Digital Mold Texturing Methods, Materials, and Substrates

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Abstract

Commercialized methods, materials, and systems for texturing mold surfaces are presented.

A first step involves generating a graphic file of a desired texture pattern. The graphics file is subsequently output to material deposition equipment such as an ink jet printer, which is configured to print using an acid- resistant UV-curable ink.

The acid etch resist ink is formulated to provide optimal properties for ink jet printing, while also providing good adhesion to metal surface and excellent acid-etch resistance to various types of acids.

The acid-etch resist ink is printed onto a sheet of coated film that allows the acid-etch resist to be transferred to a mold surface, after which the mold surface is etched in an acid bath.

Introduction

Consumer articles made of plastic today predominantly have a textured, rather than smooth, surface. Familiar examples include vinyl siding, plastic bottles, and artificial leather of car interiors, to name a few.

These articles are made by injection molding and therefore the metal molds and embossing rolls used in their production need to have a textured surface. For this, the surface of the mold is selectively protected with acid resist (AR) material according to the design specified and then the mold is etched in an acid bath. Application of AR on complexly curved mold surfaces is a lengthy, tedious and very labor intensive process that is done manually.

Figure 1. *Typical textured surface of car interior*

Automation, or at least simplification, of the process is highly desirable. In some instances an ink-jettable acid-resist (AR) used for applications such as circuit board etching can be used, but this method is limited in applications for only flat and thin surfaces.

The mold texturing industry had developed methods of transfer of printed acid resistant pressure sensitive adhesive (AR-PSA) patterns prepared off-line to a mold surface.

One of the methods consists of deposition of AR-PSA on a thin, transparent and flexible substrate by screen printing, for instance, with subsequent transfer of AR-PSA to the curved mold surface and removal of the carrier.

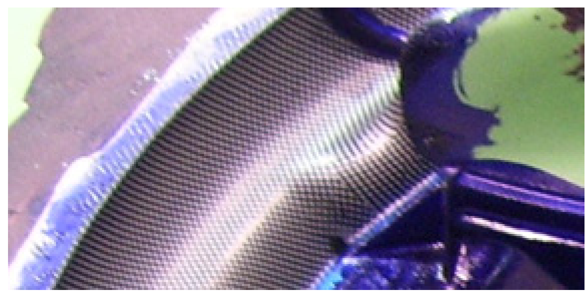

Figure 2. *Interior of steering wheel mold with AR-PSA applied prior to etching.*

The screen-printing method requires a rather long set-up time for a rather small number of prints used for each job. An opportunity was identified to develop a better method that would be faster, more accurate and precise, and being more suitable for modern day's technological needs.

Modern ink-jet technology surpasses screen-printing technology, especially in short runs, because of short set-up times, repeatability, and high accuracy. Therefore, ink-jet technology fits well into the niche of the mold-making industry with its increased technical demands.

Process Requirements

Ink-jet applications combine three key components: ink, printing media (substrate) and the printer/printhead.

The ink must have several specific properties:

1. be thermally stable and show good jetting ability
2. have good adhesion to metal (stainless steel, instrumental steel, aluminum)
3. have contrast color for ease of print registration and inspection
4. be strongly water and acid resistant to nitric acid and

ferric chloride solution
5. must not smear or deform ("flow") upon transfer to metal with burnishing

The printing substrate should satisfy several requirements:

1. Thin (1-2 mils max; preferably 0.5-1 mil)
2. Transparent and flexible
3. Dimensionally stable (non–stretchy)
4. Have a surface tension (or coatable layer) that prevents excessive ink spread during printing
5. Ink/substrate must interact (by any means) for ink to transfer to metal upon burnishing

Ink-jet printer must have high accuracy and precision, high speed of printing and large print area, preferably up to 36x48 inches.

The Ink

Initially, we evaluated a number of samples of water and solvent-based PSA available on the market today that show acid resistance, in an attempt to adopt them either directly or after modification for printing via ink-jetting.

After an extensive search of such PSA materials we found that none of them have the proper set of characteristics (viscosity, surface tension and/or particle size, etc.) required for this application.

Dilution of available materials with water or suitable solvent to achieve the required viscosity of 8-20 cps reduced the solid content of the PSAs to less than 8 wt%. This low level of solids content was deemed to be unacceptable due to the extreme change in the printed dot size and the dot size following solvent evaporation. Due to these limitations, we focused on the development of a radiation-curable (UV) AR-PSA for ink-jet deposition.

UV-curable PSA widely used in coating industry were evaluated as well. We have found several pre-formulated materials with relatively low viscosities (300-500 cps at 25oC) that could be further modified to acceptable viscosity levels (8-20 cps at 25oC).

Formulation of UV-curable PSA (Table 1) available from Sartomer Co., which has viscosity of 290 cps (25oC), was considered for further modification.

To lower viscosity, the level of tackifier resin was reduced by dilution of presented composition with low-viscosity monomers (SR-504 and SR-256). The amount of photo-initiator was adjusted accordingly.

Samples made were evaluated first by coating them on polyester to ~20µm thickness, exposing to UV-light (1KW Hg-bulb, 15 cm distance, 100-200mJ/cm2) and measuring achieved level of tack using Imass SP-2000 peel-tester (the tack was deemed acceptable when the peel force was >400g with a 1" wide sample).

All formulations found acceptable for the tack-after-cure level had viscosities at or above 100 cps (25°C) and therefore must be used with heat to reduce their viscosities to required ink-jet level of 8-20 cps.

On the second step of ink development, we studied droplet formation of developed UV-PSA fluids using a Spectra SE128 print head (FUJIFILM Dimatix, Inc.), Apollo II print head controller in combination with Dropwatcher Model II equipment and software (Imaging Technology International, Boulder, Co)

The temperature required to bring the ink to the proper viscosity for jetting was roughly determined by heating the fluid and measuring the viscosity response using a standard viscometer. Using the Dropwatcher in conjunction with the Apollo II software, the temperature and firing pulse were refined to obtain the proper drop formation and velocity. These values were evaluated across a number of firing frequencies to ensure jetting stability.

Several formulations demonstrated good ink-jetting properties (one example is shown in Table 2) and were considered for further development.

Table 1: Sample UV-PSA Formulation (290cps @ 25C)

S-135	Sartomer	32.95	Tackifier
SR-256	Sartomer	31.43	Monomer
SR-504	Sartomer	33.52	Monomer
MEHQ	Aldrich	0.04	Stabilizer
I-1076	CIBA	0.10	Antioxidant
TZT	Sartomer	1.96	Photoinitiator

Table 2: Sample Ink Formulation with Proper Jetting Properties (110cps @ 25C)

S-135	Sartomer	24.27	Tackifier
SR-256	Sartomer	35.17	Monomer
SR-504	Sartomer	37.65	Monomer
MEHQ	Aldrich	0.04	Stabilizer
I-1076	Ciba	0.10	Antioxidant
I-819	Ciba	2.77	Photoinitiator

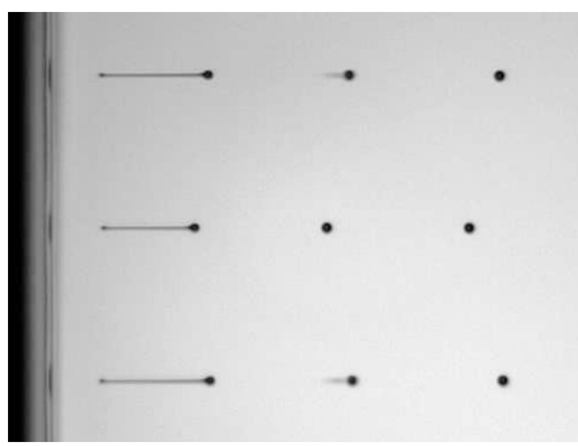

***Figure 3**. Ejected Droplets of Modified UV-PSA Ink*

For ease of registration of the printed AR-PSA articles on a mold, the ink must have contrast color. For ease of formulation we chose to use dyes, rather than pigment, allowing for a homogeneous solution and therefore simplifying future manufacturing.

Prior to use in a print head, all dyed formulations were evaluated for thermal stability. Samples of dyed inks as well as non-dyed formulations were held in an oven at 70°C for a prolonged period of time while their viscosity was monitored. Several dyes were disqualified on the basis of increasing viscosity or even gelling of the ink sample after one week.

With dye addition some jetting parameters (pulse, voltage) had to be adjusted for proper printing.

Printing

At this stage of product development, several aspects affecting print quality had to be studied and refined simultaneously.

For these steps, utilizing an instrument such as the XY MDS 2.0 is absolutely necessary as it has the flexibility that allows for many parameters to be adjusted for print quality and reliability. Further adjustment of ink temperature and the firing pulse, along with the meniscus vacuum level, were necessary to obtain consistent start of print quality and to assure that no nozzles were dropped when printing across the platen. Print speed was also adjusted to find the best balance of print speed and drop placement precision.

The next step was to determine the resolution necessary for full ink coverage of solid printing areas. Once the substrate formulation was roughly determined for processing capabilities after printing, we concluded that pinning of the ink during printing was necessary (refer to the next section for pinning lamp and substrate description). The pinning level was determined to balance drop spread on the substrate while allowing adjacent drops to merge and form smooth edges of the printed images. Once the pinning level was determined, the printed drop diameter on the substrate was measured and the resolution required for full coverage was determined to be 800 dots per inch. Higher resolutions would also give full coverage of solid areas, but would reduce the ability to resolve fine images due to ink buildup above the substrate.

The Dimatix SE-128 jetting assembly used for printing has a native resolution of 50 dpi. Therefore, 16 microsteps are necessary to achieve the 800 dpi we determined was necessary for each print swath (width of the printhead).

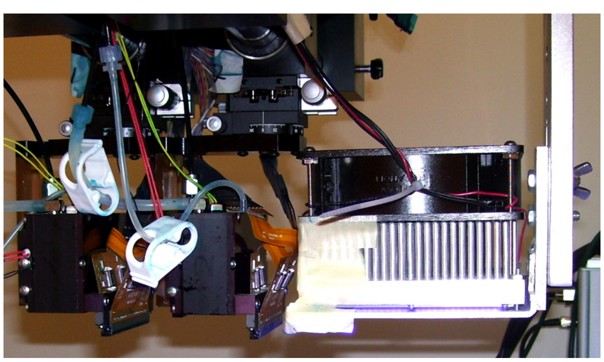

***Figure 4**. Two (2) Dimatix SE-128 Printheads with Norlux L2A2 LED Array Mounted on an XY MDS 2.0*

We encountered several issues involving pinning of the ink that relate to microstep printing. The first is that of unequal pinning dose from the first microstep to the last microstep for each print swath. With the pinning lamp turned on for each print pass, the first microstep printed receives a pinning dose 16 times higher than the last pass printed. If the pinning lamp is only turned on for the last microstep, giving each microstep the same pinning dose, the ink deposited on the first microstep will spread to a greater degree than ink deposited thereafter.

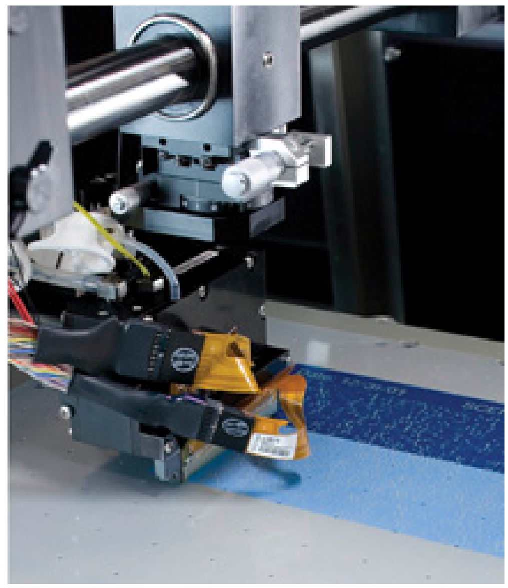

***Figure 5**. XY MDS 2.0 with Single Dimatix SE-128 Jetting Assembly.*

Another issue relating to pinning multiple microsteps is that of visible printing lines in the completed print (Figure 6). If the pinning dose is too high, each microstep will not be able to flow into the previous and subsequent microsteps, resulting in a rough 'corduroy' appearance. Along with the visual problem with this phenomenon, the uneven surface would allow acid to flow through the channels created by these printing lines during the etching process, resulting in the lines being visible in the etched mold texture. Overcoming this obstacle took a great deal of care in determining ink initiator levels, substrate formulation, and the pinning power emitted.

One of the advantages we found in utilizing a UV cure ink is that the 'step' appearance often associated with printing at lower resolutions on standard inkjet printers could be avoided. By controlling the dose of the pinning lamps to allow for controlled drop merging, it is possible to print smooth line edges at 800 dots per inch (Figure 8).

Substrates and Curing

Choice of substrates for this application was limited to thin, smooth, dimensionally stable (non-stretchy) and transparent materials.

Polyester, cellophane and polypropylene sheets were tested for print quality and the ability to transfer cured AR-PSA to a metal surface.

Only cellophane, being moistened after burnishing AR-PSA to the mold, allowed for transfer of cured AR-PSA to a mold surface. However, cellophane did not show acceptable dimensional stability when used in humid environment.

Therefore we chose to make a hybrid construction of a substrate, combining transparency, dimensional stability and smoothness of polyester with thin coated layer having better ink-receptive properties and ease of cured-ink release.

Fully hydrolyzed polyvinyl alcohol (PVA) solution coated on polyester to dry thickness of 5-7 mk allowed for acceptable ink reception, if used in conjunction with a pinning lamp.

For pinning exposure we have tested several UV-light sources.

We have found that some of them generate too much heat that brings the temperature of the printing plate and printing substrate from ambient to ~35°C just for the duration of one 9x9" area print resulting in the spread of inks differently at the beginning and at the end of the print.

Compact UV-LED light sources (like the LEDZero from Integration Technology and the L2A2 Array from Norlux) that emit in the desired UV-range (390-415nm) were found sufficient for pinning and the small size of the LED assemblies allowed moving them closer to the print head (figure 4) for immediate ink exposure, resulting in less and even spread of inks.

Directly after printing, the surface of the pinned inks is quite oily and therefore can not be used for transferred to the metal surface.

To eliminate oiliness and to achieve the required tack, the ink has to be additionally exposed to strong UV-source under a blanket of inert gas.

5KW medium pressure Hg-bulb at a distance of 36 inches was used for final print cure. Sufficient curing of AR-PSA is achieved with a dose of radiation from 100mJ/cm2 to 200mJ/cm2. This final cure dose must be adjusted in conjunction with the pinning dose applied during printing to maintain the required ink adhesion levels.

One feature that is possible by the use of a UV-cure PSA ink is that the final tack level can be finely tuned to the customer's adhesion requirements by adjusting the final cure dose. For repositioning of the printed sample on the metal mold, a higher final dose can be used to reduce the initial level of adhesion. For applications requiring the highest bond of AR-PSA to the metal, a lower final dose can be used to retain a higher adhesion level during acid etching.

For storage of printed and cured articles, Si-treated polyethylene (PE) sheets were used to cover the prints. The treated surface of PE allows for traceless removal of the PE-sheet from the printed image before application of AR-PSA to a mold (figure 7). This construction (after removal of slip-sheet) being pressed upon highly polished metal surface (instrumental steel, stainless steel, aluminum alloys) adheres well to the metal mold. Then the polyester backing is separated from the PVA membrane and water is misted over the membrane, which allows for clean removal of the PVA from the AR-PSA.

We have also found that using smaller doses of radiation upon film preparation allowed for AR-PSA to be post-exposed (UV) after its application to the mold. Etching tests had shown increased bonding of AR-PSA to the metal allowing for very deep etching.

Removal of AR-PSA from the metal surface after acid etching is done by rinsing with polar solvents as acetone or ethyl acetate or simply by sandblasting.

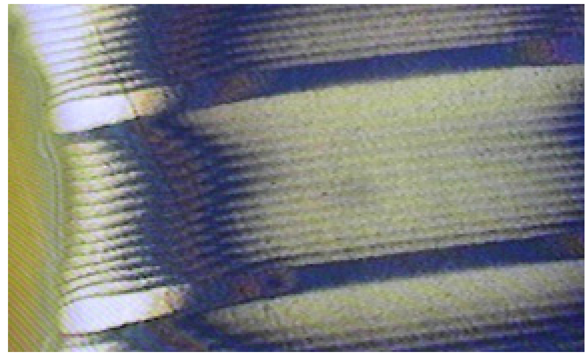

Figure 6*. Printing Lines of a Typical 800 DPI Image*

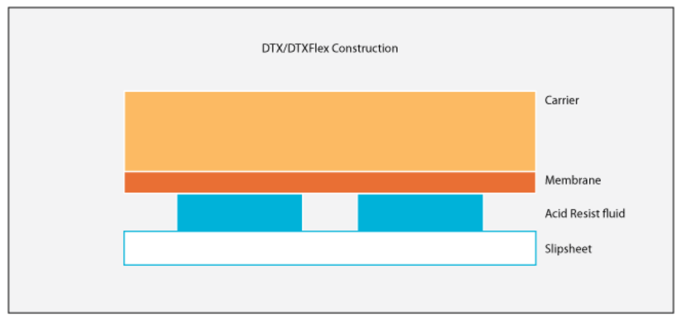

Figure 7*. Printed Substrate Construction*

Figure 8*. Printed Geometrical Pattern (800dpi) using Ikonics Ink and Substrate*

Transition to Production

Following the establishment of materials and settings that fulfilled the final product requirements, work was performed to begin the transition of the printing process to a production environment. Through discussions with iTi, we determined that the proper instrument for creating our product in a production environment would be iTi's Versatile JET (VJET) 5000 large format printer equipped with four (4) Dimatix SE-128 jetting assemblies. The VJET allows for higher print throughput and larger print sizes (up to 36"x48").

Figure 9*. Versatile JET 5000 (Courtesy of iTi)*

At this stage, it was necessary to determine the proper setup of the VJET for our application. The first step taken was mounting an additional jetting assembly on the XY MDS 2.0 (bringing the native resolution per print pass to 100 dpi) to evaluate any changes to print settings and final print quality relating to the move from a single printhead to a multiple printhead setup. The pinning and final cure doses were adjusted accordingly and the resulting print quality was improved over the 1-printhead setup. This was attributed to the reduced number of microsteps required thus reducing the ratio of pinning exposure for the first and last printing pass from 16:1 down to 8:1. The result is a more even distribution of pinning dose.

Utilizing these settings, sample prints were sent to customer sites for evaluation. Pinning and final cure doses were adjusted further to match customer requirements of adhesion and print quality. Initial feedback was favorable and small production runs were processed using the XY MDS 2.0 to ensure quality and product capabilities on larger scales.

Continued feedback from the customer base was encouraging so plans for the VJET prototype machine were started. Because all the printing parameters were established previously on the XY MDS 2.0, the necessary parameters for the VJET prototype were known. These parameters included: print resolution in the scan and step directions, desired print speed, fluid temperature, pinning dose, and firing pulse requirements, among others. As mentioned previously, the VJET plans called for four (4) Dimatix SE-128 jetting assemblies, and it was decided that two (2) Excelerate PIN-100 LED heads (EXFO) would be used for pinning of the ink because of performance and ease of integration.

Conclusion

A versatile method for preparation of ink-jetted AR-PSA films for mold decoration has been developed. The method consist of printing ink-jettable UV-curable acid resistant pressure sensitive adhesive (UV-AR-PSA) on a specially formulated substrate (transfer membrane), curing the AR-PSA, applying it to the metal and removing the membrane followed by etching metal in acid bath. Required level of adhesion of AR-PSA to the metal is adjusted by varying the dose of UV radiation during pinning and post exposure of printed AR-PSA.

Acknowledgements

The authors would like to express their appreciation to the employees of iTi Corporation that assisted in choosing the right strategies during the project development process, especially to Dr. Ross Mills and Mr. Toshifumi Komatsu.

Author Biography

Dr. Gybin is Senior Research Scientist with Ikonics Corporation. He received his MS in chemistry from Chernovtsy State University in 1975 and Ph.D. in organic chemistry from Zelinsky Institute for Organic Chemistry (Moscow, Russia) in 1979. His subsequent research was in the area of fine organic synthesis and reaction mechanism investigation (Zelinsky institute, Soviet Academy of Science). He joined University of Minnesota as a research scientist in 1990 and established a research project with Chromaline Corp. (now known as Ikonics Corp.) developing synthetic pathways to water-soluble photopolymers for screen printing industry. His research interests are in the area of photo-polymeric materials and their practical applications.