Screen Printing PVC Film with UV Ink

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Abstract

The purpose of this study was to develop a process for screen printing flexible PVC film with UV-curing ink. PVC film may contain additives that can migrate to the surface and reduce ink adhesion. Various surface treatments and UV-curing ink additives were investigated. Initially, screen printing failed the quality standards of Pittsburgh Plastics Mfg. (PPM). For recently manufactured film, the study showed that poor ink adhesion was a result of incomplete cure. Penetration of UV radiation was impeded by the ink's high pigment loading. Dilution of the pigment with clear base enabled complete cure. Corona treatment of the film eliminated the need for surface wipes for recently manufactured/corona treated film.

Introduction

PPM is a contract manufacturer of products for medical, foot care, safety and other industrial markets. An important product for medical applications is gel pads for prevention, care and treatment of pressure sores. To make a gel pad, PPM first die cuts and then RF welds film or laminated fabric to make a bladder. Next, the bladder is filled with a cushioning-type polyurethane gel; alternate gel chemistries are hydrogel and silicone. Lastly, the pad is sealed and packaged. PPM has these capabilities, among others, at the primary manufacturing facility in Butler, PA.

PPM's customers differentiate their medical pad or other cushioning type product with gel, film or fabric of a particular tint, and/or with writing on the film. PPM is equipped to print various types of film with UV-curing screen printing inks. The inks have 100% solids and are considered environmentally friendly.

PVC is a type of film that is printed for medical applications, and PPM's manufacturing experienced some difficulty printing this type of film. Reject rates were higher with PVC film than with urethane film. This is partially due to additives in flexible PVC film that tend to bloom to the surface. The purpose of this study was to reduce reject rates and improve print quality.

Materials

PPM maintains confidentially of trade names of materials, such as inks and films, specified by customers. The UV-curing ink was a urethane acrylate blend, and was designed for soft vinyls. Solids level was 100% (VOC's <0.5%). PPM's custom colors (opaque pastels) are multi-pigment inks.

The PVC film is biocompatible for skin contact. The film's Shore hardness is 76A, thickness is 15 mil and specific gravity is 1.19 g/cm^3.

Two solutions were used for surface treatments. One was a 70/30 blend of isopropyl alcohol (99%) and 3M™ Prep Solvent-70; the other was butyl cellosolve (2-butoxyethanol, 99%).

Methods

Adhesion of ink to film substrate was measured by the cross hatch tape test. Briefly, the cured ink is scored in a grid type pattern with a carton cutter blade. 3M #600 Scotch® tape is applied across the cuts, and then further pressure is exerted by running the back of the cutter blade over the taped area. After 30 seconds, the tape is removed at a near 180 º angle at a rapid and uniform rate.

PPM's standard for this test is based on two aspects of area of ink removed by the tape. One is the overall area of ink removed and the other is the highest proportion removed from any single letter. Print adhesion is acceptable if less than 5% of the overall area and 5 % of any single letter is removed by the tape.

EIT's UVICURE® Plus II radiometer was used to measure UV lamp power and UV total energy (a function of power over time).

Results

The purpose of this study was to develop a process for printing PVC film with a lower reject rate. To begin, a UV-curing ink that works well with soft vinyls was selected (see Materials). This ink was modified with 10% (w/w) of a vinyl adhesion modifier that combines a reactive surfactant with an amine initiator. The surfactant serves as a wetting agent and the amine promotes adhesion and increases the rate of cure. Additives migrate to the surface gradually, so experiments were performed with two lots of film. Film age from the date of manufacture was one month for one lot and five months for the other. Lamp power for PPM's UV conveyor curing system was 423 mW/cm^2 and total energy was 202 mJ/cm^2. Lamp power and energy were kept consistent for all experiments. Printing performance with various surface treatments is shown in Table 1 (located on the last page). Experiments were performed in triplicate with production equipment; the numbers represent an average.

Film surface was wiped with either Prep solution or butyl cellosolve (to remove additives on the surface). Also, film was heated at 160 ºF for 12 minutes (to vaporize additives on the surface). According to PPM's criteria for ink adhesion (see Methods), none of the print samples from Table 1 qualified. The best sample was with film aged one month and treated with heat; however, heating shrank the film by 5%.

Next, the level of vinyl adhesion modifier was doubled from 10 to 20%, and the tape test showed an increase in adhesion. On the other hand, the samples performed poorly with a fingernail scratch test. The modifier contains a reactive surfactant, and there is a limit to the amount of surfactant that can react with the ink. Unreacted surfactant lays on the surface of the ink, and interferes with adhesion of Scotch® tape to the ink. So for this experiment, the cross hatch tape test falsely indicated better adhesion.

Since all the samples in the first experiment failed to meet PPM's criteria for print adhesion, the next experiment focused on additives for the UV-curing ink. In addition to vinyl adhesion modifier and a control without additive, two other additives were evaluated. Cure promoter is a blend of photoinitiators that increases the rate of cure and surface hardness. Also tried was the non-pigmented base of the opaque UV-curing ink. The purpose of the clear base is to dilute the opaque pigment in order to enhance penetration of the UV energy through the ink.

Surface treatments such as multiple wipes with a solution are labor intensive, so none of the surface treatments from the first experiment was performed. However, the PVC film was corona treated during its manufacture to raise surface energy (dyne level). The efficacy of corona treatment gradually decreases, so all experiments were performed within two weeks of the film's manufacture date.

Table 2 shows that the level of ink adhesion with cure promoter was less than the control, and with vinyl adhesion modifier was more than the control. However, ink modified with clear base was the only sample that met PPM's criteria for ink adhesion; in fact, overall area and single letter proportion of ink removed by the tape test were both 0%.

Besides diluting the ink's pigment, another way to achieve more complete cure is increasing the exposure time to UV radiation by slowing the conveyor system through the UV tunnel. One disadvantage of this approach is longer manufacturing times. Another disadvantage is film shrinkage due to higher temperatures.

The last part of the study repeated the initial experiment except with the UV-curing ink modified with 10% non-pigmented base (in place of vinyl adhesion modifier). Unlike the original experiment, the film was corona treated (on the date of manufacture). The purpose of this experiment was to try to extend the time window for printing vinyl film. Lamp power for PPM's UV conveyor curing system was 427 mW/cm^2 and total energy was 202 mJ/cm^2. Table 3 shows that the time window for printing was extended to a month by wipes with either Prep solution or butyl cellosolve.

Discussion

The above experiments show that modification of the opaque ink with the ink's clear base dramatically helped adhesion. Cure of the ink occurs by polymerization of monomers in the ink by photo-initiated radical polymerization. A photoinitiator decomposes into two radicals upon exposure to UV light. The radicals initiate the free radical polymerization of monomers, and the ink cures.

Pigments in the ink selectively absorb visible light, resulting in the perception of colors. These same pigments also selectively absorb UV light. Therefore pigments can interfere with UV light impacting photoinitiators, and incomplete cure results. Besides pigment loading, other factors influencing UV light penetration through the ink are pigment type and number of pigments. Generally the amount of UV radiation absorbed increases as the number of pigments increases. Print quality (ink cure/adhesion) is improved by formulation of UV inks with pigments that do not highly absorb in the UV range.

Cure promoter is recommended by the supplier of the UV-curing ink to increase the rate of cure and surface hardness. However, Table 2 shows that this additive did not help cure/adhesion. Cure promoter was tried with a single white pigment ink, and the level of cure was improved. Pigment loading for this single pigment ink was slightly higher than for PPM's opaque, pastel multi-pigment inks. This supports that pigment type and number of pigments influence ability of UV light to penetrate ink, as well as pigment loading.

Experimental results indicated that surface wipes were less effective over time. Flexible PVC film is made using a variety of additives that migrate at different rates. Therefore, additive quantity and variety change with time. Some additives may be more difficult to remove by surface wipes with solvent.

Corona treated PVC film was successfully printed without any surface wipes if printing occurred in less than a month of the date of film manufacture/corona treatment. This is beneficial for three reasons. First, the process of film surface wipes is tedious labor. Second, the cost of manufacturing parts is reduced. Third, air quality is improved by avoiding the use of solvents.

Conclusions

One cause of poor UV-curing ink adhesion to flexible PVC film is migration of additives to the film's surface. This study showed that incomplete cure of the ink may also cause screen printing to fail adhesion testing. Inks with high pigment loading impede penetration of UV radiation.

Solutions recommended by this study for reducing reject rates are simple to implement. One is dilution of the pigment with clear base and the other is corona treatment of the film by the film manufacturer. Benefits are improved print quality and lower cost due to less rejects. Elimination of tedious surface wipes for film less than two weeks also lowers cost.

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Table 1. Printing Performance with Various Surface Treatments

	PVC Film, aged 1 month		PVC Film, aged 5 months	
Surface treatment	Overall area, % [1]	Single letter, % [2]	Overall area, % [1]	Single letter, % [2]
None (Control)	95	100	99	100
Prep Solution [3]	90	100	95	100
Butyl Cellosolve [4]	11	95	95	100
Heat, 160 ºF [5]	3	75	99	100

[1] Overall area of ink removed by cross hatch tape test
[2] Highest proportion of any single letter removed
[3] Prep solution was 70:30 blend of isopropyl alcohol and 3M Prep Solvent 70.
[4] Film was wiped 5x in each of two directions
[5] Film was heated in an oven at 160 ºF for 12 minutes

Table 2. Effect of UV Cure Ink Additives

	Additive Level Wt. %	UV Power, UV Total Energy	Corona Treated PVC Film	
Additive Type			Overall area, % [1]	Single letter, % [2]
None (Control)	--	432 mW, 199 mJ	60	97
Vinyl adhesion modifier	10	439 mW, 200 mJ	8	95
Cure promoter [3]	10	434 mw, 200 mJ	100	100
Clear ink base [4]	10	444 mW, 199 mJ	0	0

[1] Overall area of ink removed by cross hatch tape test
[2] Highest proportion of any single letter removed
[3] Blend of photoinitiators
[4] Non-pigmented base of UV-curing ink

Table 3. Effect of Surface Treatments

	PVC Film, aged 1 month		PVC Film, aged 5 months	
Surface treatment	Overall area, % [1]	Single letter, % [2]	Overall area, % [1]	Single letter, % [2]
None (Control)	3	100	95	100
Prep Solution [3]	0	0	4	90
Butyl Cellosolve [4]	0	0	15	95
Heat, 160 ºF [5]	1	75	95	100

[1] Overall area of ink removed by cross hatch tape test
[2] Highest proportion of any single letter removed
[3] Prep solution was 70:30 blend of isopropyl alcohol and 3M Prep Solvent 70.
[4] Film was wiped 5x in each of two directions
[5] Film was heated in an oven at 160 ºF for 12 minutes