UV Flexographic Inks for Shrink Sleeve Applications

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Abstract

Ink blocking, inadequate ink resistance, high retained solvents, erratic adhesion, and make-ready waste can reduce productivity during conversion of PVC, PET-G and OPS films for shrink sleeve applications. When these problems arise, reformulation of the inks (typically solvent- and water-based) and/or modification of application conditions must be completed to try to address these productivity issues. Since energy-cured (EC) inks have no/low volatiles and high chemical resistance, it may be possible to formulate an EC ink system that will significantly reduce or eliminate the above-mentioned problems.

Currently, EC inks are used in some shrink sleeve applications where specific properties are required. However, in order to encourage widespread use of EC inks, improvements in flexibility and cure speed on heat sensitive shrink films must be obtained. The oligomers, monomers, photoinitiators, and additives must be carefully selected to meet processing and end-use requirements, and to maintain sufficient cure speeds in order to minimize substrate heat exposure and maximize print speeds. There are many factors that influence substrate heat exposure, ink cure rate, and print speed. This paper focuses on the influence of raw material selection on ink performance in shrink sleeve applications.

Introduction

Shrink sleeve conversion has increased significantly in North America over the past five to seven years expanding in use from decorating tobacco and tea-based beverage containers to use on packaging for milk, juice, yogurt, pasta sauce, mayonnaise, wine, beer and dry goods packaging. Unlike conventional wraparound and pressure-sensitive labels, shrink sleeves allow full coverage decoration, which provides an increased area for product information, plus higher gloss with increased ink protection since the sleeves are usually reverse-printed. At this time, the majority of shrink sleeve printing is completed with solventborne inks on rotogravure presses in order to achieve high speed conversion of the three main high-shrink films, increased opacity of the back-up white ink, and high print quality. Concurrently, the use of flexographic printing on shrink sleeves, with both solventborne and waterborne inks, is increasing due to shorter print jobs, demands for lower unit costs, requests for lower retained solvents (with waterborne inks), and to the entry of flexo converters into the market.

Notwithstanding the dominance of rotogravure with solvent-based inks, problems such as scumming, premature film shrink caused by the heat required for ink drying, and ink transfer/blocking continue to adversely affect production. With the solvent- and water-based inks used for flexo printing, other problems such as erratic ink adhesion, reduced print quality, high retained solvents and poor ink resolubility are experienced.

Given the nature and performance of existing energy-cured inks, it is expected that the use of UV flexographic inks for printing of shrink sleeves will likely provide a good combination of press and end-use performance. Table 1 lists the main pros and cons of the inks used for shrink sleeve printing. UV inks are solvent-free and provide good print quality, excellent ink stability and high resistance properties. UV inks will not exhibit print blocking/transfer if properly cured, and since heat is not applied to remove volatile material, premature film shrink should not be a problem. Also, consistent adhesion on the three main high-shrink films should be possible, provided the optimum combination of raw materials is identified. This paper describes the experimental work and results in the search for the optimum formulation.

It must be noted that this study focused on flexo applications because there are other challenges to be considered with UV gravure inks, such as obtaining suitable print viscosity while maintaining reactivity and product resistance.

Table 1. Main attributes of flexo and gravure inks used for shrink sleeve conversion

	PROS	CONS
Solvent-based inks	• High press speeds • Good print quality	• Retained volatile materials • Erratic adhesion • Ink stability on press
Water-based inks	• Ink cost • Low retained solvents	• Chemical resistance • Drying requirements • Crosslinkers sometimes needed
Energy-cured inks	• Low/No volatiles • Good print quality • Good chemical resistance • Low make-ready waste • Ink stability on press	• Ink cost • Reactivity/press speed

Experimental Procedures

Raw material screening involved testing acrylated oligomers for basic properties of reactivity, adhesion, scratch and wrinkle. The best acrylated oligomer was then tested with selected monomers to identify possible advantages from monomer selection. The most encouraging oligomer/monomer combination was then evaluated with various photoinitiator combinations to optimize reactivity (press speed) while maintaining desired performance. A low level (5%) of cyan pigment dispersion was included in the test formulations to allow observation.

Evaluations were initially completed using bench testing with typical laboratory equipment on Bonset's SRHL PVC shrink film and Bonset's Bonpet 5A PETG shrink film. Reactivity, adhesion, wrinkle and clarity were tested on both substrates and relative performance ratings were assigned. Starting formulations identified by bench evaluation were subsequently tested on an Aquaflex brand two-unit printing press using Bonset's SRHL PVC shrink film that was corona-treated.

Bench evaluations were completed using a K-Proofer brand pilot press fitted with a flexo print head and a 150 lines/inch plate screened to 100%, 60% and 40%. The 100% print area was used for testing. All bench-produced prints were cured in a Fusion brand Aetek UV unit set at 175 fpm using one 400W/inch "H" Mercury lamp in an air environment. Exposure was 118 mJ/cm^2.

Press evaluation involved blue and white inks, reverse printed at 200, 300 and 400 feet per minute (fpm). The blue ink was printed with a banded anilox roll with 440 line/3.0 BCM; 360 line/4.0 BCM; 300 line/6.0 BCM and 250 line/7.2 BCM bands. The white ink was printed with a 360 line anilox at 4.8 BCM. The printing press is equipped with Fusion's Aetek UltraPak 400W/inch lamps, one at each station.

Reactivity was tested by checking for print mar or damage using a wooden tongue depressor with a mar-free surface indicating good reactivity. Adhesion was tested after cure using 3M's 610 Scotch Tape on an unscored print surface. Relative performance ratings were assigned.

The wrinkle test involved holding a print with thumbs and forefingers and with hands approximately one-two inches apart. The print was rotated in a clockwise direction for 20 cycles and then in a counterclockwise direction for 20 cycles. The print was observed for ink removal and/or print damage, and a relative performance rating was assigned.

Clarity of the print was visually inspected. This test involved cutting a cured print into two pieces and exposing one piece to shrink conditions. After shrinking, the two pieces are compared against each other to observe for changes in ink clarity or haze, and a relative rating was assigned.

All prints were tested before and after shrinking to check the effect of substrate shrink on adhesion, wrinkle and clarity. The prints were placed in a 90-95°C oven for six seconds to obtain film shrink.

In addition to the tests mentioned above, the press prints produced at 400 fpm were tested for water resistance, ink/film block resistance and bottle-block via the following methods.

Water resistance was tested by soaking a print in tap water at 25°C for one hour and then wrinkling the print under running tap water at 25°C. The print was then visually inspected for ink damage or removal, and a relative rating was assigned.

Ink to film block resistance was checked with prints placed in a Specac brand hydraulic block tester at 10 tons pressure for 24 hours at 25°C. After removal from the block tester, the ink and film surfaces were visually inspected for ink damage and/or transfer, and a relative rating was assigned.

The bottle-block test involved attaching the print, using 3M's 610 Scotch Tape, to a glass bottle with the ink side in direct contact with the glass. The bottle was then placed in water at 90-95°C for 12 seconds. The bottle was removed from the hot water and allowed to cool. After cooling, the print was removed from the bottle and observed for ink damage and/or transfer to the glass. A relative rating was assigned for the level of ink damage and/or transfer.

Color density of the blue ink was measured with X-Rite's 500 Series Spectrodensitometer. Opacity of the white ink was also assessed with the spectrodensitometer by comparing contrast over the black area of BYK Gardner's Opacity Chart AG-5305/2813.

Results and Discussion

Oligomers were blended with other ingredients to produce a starting formula (Table 2). This starting formula was printed with a K-Proofer brand pilot press on PVC and PETG shrink films and tested for reactivity, adhesion, wrinkle and clarity. The results, as listed in Table 3, were the same on both films.

Table 2

Oligomer	50
Tripropylene Glycol Diacrylate	37
Cyan dispersion	5
Liquid photoinitiator	8
	100

Table 3. Oligomer evaluation – using starting formula in Table 2

				Pre-Shrink				Post-Shrink		
				Adhesion	Wrinkle	Clarity		Adhesion	Wrinkle	Clarity
ID	Acrylate Type	Relative Functionality	Reactivity							
100	Low Viscosity Epoxy	Low	1	1	1	4		1	1	4
101	Rubber Modified Epoxy	Low	1	5	5	4		5	5	4
102	Fatty Acid Modified Epoxy	Low	4	4	4	4		4	4	1
103	Amine Modified Epoxy	Low	5	3	2	3		3	2	3
104	Bisphenol-A Epoxy	Low	3	3	3	3		2	3	2
105	Aromatic Urethane	Mid	5	5	5	5		5	5	2
106	Aromatic Urethane	Low	1	3	1	4		3	1	3
107	Aromatic Urethane	High	5	4	3	4		4	3	4
108	Aliphatic Urethane	Low	5	5	5	5		3	3	5
109	Aliphatic Urethane	Low	2	4	4	5		4	4	3
110	Aliphatic Urethane	Mid	5	5	5	5		5	5	5
111	Aliphatic Urethane	High	5	4	2	3		3	2	3
112	Polyester	Mid	1	5	5	5		5	5	3
113	Polyester	Mid	5	5	5	5		5	5	3
114	Polyester	High	5	5	5	5		5	5	3

Results for reactivity, adhesion, wrinkle and clarity were assessed on a scale of 1-5 with 1=poor and 5=excellent

The evaluation of the range of oligomers identified differences in reactivity, adhesion, wrinkle and clarity. Samples #105, #110, #113 and #114 exhibited encouraging performance results. Oligomer Sample #110 (aliphatic urethane) was selected for further work because this oligomer provided the best combination of application performance and clarity after shrink. This combination of properties probably results from the inherent adhesion and flexibility of the urethane backbone, and the reactivity and crosslink density due to functionality.

Maintaining print clarity after shrink will enhance the perception of the package during its shelf-life. Also, in some cases, coatings are applied on the outer surface and/or clear areas of the package for effects such as slip, a matte finish or tactile feel. Therefore, clarity of the resins used in these coatings must be predictable and consistent.

Blends were prepared with the selected oligomer and various monomers using the formulas in Table 4 below. These blends were printed with the K-Proofer brand pilot press on shrink PVC, cured and tested for reactivity, adhesion, wrinkle and clarity. Results of these tests are listed in Table 5.

Table 4. Monomer evaluation

Description	Sample 200	Sample 201	Sample 202	Sample 203	Sample 204	Sample 205
Oligomer # 110	50	50	50	50	50	50
Isobornyl Acrylate (IBOA)	37	---	---	---	---	---
Octyl/Decyl Acrylate (ODA)	---	37	---	---	---	---
Tripropylene Glycol Diacrylate (TRPGDA)	---	---	37	---	---	---
1,6-Hexanediol Diacrylate (HDODA)	---	---	---	37	---	---
Propoxylated Glycerol Triacrylate (GPTA)	---	---	---	---	37	---
Trimethylolpropane Ethoxy Triacrylate (TMPEOTA)	---	---	---	---	---	37
Cyan dispersion	5	5	5	5	5	5
Liquid Photoinitiator	8	8	8	8	8	8
	100	100	100	100	100	100

Table 5. Results from monomer evaluation – using formulations in Table 4

			Pre-Shrink				Post-Shrink		
			Adhesion	Wrinkle	Clarity		Adhesion	Wrinkle	Clarity
ID	Monomer	Reactivity							
200	Isobornyl Acrylate	2	2	3	3		2	3	3
201	Octyl/Decyl Acrylate	2	3	3	3		3	3	3
202	Tripropylene Glycol Diacrylate	4	5	4	5		5	4	5
203	1,6-Hexanediol Diacrylate	4	5	4	4		5	4	4
204	Propoxylated Glycerol Triacrylate	4	3	3	3		2	3	2
205	Trimethylolpropane Ethoxy Triacrylate	3	4	3	5		4	3	5

Results for reactivity, adhesion, wrinkle and clarity were assessed on a scale of 1-5 with 1=poor and 5=excellent

Based on the results (Table 5) from the monomer evaluation, TRPGDA was chosen as the best monomer. TRPGDA is commonly used for viscosity reduction in applications requiring a combination of flexibility, moisture resistance and reactivity. HDODA also offered encouraging results, but was

inferior for wrinkle and clarity. While the wrinkle performance with HDODA might be improved with the use of additives, the reduced clarity is a disadvantage.

At this point, the best oligomer and monomer combination (Sample #110 aliphatic urethane and TRPGDA) were formulated into full-strength cyan and white inks. These inks were then evaluated with various photoinitiator packages to check reactivity and optimize press speeds.

Table 6. Evaluation of cyan and white inks with various photoinitiators

	Cyan							White				
Sample ID	# 301	# 302	# 303	# 304	# 305	# 306		# 350	# 351	# 352	# 353	# 354
Pigment dispersion	35.0	35.0	35.0	35.0	35.0	35.0		---	---	---	---	---
White pigment	---	---	---	---	---	---		40.0	40.0	40.0	40.0	40.0
Oligomer # 110	35.0	35.0	35.0	35.0	35.0	35.0		25.0	25.0	25.0	25.0	20.0
TRPGDA	22.0	25.0	20.0	20.0	20.0	20.0		25.0	25.0	25.0	25.0	20.0
Liquid Photoinitiator Blend 1	8.0	---	---	---	---	---		10.0	---	---	---	---
Liquid Photoinitiator Blend 1	---	5.0	---	---	---	---		---	---	---	---	---
Liquid Photoinitiator Blend 1	---	---	10.0	---	---	---		---	---	---	---	---
Liquid Photoinitiator Blend 1	---	---	---	7.0	---	---		---	---	---	---	---
2-benzyl-2-N,N-(dimethylamino)-1-(4-morpholinophenyl]-1-butanone	---	---	---	---	10.0	---		---	---	---	---	---
Acrylated Amine	---	---	---	3.0	---	---		---	---	---	---	10.0
2-Methyl-1-[4-(methylthio)phenyl]-2-morpholino-propan-1-one	---	---	---	---	---	9.6		---	---	---	---	---
Isopropyl thioxanthone	---	---	---	---	---	0.4		---	---	---	---	---
Liquid Photoinitiator Blend 2	---	---	---	---	---	---		---	10.0	---	---	---
2,4,6-Trimethylbenzoyl diphenyl phosphine oxide	---	---	---	---	---	---		---	---	4.0	6.0	6.0
1-Hydroxy-cyclohexylphenyl-ketone	---	---	---	---	---	---		---	---	3.0	4.0	4.0
Bis(2,4,6-trimethylbenzoyl)-phenylphosphineoxide	---	---	---	---	---	---		---	---	3.0	---	---
	100.0	100.0	100.0	100.0	100.0	100.0		100.0	100.0	100.0	100.0	100.0

As anticipated, the various photoinitator packages gave different cure rates as tested by print resistance to mar. In the cyan ink, Formula #306 provided the highest reactivity and no signs of ink mar. In the white ink, Liquid Photoinitiator Blends 1 and 2 (Formulas #350 and #351) provided the best reactivity while maintaining adhesion to the substrate. However, Liquid Photoinitiator Blend 2 (Formula #351) was selected to maximize the non-yellowing property of the white ink.

The next stage of testing involved press evaluation of the best starting point formulations for blue ink (Formula #306) and white ink (Formula #351). Press performance was good for both formulations, tested individually and in a reverse (blue/white) sequence. According to the press operator, “dot formation and image quality were very good with the digital flexographic plate” and clean-up was “quick and easy” with a commercially available, non-solvent/low VOC UV ink cleaner.

The density of the blue ink was between 1.4 on the 440 line/3.0 BCM anilox band and 1.8 on the 250 line/7.2 BCM anilox band. Opacity of the white ink was measured at 2.0. Both color density and opacity are as good as, or better, than measurements taken from samples of commercial prints produced with solvent-based and water-based inks.

Adhesion, wrinkle, clarity, water resistance, ink/film block resistance and bottle-block resistance were evaluated with the press prints, and there was no deterioration in performance after the prints were exposed to shrink conditions. These results were as good as or better than results obtained from testing of commercial prints produced with solvent-based and water-based inks. Results from testing of the press prints are listed in Table 7.

Table 7. Evaluation of press prints

	Pre-Shrink							Post-Shrink					
Print Area	Adhesion	Wrinkle	Clarity	Water Resistance	Ink/Film Block	Bottle Block		Adhesion	Wrinkle	Clarity	Water Resistance	Ink/Film Block	Bottle Block
Cyan	5	5	5	5	5	5		5	5	5	5	5	5
White	5	4	5	4	5	5		5	4	5	4	5	5
Cyan & White	5	5	5	4	5	5		5	5	5	4	5	5

Based on the acceptable performance of the cyan and white inks in bench and press evaluations, bench evaluations were completed with starting formulations for yellow, rubine and black inks. Commercially available yellow, rubine and black pigment dispersions were let-down into inks using Oligomer #110, TRPGDA and photoinitiator per Formula #306 in Table 6. The resultant inks were tested for adhesion, wrinkle, clarity, water resistance, ink/film block resistance and bottle-block resistance on PVC and PETG shrink films. The results with all three inks were good on both PVC and PETG shrink films.

Conclusions

The best raw materials and starting formulations identified during this project showed very good performance in UV flexographic inks printed on PVC shrink film at speeds up to 400 fpm on the Aquaflex brand printing press. While further work may be necessary to modify the starting point formulation to meet specific end-use requirements, it has been shown that it is possible to formulate energy-cured flexographic inks to meet application and end-use requirements for shrink sleeve packaging.

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