Bringing 2D Inkjet into 3D Forming Applications Using Monofunctional, Low-crosslinking and Heat-stable UV Inks

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Abstract

UV inkjet printing is one of the predominant imaging platforms in wide-format graphics production, thanks to the health and safety advantages UV inkjet inks offer over solvent-based inks, their high productivity with nearly instant curing and superior adhesion, and the compatibility they offer with a broad range of media. But some of the properties that make UV inkjet such an attractive option also impose limitations in inkjet's technical capabilities. By carefully altering the formulations used, UV inkjet has many potential uses as an alternative to time-consuming, manual decal decoration and airbrush painting in industrial thermoforming applications.

While the market potential for converting these types of applications to digital printing is attractive, the status quo in inkjet ink development emphasizes difunctional, high-crosslinking acrylates that cannot withstand the heat, pressure and elongation needed in the thermoforming process.

By carefully examining the role monofunctional acrylates can play, the industry can develop a potentially important new niche for custom printing of industrial and packaging products using inks that can withstand superior elongation under high-heat thermoforming conditions. Monofunctional acrylates enable UV inkjet inks to be flexible enough to meet or exceed the percentage of elongation possible with the underlying substrate. Rethinking the color pigmentation process, augmenting inks to develop process colors that don't change under heat and don't fade when stretched, helps to complete this important technical innovation.

This paper will highlight the essential development concept behind this new type of highly flexible ink: a patented formulation EFI acquired in 2014 and uses in its VUTEk GS Pro-TF products.

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Introduction

Thermoforming is a manufacturing process wherein a plastic substrate is heated to a pliable forming temperature. It is then formed to a specific shape using a mold and trimmed to create a product or package. Substrates can be thin-gauge (for disposable cups, containers, lids, trays, blister packs, clamshells and other products used in the food, medical and general retail industries) or thick-gauge (for items such as vehicle doors and dash panels, refrigerator liners, utility vehicle beds and plastic pallets).

Thermoforming, then, is a type of vacuum forming process that requires heat and pressure. Standard heat applied in the thermoforming process is in the 280-460+ degree Fahrenheit range. The type of mold or tool configuration used depends on the specific product or signage needs or applications.

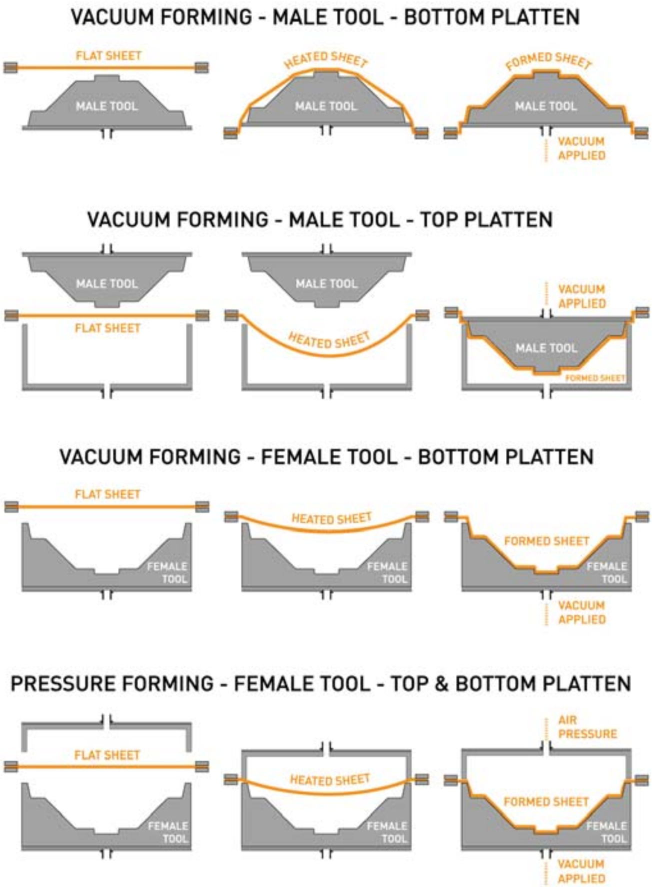

Figure 1: *Forming processes used to create thermoformed products.*
Illustration from Creative Form Plastics Inc., Scarborough, Ontario • www.creativeformplastics.com

Every single one of us comes in contact with thermoformed products almost every day of our lives. Here are just a few examples:

- Aeronautical: Interior trim, covers and cowlings.
- Agricultural: Trays, tubs, clear growing domes, lawn mower enclosures.
- Automotive: Wheel and hub covers, auto interiors, deflectors, dash clusters, sports and outdoor vehicle cowlings.
- Marine: Boat hulls, canoes and kayaks; hatches and dashboards.
- Electronics: Handhelds, appliances, computers, instrumentation.
- Entertainment: Backdrops, costumes, animation models, simulations, gaming kiosks.
- Medical: Scanners, masks, prosthesis parts.
- Architectural: Tub and shower enclosures, Jacuzzis, custom counters.
- Retail: Packaging, blister packs, signage, vending machines.

Increasingly, brand owners, retailers and others are interested in using this technology to create 3D point-of-sale signage, gaming kiosks and products such as car-top carriers and more, in full-color and in smaller quantities than conventional manufacturing processes have allowed. In a typical example using conventional thermoforming processes, it might take 7.5 hours of labor to produce two 13.5' x 4' vacuum formed signs using current printing and painting processes. What if that time and cost could be significantly reduced?

Enter: wide-format inkjet. As with any digital printing process, wide-format inkjet allows runs as short as one for fast-turn, highly customized materials for both samples and final product. Using digitally printed thermoforming technology, 34 of the same signs described above can be produced in the same 7.5 hours – a reduction of 93% in labor costs and an increase of productivity of 95%. Using conventional processes, these 34 signs would have taken 3.5 weeks to produce.

It is for this reason that digital printing technologies are attractive for thermoformed products. However, the inks used in digital wide-format inkjet printing have heretofore been inappropriate for these applications.

UV Inkjet Inks: The Status Quo

Thermoforming not only involves heat and pressure, it also requires elongation of the substrate to be formed. The status quo in inkjet ink development emphasizes difunctional, high-crosslinking acrylates that cannot withstand the heat and pressure needed in the thermoforming process. Nor can these inks stand up to the type of elongation required for most thermoforming applications.

During the heating cycle in the thermoforming process, both the inks and the plastic substrate become malleable. In the business, this is known as thermo-sag, glass transition phase or Bubble. Pigments can shift in color or hue during the heating or forming process. And elongation during forming can cause cracking or mosaic features in the final product that make it unacceptable from a quality perspective.

This is due to the fact that the difunctional acrylates commonly used in UV inkjet formulations have two highly reactive sites in their molecules for faster, harder curing, which add to an ink's durability and productivity, but limit flexibility.

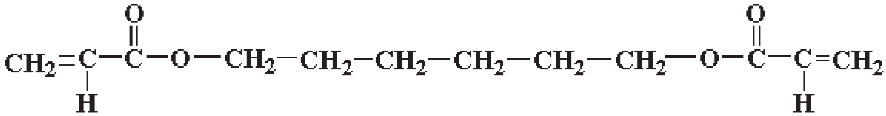

Figure 2: *Difunctional structure for Hexaneidiol Diacrylate (HDDA), a reactive diluent used in flexible, energy-cured inks and coatings*

The advantages of UV inkjet formulations centered around difunctional, high-cross-linking acrylates include fast cure speeds, excellent chemical resistance and surface hardness. But for thermoforming applications, its disadvantages include limited adhesion ranges, brittleness and a tendency to experience shrinkage and edge-curl.

Exploring Monofunctional Acrylates for Thermoforming Applications

By carefully examining the role monofunctional acrylates can play, the industry can develop a potentially important new niche for custom printing of industrial products using inks that can withstand superior elongation under high-heat thermoforming conditions. This technology can be utilized by traditional industrial thermoforming operators, but can also offer new revenue streams and expanded product offerings for printing companies with enhanced print capabilities by bringing imaging and decoration in house.

The result? High elongation 3D graphics with vivid color and visually compelling design capabilities.

Digital Thermoforming Inkjet Inks: The Background

Don Sloan has been developing UV printing inks since the 1970s. In 1993, he established Polymeric Imaging (PI) to create UV ink formulations to replace solvent-based chemistry. And in 2010, PI developed a patented formulation for deep-draw thermoformable UV inkjet inks and coatings. PI's patents and intellectual property related to digital thermoforming technology were acquired by EFI in October of 2014.

Less is More: Monofunctional, Low-Crosslinking Acrylates

The original custom inkjet formulations for digital thermoformable UV inkjet inks and coatings worked well in PI lab tests but required years of refinement before they could be introduced to real-world production environments. These inks enable deep draw thermoforming without the cracking or mosaic features that occur with conventional difunctional, high-crosslinking UV inkjet inks. Now, this work has yielded a fully-functional solution to digital thermoforming printing using wide-format UV inkjet printers such as the EFI VUTEk GS Pro-TF.

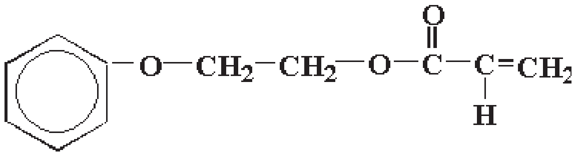

Figure 3: *Monofunctional structure for Phenoxyethyl Acrylate, commonly used in energy-cured inks and coatings*

Using monofunctional, low-crosslinking acrylates has resulted in some major differences as compared to traditional difunctional, high-crosslinking UV inkjet inks that now deliver a functional solution for digitally printed thermoformed products as demonstrated in Figures 4 and 5 below. These include:

- Pigments or dispersions are not thermo-chromatic; that is, they do not shift in color or hue during the heating or forming process.
- The inks enable unlimited elongation, with the ability to meet or exceed the elongation characteristics of the plastic substrate. There have been successful applications with more than 24 inches of draw, more than 1000% elongation, with aspect ratios greater than 30:1.
- These inks feature extremely broad adhesion ranges with a vast application range that goes beyond the capabilities of conventional vacuum forming techniques.

Vending Gaming POS Display

Figure 4: *Softer cure and high heat tolerances for signage applications*

Digitally printed hunting blind

Camo-body Polaris Utility Task Vehicle

Custom automotive bumper

Figure 5: *Softer cure and high heat tolerances for functional/industrial applications*

The Softer Side of Thermoforming

Developing the inks was only part of the process required to bring this technology to market. In order to create the types of applications included in Figures 4 and 5 above, distortion software is required for proper alignment of the graphic image to the mold. Distortion printing keeps the colors intact and prevents the loss of color strength when the substrate is elongated. Distortion software allows the design to take into account the required distortion factor. Thermo 3D Suite from Quadraxis (distributed by R&R Graphix in the U.S.), is an example of this type of software.

And clearly, exceptional color management techniques are required to ensure color accuracy in the final product. In most cases, with proper color profiling of the printer, color hue adjustments are not required in the design process. Images are printed at a higher density, but with the same hue/chromatic value. When done correctly, this results in a final elongated product that complies with design intent.

However, successful color placement for thermoforming applications places another burden on the ink: it must exhibit free film characteristics; in other words, the cured ink film could almost stand alone as its own layer, like a sheet of cellophane. Free film properties, combined with high density, provide consistent color during the forming process.

Key Attributes of Monofunctional, Low-Crosslinking Inkjet Inks

In the lab and in the field, these new inks have proven to have several key attributes that revolutionize the thermoforming manufacturing process using UV inkjet printing.

These include:

- The ability to form parts or signage decoration with fewer steps and in a significantly shorter time.
- The elimination of screen printing set-up costs or the hand painting and vinyl lettering process used in conventional thermoforming.
- Superior elongation characteristics that support deep draw thermoforming while maintaining opacity on various plastics, including PETG, acrylic, polycarbonate, polystyrene and PVC.
- Inks that withstand heat forming and cutting without cracking, chipping or loss of adhesion.
- Water and moisture resistance that enables durable, lasting images.

LED Curing: A New Frontier

As with most technologies, there is still opportunity to continue to improve the monofunctional low-crosslinking UV inkjet inks for even better thermoforming performance. One project currently underway is the development of LED cool cure ink formulations with LED-based photo-initiators using wavelengths of 365 to 400 nanometers, compared to conventional UV inks which use wavelengths of 320 to 365 nanometers. This leverages EFI's LED inkjet expertise into the arena of thermoformable high elongation ink technology and enhancement coatings.

Conventional UV curing uses UV lights with an elevated temperature, which limits the ability to use lighter weight and heat-sensitive or dimensionally unstable substrates. LED curing takes place at 81 degrees Fahrenheit and results in increased material stability, lower distortion factors and reduced material degradation. As an added benefit, LED lamps feature extended lamp life and lower energy costs.

With LED curing, deep draw characteristics on a thin film could create new opportunities in vacuum forming by leveraging superior flexibility and color consistency in thin film packaging applications such as direct decorating for blister packs.

Process Simplification

In addition, elongation during thermoforming, whether LED or conventionally cured, can translate into stretching profits and shrinking production costs. With a move toward packaging simplification, both for cost reduction and environmental sustainability reasons, thermoformed packaging has the potential to eliminate the need for cardboard inserts on packaging, and reduce cost and time in the packaging assembly process. Direct printing on the thermoformed packaging can also eliminate the need for labels. This offers the additonal opportunity to use variable data on 3D plastic packaging for inclusion of bar codes, serialization and even personalization.

The Future is Bright

The technology advances that have been achieved in the development of monofunctional low-crosslinking UV inkjet inks for thermoforming opens up a bright new future for thermoformed applications across a number of industries as demonstrated by the examples cited in this paper. As this technology is adopted on a broader scale, it will result in:

- Faster time to market.
- Higher quality, more relevant thermoformed products.
- Reduction in the amount of packaging materials used.
- And more …

The only limit is our imagination. This is just the beginning.