Key to Purity of Recycled Resins

Integration of Digital Watermarks in Complex Injection Molded Packaging Products

Digital watermarks can make the sorting of post-consumer plastic waste more accurate and efficient in the future. For the first time, through advancements in injection molding technology, a readable digital watermark, imperceptible to the naked eye, has been incorporated into an injection-molded flip cap.

On the flip cap, the digital watermark is not visually perceptible, but can be read like a code by specialized high speed camera © Männer

Currently, a large proportion of collected post-consumer plastic packaging still cannot be recycled. One of the main reasons for this is that the exact composition of the plastic molding compound cannot be detected during the sorting process. However, higher sorting rates between 95 and 100% represents one of the essential goals to transition from a "Linear Plastics Economy" to a "Circular Plastics Economy." Therefore, in 2016, the HolyGrail initiative was initiated to develop solutions for sorting plastic packaging under the leadership of The Procter & Gamble Company and facilitated by the Ellen MacArthur Foundation. The project analyzed different technologies for the detection of plastic packaging. In 2018, the technology of a visually imperceptible digital watermark was finally selected. [1]

The follow-up project, Digital Watermarks Initiative HolyGrail 2.0, driven by AIM – European Brands Association and powered by the Alliance to End Plastic Waste, was officially launched in September 2020. The objective of the initiative is to investigate digital watermarks from insertion to pilot sorting systems for various plastic packaging, enabling industrial scale-up. Foboha (Germany) GmbH, a business within Barnes Molding Solutions, is actively participating as a "technology enabler" in injection molding technology, strongly contributing to the working group to introduce digital watermarks into injection molds and define guidelines.

The Advantage of Digital Watermarks in the Sorting Process

Sorting by grade is the most important criteria in the recycling process for the subsequent recyclate quality. Today, plastic waste can be identified at high speed based on physical properties such as near-infrared sorting. One of the limiting factors is that dark-colored plastics often cannot be identified [2]. Alternatively, localized information can be placed on the product directly in the molding process using identification stamps, such as the ASTM International Resin Identification Coding System introduced in 1988 [3].

In comparison, digital watermarks are almost invisible and offer the possibility of integrating information over the entire surface. These are technical, hidden markings embedded in a carrier medium, such as in the printing of packaging. The digital watermarking technology currently being used in the HolyGrail 2.0 initiative is being developed by Digimarc Corporation. In a simplified description, a limited, pixel-based bar- »

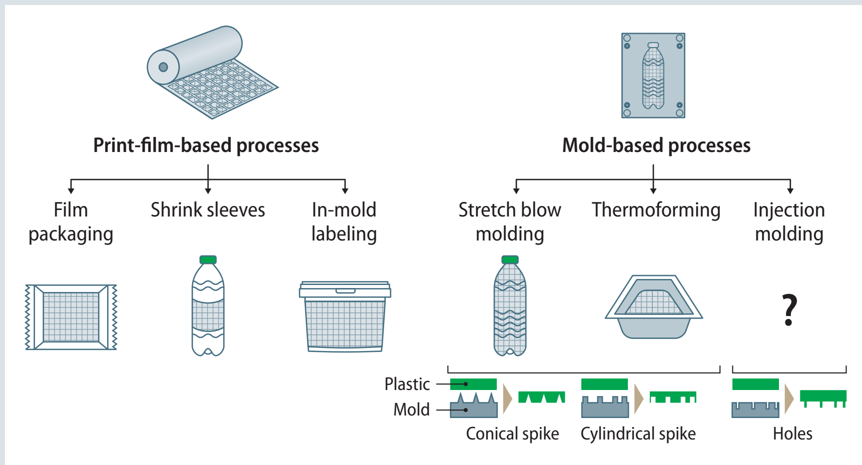

Fig. 1. Previously investigated applications of digital watermarks in plastics processing Source: Barnes Molding Solutions; graphic: © Hanser

code 22 x 22 mm^2 in size is applied on the whole product surface like a mosaic.

The digital watermark itself is an overlay of a message signal for addressing a database entry and a synchronization signal to determine the objects' orientation. By integrating camera-based detection systems into sorting systems, information including plastic type, additives, or application area (such as food/non-food) can be read out from a database.

In terms of the application method, a distinction can be made between print-film-based and mold-based processes (**Fig. 1**). In the former, the digital watermark is integrated two-dimensionally into the pixels of the print. Films printed in this way have already been studied in various processes. In mold-based processes, a three-dimensional digital watermark is molded onto the surface of the plastic component. Blow molding and thermoforming processes have also been investigated: with these methods, the forming occurs in the rubber-elastic state; thus, the molding accuracy is lower than in injection molding. Therefore, conical or cylindrical spikes are used, where the digital watermark is more coarsely marked and can be more easily perceived by the customer. [4]

Cycle-Neutral Impression

Fine holes in the mold surface can be used in injection molding (**Fig. 1, right**) instead of larger protruding spikes. The molding accuracy of such microstructures between 0.5 and 500 µm is influenced by the processing properties of the plastic and by the process parameters. High holding pressure, short injection times, high mold temperatures, and melt temperatures have a positive effect [5, 6].

In the case of digital watermarks for plastic packaging, the focus is on readability instead of precise molding. The structures must be large and deep so they can be molded reliably and simultaneously have as little impact as possible on the appearance of the plastic part. In the packaging industry, the digital watermark must also be reliably molded without increasing the melt or mold temperature, as an extension of the cycle time will often not be tolerated.

First, preliminary tests are carried out on the readability of variations of the digital watermark with different texture depths on injection-molded test plates (180 x 150 mm^2) (**Fig. 2**). The plate thickness is set at 1.1 mm so that it reflects the wall thickness range of subsequent applications and is gated by a film gate. The mold insert is mirror polished. Using a laser texturing pro-

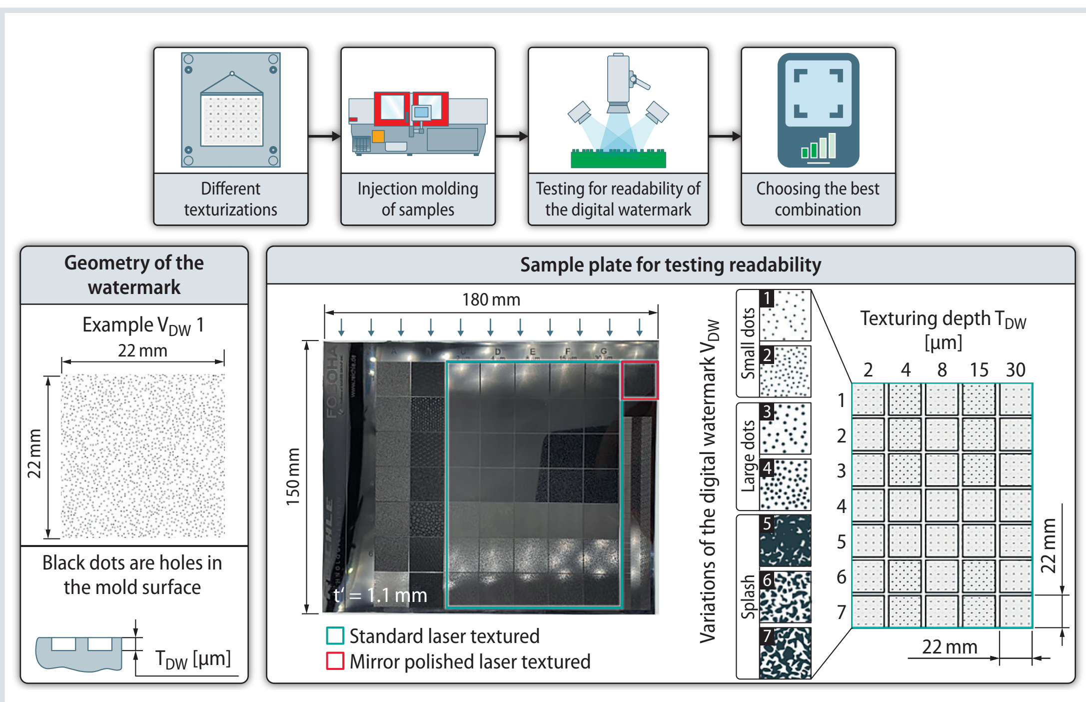

Fig. 2. Geometry textures of the digital watermark and the test plate for testing the readability Source: Barnes Molding Solutions; graphic: © Hanser

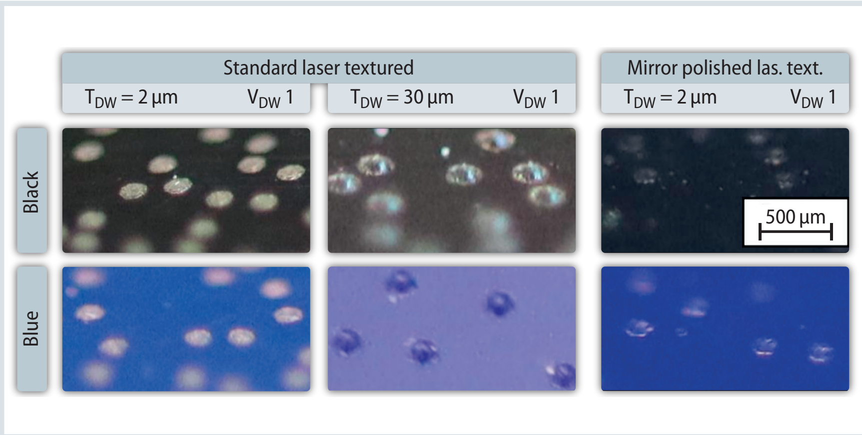

Fig. 3. Macro images of the structures on the test plate surface

Source: Barnes Molding Solutions; graphic: © Hanser

cess, seven variations (V_{DW}) of the digital watermark (columns) in the texturing depths T_{DW} 2, 4, 8, 15 and 30 µm (lines) are introduced into the mold insert by the company Reichle Technologiezentrum GmbH. Standard laser texturing with matte structures is used in the area marked in turquoise, while high-gloss laser texturing is used in the red area with a new process developed by Reichle. For example, the V_{DW} 1 used (few, small dots) is shown in **Figure 2, left.** The black areas are laser textured as a depression in the surface.

Readability of Digital Watermarks on Injection Molded Parts

The test plates are molded with a polypropylene molding compound suitable for caps and closures (grade: Moplen RP340N, manufacturer: LyondellBasell). In addition, the naturally transparent molding compound is colored for the tests with 2 % color masterbatch in blue transparent, black, and white – both latter being opaque. The influence of the variation VDW on the appearance of the surface can be seen on the black test plate shown in **Figure 2**.

While only a slight effect on the gloss of the plate can be seen purely optically with the dot-shaped codes, the "splash"-like variation of the digital watermark leads to a duller surface. This correlates with the percentage of black areas (depressions). Therefore, these variations are only suitable for matte items and will not be analyzed in more detail below.

In the dot variations, the visibility of the digital watermark becomes more visible as the number and size of the dots increase. In the macro images of the example of V_{DW} 1 (**Fig. 3**), the textures stand out brightly from the molded surface. When the texture is molded, a small irregular surface structure is created on the plastic part, which leads to light scattering and thus contrast with the highly polished surface.

Using standard laser texturing with a depth of 2 µm, the structure is flat with a diameter of approx. 160 µm. With high-gloss laser texturing, the structure stands out less strongly at the same texture depth and is thus more difficult for the human eye to detect. With a texture depth of 30 µm, the diameter increases to approx. 180 µm, and the structure is formed on the surface as a hemisphere a few micrometers high. Variations 3 and 4, which are not shown, have a larger structure diameter of approximately 240 µm. This increases the surface area by »

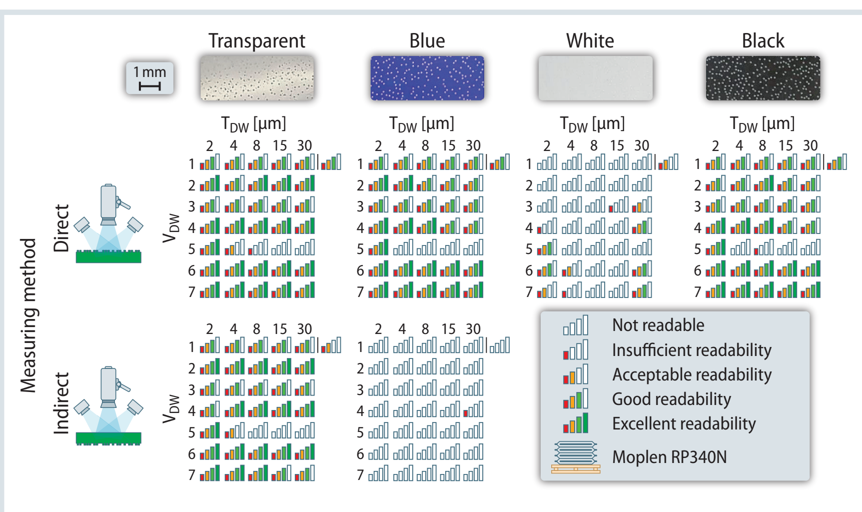

Fig. 4. Results of the readability of the digital watermark as a function of the application parameters and the molding compound color Source: Barnes Molding Solutions; graphic: © Hanser

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Service

References & Digital Version

- You can find the list of references and a PDF file of the article at *www.kunststoffe-international.com/archive*

German Version

- Read the German version of the article in our magazine *Kunststoffe* or at *www.kunststoffe.de* more than 100%, making the digital watermark more easily visible to the naked eye.

Indirect Readability Only with Transparency

On the test plates, the readability of the digital watermark is analyzed for each texture field with the support of the Digimarc company using the camera system and evaluation algorithm developed for HolyGrail2.0. **Figure 4** shows the evaluation of the readability using four signal bars following the arrangement on the test plate (**Fig. 2**). Two bars represent the limit above which the digital watermark can be read.

In the direct measurement on the side of the digital watermark, good to excellent readability is given for transparent, blue, and black test plates for all dot structures (V_{DW} 1 to 4) and in all texture depths. Thereby, the trend of readability of variants with many dots is slightly better. The texture diameter and texture depth have no significant influence on the readability.

In the case of white-colored test plates, the digital watermark is only readable with large texture diameters and texture depths. The reason for this is the lack of contrast between the highly polished surface and the molded textures (**Fig. 4, top**). Despite the lower contrast (**Fig. 3**), the readability of the high-gloss laser-textured digital watermark is comparable to that of standard laser texturing.

Complementing the direct measurement, indirect readability via the reverse side of the plate is investigated for the transparent plates and the blue transparent plates. The advantage of indirect readability would be that only one surface would have to be marked with the digital watermark to ensure suitable coverage of the part surface. For the transparent plate, the readability is comparable to the direct measurement. Indirect readability is prevented by coloring with the blue transparent color additive.

Analysis of the Transferability to a Complex Part

The use of a digital watermark for a complex injection molded part is analyzed using a single-cavity prototype mold for a flip-cap geometry (base area 68 x 38 mm^2, max. height 42 mm, wall thickness 1.0 to 1.2 mm) by Procter & Gamble (**Fig. 5**). Based on the preliminary tests, V_{DW} 1 in 2 µm is selected as a combination of good readability with minimal influence on the article's appearance.

In the first phase, the digital watermark is first added to the highly polished outer surface of the article (orange), and the readability is analyzed for different viewing directions. Due to the mold design, textur-

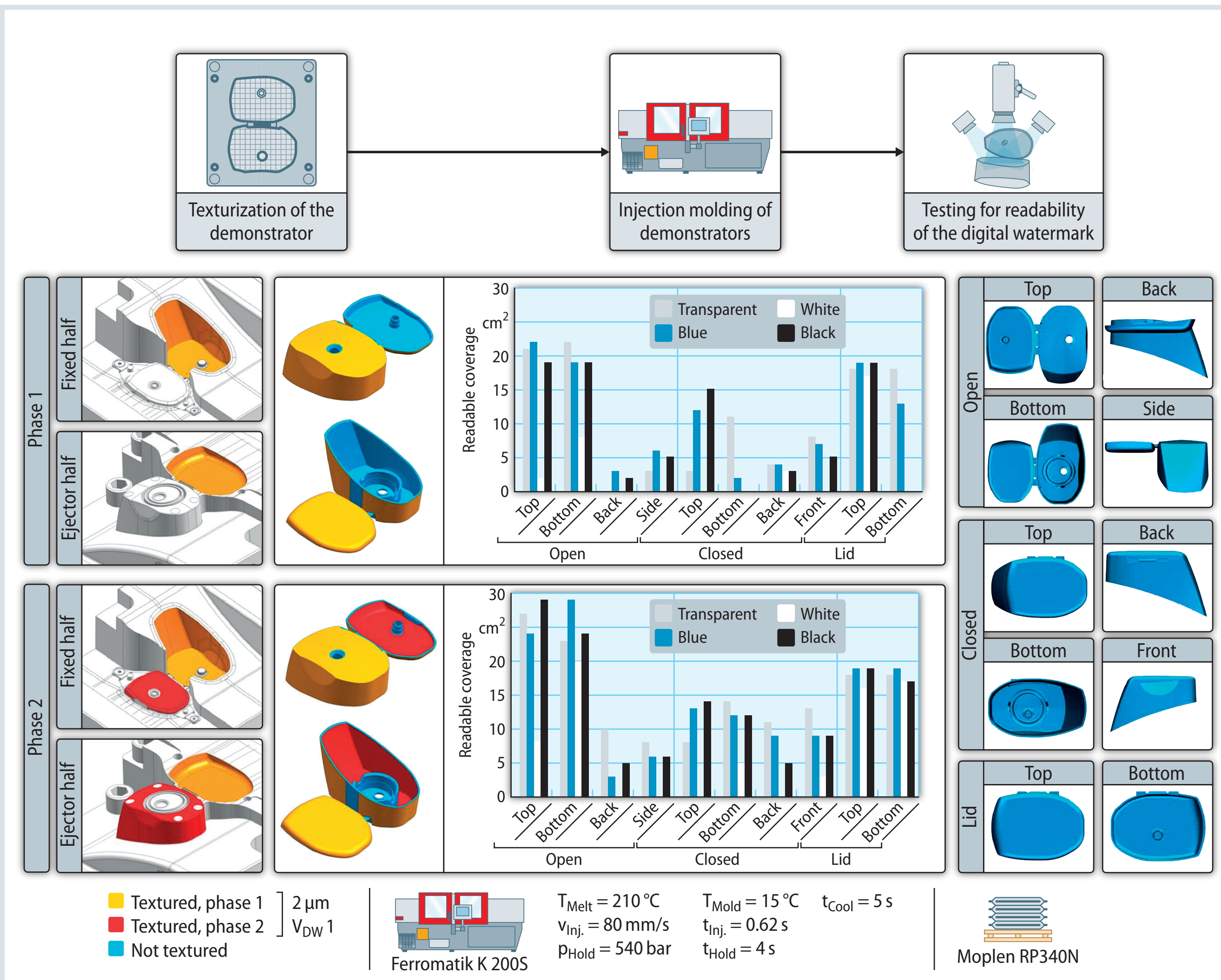

Fig. 5. Results of the use of a digital watermark on a flip cap Source: Barnes Molding Solutions; graphic: © Hanser

ing below the film hinge is not possible. In the second phase, the digital watermark is additionally applied to the inside of the lid using high-gloss laser texturing. It is applied to the inner part of the flip cap using standard laser texturing (red), while rotatable elements such as ejector pins are left out. The injection molding parameters used are based on those of the series production process. However, there are extended non-productive times due to the demolding of the cold sprue system of the prototype mold.

The analysis of the molding of the digital watermark shows comparable results to those of the test plate in **Figure 4**. Here, under magnification, no change in the textures can be detected due to demolding either. Since the readability of the digital watermark has already been demonstrated in the test plate used, the area on which readable digital watermarks are detected is determined instead. Various orientations and conditions (open, closed, detached lid) of the flip-cap are considered (**Fig. 5, right**), which can occur during sorting. Depending on the orientation, the projected area differs, which must be set in relation to the readable area. Due to the shape of the flip-cap, the angle at which the areas are viewed also differs.

In the case of the cut-off cap, a flat, slightly curved area of about 19 cm^2 is examined. For all colors, about 95 to 99% of the digital watermark is readable on the textured side (top), confirming the results of the preliminary tests. The nearly 90% readable area for the white cap can perhaps be attributed to the curvature of the lid, which increases the contrast. The transparent and blue transparent, 95% and 70%, respectively, are still legible from the reverse side. The indirect legibility of the blue transparent cap can be explained by the highly polished surface on both sides but cannot be confirmed conclusively.

Thanks to the texture applied to the inside of the lid in phase 2, a very high readable area percentage can also be achieved with the opaque molding compounds. It must be noted that the textured area is smaller due to the functional elements. An important finding is that a digital watermark introduced on both sides does not disturb readability with transparent components.

When viewed from above, only the top of the cap (when open) and the shell surface are textured in phase 1 demonstrators. When viewed from below, the top of the cap is visible. Although the textured area is approximately 4 cm^2 larger when viewed from the top, comparable readable area contents of 45 to 52% of the projected area are measured. This is most likely explained by the angle towards the camera under which measurements are taken in the setups. This can lead to stronger reflection and thus poorer readability and would also explain the results when viewed from the side and in the closed condition.

Due to the almost full cover texturing, except for the white caps, readability of more than 30% of the projected area can be achieved for all viewing directions analyzed. The texture on both sides has the greatest effect on the transparent demonstrators. A considerable increase is also possible with the black demonstrators. However, the fact that the increase is smaller can be explained by the fact that many of the additionally textured areas have only limited effects in the perspectives investigated or are viewed at a steep angle. In summary, apart from the white demonstrator, a sufficiently large area is readable in phase 2 to allow sorting based on the digital watermark.

Conclusion

In cooperation with partners from the "HolyGrail2.0" initiative, for the first time, Foboha (Germany) GmbH has introduced a readable digital watermark into an injection-molded packaging product using the example of a flip-cap. In addition to the digital watermark's design and texture's depth, it was shown that the color of the subsequent article is also critical for good readability. Transparent articles, for example, can enable readability from the back of the article and thus reduce the area to be textured. White, highly reflective surfaces may make readability more difficult due to lack of contrast. The results will be incorporated into a guideline for the future use of digital watermarks.

The flip caps produced in this subproject will be used for sorting trials on a pilot sorting machine to confirm the successful trials. Furthermore, Foboha plans to introduce the texture into a production mold to investigate its durability over the mold lifetime and collect additional results for an industrial scale-up. ■