognize different types by all kind of characteristics, including pressed packs and covered with dirt. In the coming decade, these AI technologies are likely to be used for sorting plastic waste.

This paper explores a digital marking technique in more detail; the CurvCode, a code with 11 dots in the shape of a curve with a width of 20 mm, between the outer dots in a straight line. The aim is to explore the possibility of sorting plastic waste with simple codes that are applied in relief in the packaging material. Furthermore, it will also address the design of this code and application method. This exploratory study was limited to thermoforming and injection moulding as production processes.

The research will focus on a sorting technique with which it is able to sort between food and non-food packaging items, that uses a limited amount of codes, that are only used in the stage of sorting of waste, with the focus on 3D codes. Two important issues need to be considered:.

- Speed of current sorting lines determines the minimum required speed for recognizing a package on a conveyor belt.
- The way of applying 3D relief codes in plastic packages made by thermoforming and injection moulding.

At first the CurvCode will be described in more detail. Then attention will be spend on the mentioned issues.

2. THE CURVCODE

The CurvCode is formed by dots (2D) or rolls (3D) positioned at a Bezier curve, a parametric curve with discrete control points. The dots are equal in size, positions of the dots are determined by dividing them equally across the curve. The distance between visible and invisible positions is equal. The location of the dots across the curve is symmetric, meaning the code can be read from left to right and right to left.

2D codes can be used for packaging that are covered with a label, (wrap around) sleeve, in-mould-label (IML), sticker etc., and 3D codes can be used for packaging or packaging items with only small labels or without labels. Also a combination of 2D and 3D is possible.
The 2D technique is an existing technique which has proven to function. It is used among others for anti-counterfeiting of printed products. For 2D codes the angle of the position of the cameras is irrelevant. By use of light a code that is made with small dots of different colour in artwork, is recognized by software and converted in a computer code.
The code is built up with 27 fixed positions. Eleven dots are placed on the curve. Six dots determine the material code. The middle dot is used as control; reading a code from left to right has to end at the same position as reading from right to left. On both sides the code starts with two dots at fixed positions. 27 minus the dot in the middle, makes 26 dots, so 13 positions for a code, minus four fixed positions makes 9 dots. Using 9 positions, and including two angle values of the lines determined by the two starting dots, make 2^{10} number of combinations possible. The system cannot read code 0, leaving 1024-1, in total 1023 possible codes. This is taken as enough for sorting materials.

For 3D codes the intention is to make the code invisible or almost invisible, meaning as small as possible. At first tests are executed in a static situation with codes of dimensions 15 mm, heart to heart from the first dot to the last dot in a straight line. First samples were made by making small holes in metal blocks because metal is used for moulds to make plastic packages. The idea of the size of the dots was taken from the codes as taken up in the heel of glass bottles and also used for sorting. Tests showed that the codes taken up in metal were readable very well. Discussing the options to put the code in a plastic packages with injection blow moulders made clear that a code of that size would be hard to create. The blow moulders preferred a code with width of 30 mm but for marketing reasons and not to influence the outer appearance of the packaging too much, a length of 19.5 mm was chosen for next tests, heart to heart of first and last dot at a straight line. A code that is larger also needs a larger surface of a crushed packaging that has to be scanned. From that perspective smaller codes are to be preferred. The diameter of the dots or balls is chosen at 0.5 mm, so from the outer diameter of the first dot to the outer diameter of the last dot the length of the line is 20.0 mm.
A dot or ball cannot be bigger than 0.7 mm, because the space between dots is 0.5 mm. Larger dots imply smaller spaces which makes the code unreadable. A code starts with two dots on both sides at fixed positions. Light is shone at the packaging surface and reflected. The reflected image is analyzed in reversed black and white. The software scans the processed image to find two black dots beside each other, being the start of the curve. If two dots are found, the software scans in a circle of 20 mm around the dots two find two other dots. If these are found, two lines are made, one from the first two dots and one from the other two dots. The angle in which the lines cross has to be one of a pattern that is in the register. If not, the software stops with the image and continues searching. If the angle is according one of the registered standards, the other dots are analyzed and the pattern is compared with the register. In this way the pattern of dots can get a registered number. The number can activate a blowing unit of the sorting machine to positively sort out the packaging.

Figure 1 – Example of a CurvCode

By coding plastic packaging they can be sorted on base of use as food or non-food. This can be done by only using codes in food packaging, or by using codes in both, food as well as non-food. The format that has been chosen is to determine the value of the angles between the two lines that are defined by the first two dots on each side of the curve. The code for a material that is food grade is a different angle than the code for non-food.

The next possible examples of codes to be able to recycle the plastic back to food use for PP and PET can be considered. For PP, transparent, white opaque, black opaque, carbon black, other colours opaque and for PET transparent, white opaque, black opaque, carbon black, other colours, opaque. This example makes ten codes for the materials and twenty in total if for food grade different codes are used as for non-food plastic packaging. It will depend on the volumes used in the market what a feasible choice for codes will be in practice. The research will not focus on economic feasibility.

3. THE FUNCTIONING OF 3D CURVCODE AND DOT SIZES

If light is shone on the surface of a plastic package with relief, the relief will reflect a part of the light. Cameras with recognition software can detect patterns of light reflection in the same way as used for 2D recognition of patterns. For reflection of light by 3D shapes, the light should shine under a certain angle, which is different than for 2D codes.
Questions that arise are about the dimensions and locations of the codes on an item.

- How big should the 3D codes be to be readable in the same way as the 2D codes?
- How many codes are needed on the package to be readable?
- Does orientation of the codes influence recognition results?
- What to do with flat items that are not transparent, like coloured lids of trays, jars or buckets? Does a code has to be taken up on both sides?
- Does transparency influence the readability of the code?
- Does the surface appearance like gloss or matt surface influence the readability of the code?

3.1 Relief of a dot

The higher a relief, the better the reflection corner will be, the better readable the code will be. Figure 1 shows a low relief with reflection in a smaller angle than the reflection shown in figure 2. The green lines represent light shining at the dots, the red lines represent reflected light. The relief in figure 1 can only be read very close to the cameras, not in a wider field. This will limit the speed of the conveyor and the readability of packaging in random positions.

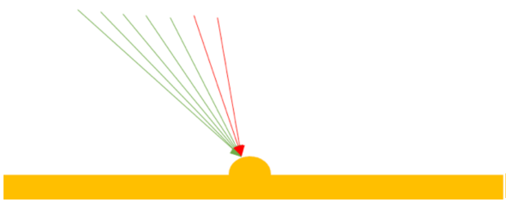

Figure 1 – light shining on a relief dot

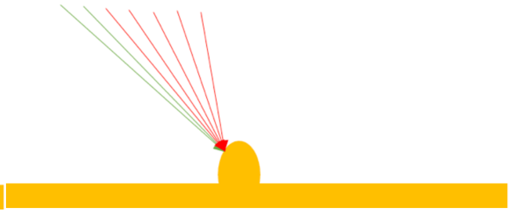

Figure 2 – light shining on a higher relief dot

It is also possible to use debossing besides embossing. In figure 3 an example is shown. The light reflects in a different way creating a pattern.

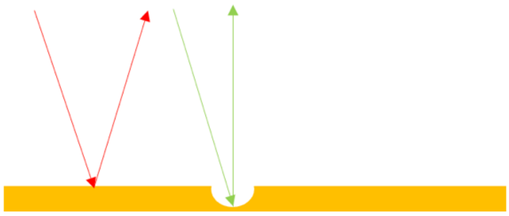

Figure 3 – Hollow shaped relief, embossing in a material

3.2 The light source

In trial tests with an injection moulded lid, white coloured, with codes on both sides, several light sources are tested.

The better the light source the more light will be reflected. The next light sources were used in sequence of order:

- First tests were executed with indirect led light, 6.450 lux., recognized 72% from 132 lids, 76% from 138 lids
- The next test with 4Pico LED, direct lightning, 25K lux., recognized 84% from 119 lids
- Led light, direct, 26K+ lux, provisional mounted (direct), 100% from 100 samples
- Led light, direct, 26K+ lux, mounted on a frame (direct), 100% from 100 samples and 96% from 100 samples

Final dynamic testing has been executed with the latest tested light conversion: Led light, direct, 26K+ lux, mounted on a frame (direct).

3.3 Dimensions of a relief dot

First tests were executed with a 3D code with a diameter of 0.5 mm and a depth of 100 micron. To ensure the readability of the code, first a static test was done. Indeed these codes proved to be well-readable.

To make testing more practical, an app for a smartphone was developed. The app uses the camera of the smartphone and this helped to greatly simplify the static testing of Curvcodes. If one code put in the mould of a package can be recognized by the app on the smartphone, the code is readable. Then more codes can be taken up in the mould with the first as template. In this way a first selection on base of colour, surface and transparency is executed.

3.4 The amount of needed codes on the package

Multiple codes are needed on a package because wasted packages can be distorted, crushed and fouled, which can limit the readability of the code. But putting too many codes on the surface, could produce unrecognizable patterns. Changing an existing mould cost money. The less changes, the lower the costs. A balance has to be found, also to avoid that the appearance of a package is visibly affected by the amount of codes.

On vertical surfaces of cups or trays with high side walls it can be difficult to get a relief code in the package. This accounts especially for thermoformed packaging. A dot made by a relief of 0.5 mm diameter with a depth of 100 micron in a mould used for injection moulding will get the dimensions of the relief. For injection moulding an issue can be the draft angles of the article. The dots should not frustrate relieving of the package from the mould, and still have to be readable. In thermoforming it is harder to get a dot of 0.5 mm in the mould. Every relief should have a vacuum channel which makes the mould rather expensive. By making the diameter of the cavity in the mould larger, up to 0.7 mm, the dots that came out were close to 0.5 mm and could be recognized by the cameras. If the dots do not have a vacuum channel, forming of the dot was hard and reading often did not work out well. Also the operational temperature and used pressure/vacuum influences the forming of the dots. The softer the material, so the closer to the glass transition temperature, the better the forming process will be, but the more energy and time are needed to form the article.

3.5 Orientation on the package

Articles with codes in the same direction were tested. Sometimes the articles were not recognized. The positioning of the article on the conveyor is of importance. It turned out that positioning of CurvCode in more directions functions better, making the positioning of the article independent from the light sources and reflection.

3.6 Type of material

Different types of materials with different colours and surface have different light reflecting characteristics resulting in different contrast ratios between positive and negative elements of the CurvCode. The software needs to use different configurations to be able to read transparent PET and white PP for example.

4. DYNAMIC TEST

To perform a dynamic test a machine has been constructed with the following functions:

- A head band to transport packaging to a conveyor on which they are dropped
- A conveyor which can be set at different speeds
- A beam with light sources and cameras with an overlap in the view of 12 mm
- An electronic connection with a blowing unit for sorting

The packaging are put one by one on the head band to transport them to the conveyor on which they pass the light beams and the cameras. If a CurvCode is recognized they are sorted out with the blowing unit. At the end the percentage sorted packages can be calculated.

Several brand and private label owners were willing to cooperate in the test and they adjusted their packaging. All the packages in which CurvCodes have been applied, were first tested in a static situation. Different surface characteristics like gloss and matt surface and different colours are chosen, including black. All the packaging used for the test are packaging that are currently used in the market, so the results will be representative for practice.

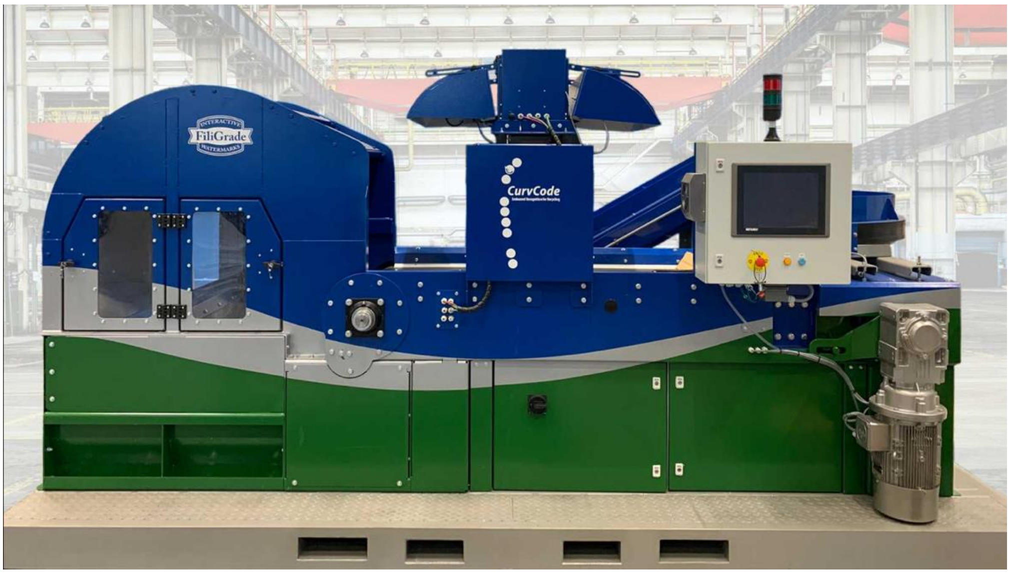

Figure 4 – Picture of the test machine for dynamic testing

Description of the picture: At the back the head band can be seen, from the middle running to the top at the right. At the right the packages fall on the conveyor behind the grey screen and are transported from right to left. The software is taken up in the grey coloured computer. The beam with light and cameras are positioned in the middle, the mushroom shaped blue part above the CurvCode logo. At the left the blowing unit is taken up with a cover with the Filigrade logo to make sure that the packages are not blown away out of the area of collecting.

The packages listed in Table 1were fitted with CurvCodes in relief and were used in the dynamic test. The packaging were put on the headband so they got randomly positioned on the conveyor. The tests were repeated 4 to 17 times, until the number of 100 sorted packages is reached each time, depending on the amounts that were available. No false positive sorting was found, proving the reliability of the technique.

Table 1 – Packaging used in the dynamic test with the test results in percentage

Packaging	**Dimensions (ca.)**	**Colour**	**Appearance**	**Position of codes**	**Dot size**	**Percentage recognized at 1.25 m/s**
PP injection moulding, mono layer material						
1. Lid for a 10 liter bucket	Diameter 230 mm Height 15 mm	Un-coloured, hazy	With IML on top	Codes on both sides	Ø 0.5 mm	100%
2. Lid for 1 liter bucket	Diameter 130 mm Height 9 mm	White	Without print	Codes on both sides	Ø 0.5 mm	98%
3. Tray	Rectangular with rounded corners 114x128 mm, height 25 mm	Un-coloured	Hazy, matt look	Codes on both sides	Ø 0.5 mm	80%
4. Tray	Diameter 170 mm Height 40 mm	Green	IML on vertical wall and a round IML diameter 7.6 cm at the bottom.	Outside surface is matt. Codes on both sides. Inside surface is not gloss, but also not very matt	Ø 0.5 mm inside and outside	82%
5. Tray	Diameter 170 mm Height 40 mm	Green	Matt surface on vertical wall and a round IML diameter 7.6 cm at the bottom, inside more glossy then other green tray	Outside surface is matt. Codes on both sides. Inside surface is more glossy than other green tray	Ø 0.5 mm outside and Ø 0.56 mm inside	87%
6. Tray	Diameter 170 mm Height 40 mm	Black	A high gloss circle in the bottom (for putting a label on) 7.3 cm diameter	Outside surface is matt. Codes on both sides	Ø 0.5 mm outside and Ø 0.56 mm inside	82%
7. Cap	Diameter 82 mm	Brown	Normal PP gloss	Codes only on the outside	Ø 0.5 mm	88%
PET thermoforming, monolayer						
8. Tray	Rectangular 140x180 mm, Height 35 mm	Transparant	No labels	Codes only on the outside	Ø 0.6 mm	98%
9. Tray	Rectangular 170x100 mm Height 10 mm	Transparant	No labels	Code only on outside, can be seen on inside	Ø 0.6 mm	99%
10. Tray	Rectangular 170x100 mm Height 10 mm	Black	No labels	Code only on outside, can be seen on inside	Ø 0.6 mm	98%

The results prove that the cameras can scan the codes rather well and recognize the packaging. This is the first dynamic test of scanning packaging for codes that is executed with the test machine with three main parameters that can be varied independantly; the type of lightening, the position of the cameras and the conveyor belt speed. The tests were used to establish a procedure to apply Curvcodes in packages in the best possible manner.

5. PROCEDURE FOR TAKING UP A CURVCODE IN A PACKAGING

The insights have been translated to a procedure in which steps are taken up for putting a code in a packaging. The procedure is called: **the Embedding Guidelines for 3D CurvCode**. The procedure starts from the perspective of a potential user that has no previous experience with Curvcode and ends by providing the user with the coded package, ready to be sorted. The guidelines contain 10 points.

1. Explanation of CurvCode
   The use of the code is explained as follows: The CurvCode is a technique to recognize packaging on base of reflection of light. It can be used on many materials and as far as known for all kind of plastics, transparent, coloured, matt surface and high gloss. The codes that are used are related to materials like PE, PP, PET etc. The codes can be used to make a distinction between food and non-food packaging.
2. The appearance of the CurvCode
   The code can be taken up as 2D in artwork or 3D in relief. This guideline is specifically developed for 3D relief codes. The code is made by 12 dots that are put in relief in the plastic by use of the mould. The relief can be positive or negative: embossing or debossing.
3. Dimensions of the code
   The code has the shape of a Bezier Curve with length from the first to the last dot of 19.5 mm, heart to heart, 20 mm on the outline. The diameter of a dot is 0.5 mm. Pictures of codes as they appear in plastic packaging are available to be shown to potential users.
4. Depth of the code
   The relief of a dot has to be around 100 microns after leaving the mould. For injection moulding this can be used as the depth for a dot taken up in the mould. For thermoforming best it to use vacuum channels under the dots and making the width 0.7 mm with a curve that is deeper than 100 microns. If 150 microns is used, the dots are very well readable. If dots are taken up in surfaces without a vacuum channel, the diameter of 0.7 mm and depth of 150 microns are minimum dimensions. The result is mostly readable, but has to be tested. The forming temperature and vacuum pressure is also of importance for forming the dots.
5. Compensating shrinkage or expanding of the plastic after leaving the mould
   The code has to be 19.5 mm heart to heart after leaving the mould and cooling down. Possibly the code in the mould is larger or smaller, depending on shrinkage or expanding of the package after leaving the mould. Scaling of dimensions has to be considered.
6. The amount of codes on a packaging
   The more codes on a package the better, but the codes may not overlap. A distance of 1 cm between the codes at least is needed to overcome false recognition of patterns. Also a distance of minimum 2 mm between other relief codes like a recycle logo is needed. It is advised to take up at least 6 codes per packaging, more or less one on every side of a package; 3 dimensions with two sides each.
7. Integration of the code in the design
   Best is to take up codes on places that are expected to be visible after crushing the package. Trays with sides that go up, cups with high sides, will be flattened during waste collection and bottoms will most likely remain flat and readable, so at least codes have to be taken up in the bottom. Codes in the side can help.
8. Putting the codes on a 3D curved surface
   Best is to design the code as seen rectangular to the 3D curved surface as a projection on the surface. In software the code can be scaled and projected on the surface. In this way the distortion is smallest seen from several directions.
9. Orientation of the code
   For reading the code it does not matter what the axis of the code is. The best is to put codes in different directions on the surface so the light shines on the curves in different directions.

10. Orientation on side of the packaging
    A code taken up in a thermoformed article can be read from both sides, if the dots are deep enough the light is reflected even if the code is taken up on one surface. For injection moulding the code has to be taken up on both sides of the article.

6. DISCUSSION

With static and dynamic tests it has been demonstrated that plastic packages with Curvcodes can be recognized and sorted. This is an important milestone in the development of this new sorting technology. But there are still many questions. For example if it is possible to recognize packaging that are crushed and covered with dirt, the influence of humidity when waste has been stored in the rain, the influence of the speed of the conveyor belt, and finally, the possibilities to put a code in extrusion blow moulded articles.

7 Conclusion

Tests have shown that it is possible to sort packages on base of a 3D code that is taken up in relief on the package. Guidelines are needed to structure the process. Design rules are needed to reach the most effective process and results.
The next step that will be executed is sorting out coded packages from waste, fully crushed and covered with dirt.

8. ACKNOWLEDGEMENT

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