The Effects of Lamination on Image Quality and Light Stability of Display Media

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Abstract

*Large format ink jet prints are widely used for graphic arts, displays, posters, and signage applications. In order to protect display media and to extend the life of image when printed with aqueous based inks, laminating of the printed image is usually employed in the inkjet printing applications. However, lamination may impact image quality and color shift, as well as the color fading rates. The purpose of this experimental study is to examine the effects of lamination on image quality and light stability of display media. In this study, a digital four-color test chart was designed and printed onto commercial available display media (adhesive vinyl and display film) by using dye and pigment ink systems. Printed display media were laminated with pressure-sensitive laminating films. Print quality of display media was evaluated in terms of optical density and color gamut. A Q-Sun Xenon test chamber was employed to examine the light fastness properties of printed display media. The color fading rates of these prints were examined according to color difference (ΔE^*_{ab}) in L*a*b* color space. The study results provide us with both visual and numerical comparisons among various media/ink/over-laminate combinations.*

Introduction

Excellent print quality, together with protecting and maintaining the longevity of a print are essential to print service providers and their customers[1]. The selection of inks and media determines the image quality of prints, as well as the degradation to the color. Dye-based inkjet prints have a tendency toward light fading due to the fact that dyes are present in monomolecular state and have a very large surface area, which provides an efficient light absorption and results in quick degradation of dye molecules. However, dye-based ink jet print is well known for its high color density and sharp image. Pigment-based inkjet prints show improved light fastness, but still not comparable to dye-based inks in terms of print quality[1, 2, 3, 4]. In order to protect display media and to extend the life of image when printed with aqueous based inks, laminating of the printed image is usually employed in the inkjet printing applications. Lamination is one of finishing methods, which protects a printed image, allows the achievement of the desired gloss level, and transforms it into a functional and durable graphic display[5]. Lamination is usually done in a roller laminator and the laminates can be liquid or films. The film laminates can be pressure sensitive/ cold (no heat is needed), heat-activated (little heat is needed) or thermal/hot (heat is required). Liquid laminates can be applied to a range of applications, from high-end fine art reproductions to vehicle wraps and banners[5, 6]. In this study, printed display media samples were laminated with pressure-sensitive PVC films.

This study included three variables, lamination, display media, and ink system. Comparing samples with various media/ink/over-laminate combinations tells us how sensitive these display media samples are to color reproduction and light fading.

Experimental

In order to examine the effects of lamination on image quality and light stability of display media, sets of samples were prepared by using commercially available inkjet printers and the recommended display media. A test target consisting of 288 color patches evenly sampled in the CIELAB color space was employed for this study. This color target was formatted as a TIFF format and printed on two display media (a polypropylene display film and an adhesive vinyl). The physical properties of display media are shown in Table 1. Two ink-jet printers with major ink-jet ink technologies were investigated in this work: an HP Designjet 800 printer with dye-based inks and an Epson Stylus Pro 9600 printer with UltraChrome pigmented inks. Display media were printed using recommended settings on each printer. Half of printed display media were dried for at least 24 hours and then laminated with pressure-sensitive laminating film (luster flexible calendered PVC film). The samples were laminated on the image side.

Table 1: The physical properties of display media

	Polypropylene	Adhesive Vinyl
Weight	130 g/m^2	450 g/m^2
Opacity	> 90%	> 95%
Color	L* > 94, a* =3.8, b*= -9	L* =89~92, a*=4 ± 2, b*= -12 ± 3
Whiteness	125 (CIE)	130 (CIE)

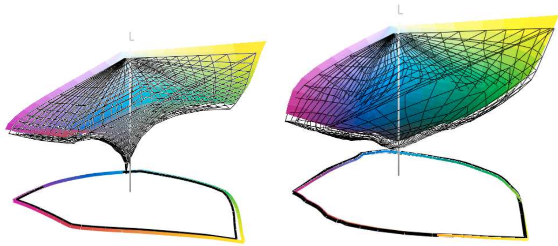
Light fastness tests were accomplished by exposing the laminated samples and non-laminated samples to artificial sunlight for 25, 50, 75, 100, 125, 150, 175 and 200 hours with a Q-Sun Xenon lamp equipped with a Daylight-Q filter. Test chamber was used at irradiance settings of 0.68 $W/m^2/nm$ at 340nm (noon summer sunlight) and 63°C for black standard temperature (BST). The color values in CIE L*a*b* color space of each color patch were measured before, during and after exposure using the X-Rite i1iO spectrophotometer (D50/2° standard illuminant). Results of accelerated light fastness tests for the different printer/ink/substrate sets were interpreted in terms of change of color gamut volume and color difference (ΔE^*_{ab}).

Image Quality Analysis

Table 2 lists color-related attributes of polypropylene display film, including optical densities and color gamut. It shows that samples with laminated yielded higher optical densities and increased gamut volumes. However, the standard deviation (S. D.) values of the laminated samples were greater than those of the samples without laminated, which meant that applying lamination increased the color reproduction variability. Laminated samples with pigmented inks boosted optical densities about 17%, while laminated samples with dye-based inks increased the optical densities around 6-8%, with exception of black ink density. It is interesting to note that the gamut volume of samples printed with dye-based ink is much smaller than that of samples printed with pigmented ink (as shown in Figure 1). With the same print settings, dye-based ink produced less cyan ink density, resulting in a smaller gamut in the cyan and blue regions and a mushroom-shape color gamut. Figure 1 shows that sample with laminated (wireframe) did add color densities by shifting the whole gamut from higher L* values to lower L* values.

Table 2. Color-related attributes of polypropylene display film

	Dye Ink				Pigmented Ink			
	Non. Lam.		Lam.		Non. Lam.		Lam.	
	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.
Cyan (C)	1.29	0.00	1.40	0.00	1.40	0.00	1.64	0.05
Magenta (M)	1.20	0.00	1.28	0.04	1.20	0.00	1.41	0.03
Yellow (Y)	1.00	0.00	1.00	0.00	1.00	0.00	1.10	0.00
Black (K)	1.50	0.00	1.79	0.03	1.36	0.05	1.58	0.05
Gamut Volume	242,043	2,449	247,348	2,993	438,906	3,972	454,083	9,090



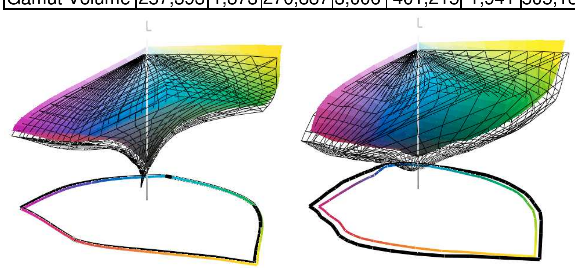
(a) Dye ink (b) Pigmented ink

***Figure 1**. Color gamut comparison of polypropylene display film: non-laminated sample (true color)* vs. laminated sample (wireframe).

Table 3 shows color-related attributes of adhesive vinyl. Again, samples with laminated yielded higher optical densities and increased gamut volumes, but increased the color reproduction variability. For the adhesive vinyl, laminated samples with pigmented inks increased optical densities about 20-32%, while laminated samples with dye-based inks increased the optical densities around 8-16%, with exception of black ink density (36%). The gamut volume of samples printed with dye-based ink is smaller than that of samples printed with pigmented ink (as shown in Figure 2). Adhesive vinyl with dye-based ink produced less cyan ink density, resulting in a smaller gamut in the cyan and blue areas. It was observed that the color gamut of adhesive vinyl is slightly larger than that of polypropylene display film in terms of gamut volume. The pigmented ink/over-laminate combination did expand the gamut volume and yield better color reproduction.

Table 3. Color-related attributes of adhesive vinyl

	Dye Ink				Pigmented Ink			
	Non. Lam.		Lam.		Non. Lam.		Lam.	
	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.
Cyan (C)	1.20	0.00	1.40	0.00	1.40	0.00	1.80	0.00
Magenta (M)	1.20	0.00	1.30	0.00	1.30	0.00	1.62	0.04
Yellow (Y)	1.00	0.00	1.10	0.00	1.00	0.00	1.20	0.00
Black (K)	1.50	0.00	2.04	0.05	1.38	0.04	1.82	0.04
Gamut Volume	257,393	1,873	270,887	3,006	401,215	1,941	505,188	8,025



(a) Dye ink (b) Pigmented ink

***Figure 2**. Color gamut comparison of adhesive vinyl: non-laminated sample (true color)* vs. laminated sample (wireframe).

Lamination did impact image quality and color shift in some ways. The primary and secondary color shift with lamination is shown in Figure 3. It shows that the adhesive vinyl/pigmented ink/over-laminate combination (black line) has significant color shift, compared to other combinations. Overall, the primary ink cyan did not change a lot, while secondary colors have noticeable changes. Samples with laminated tended to produce more saturated colors.

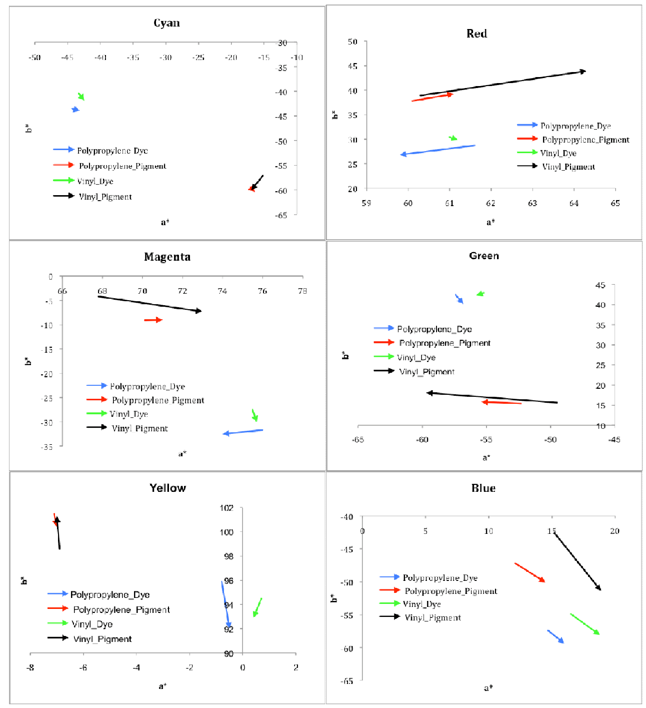


***Figure 3**. Color shift with lamination.*

Table 4 summarizes primary and secondary color changes with and without lamination, based on color differences- the Lightness/darkness differences (ΔL*), the chroma differences (ΔC*), and color differences (ΔE^*_{ab}). It shows that ΔL* contributes more ΔE^*_{ab} than ΔC*, regardless which media/ink/over-laminate combination was used. It also shows that black color shifts the most. Lamination adds density in the black color, as well as a little bit color cast to the samples.

Table 4. Summary of primary and secondary color changes with and without lamination.

Media	Ink Type	Color	Non. Lam.			Lam.			ΔL*	ΔC*	ΔE^*_{ab}
			L*	a*	b*	L*	a*	b*			
Polypro-pylene	Dye	C	62.2	-44.3	-43.5	58.5	-43.1	-43.9	3.7	1.3	3.9
		M	49.2	76.0	-31.7	46.0	74.0	-32.5	3.2	2.2	3.9
		Y	92.7	-0.8	95.9	88.4	-0.5	92.0	4.3	3.9	5.8
		R	49.9	61.6	28.7	46.5	59.8	26.8	3.4	2.6	4.3
		G	64.6	-57.4	42.4	60.7	-56.8	40.1	3.9	2.4	4.6
		B	33.7	14.7	-57.4	29.9	16.0	-59.4	3.8	2.4	4.5
		K	20.6	0.5	0.6	13.6	1.4	-3.3	7.0	4.0	8.1
	Pigment	C	47.0	-17.1	-59.5	43.0	-16.4	-60.4	4.0	1.1	4.2
		M	49.0	70.1	-9.1	44.6	71.0	-9.0	4.4	0.9	4.5
		Y	94.5	-7.1	101.5	90.1	-7.0	100.4	4.4	1.1	4.5
		R	52.8	60.1	37.8	48.5	61.1	39.2	4.3	1.7	4.6
		G	43.1	-52.3	15.4	38.8	-55.4	15.8	4.3	3.1	5.3
		B	28.5	12.1	-47.2	23.1	14.5	-50.1	5.4	3.8	6.6
		K	25.2	-0.3	-0.5	18.5	0.3	-2.8	6.7	2.4	7.1

Table 4 continued.

Media	Ink Type	Color	Non. Lam. L*	Non. Lam. a*	Non. Lam. b*	Lam. L*	Lam. a*	Lam. b*	ΔL*	ΔC*	ΔE^*_{ab}
Adhesive Vinyl	Dye	C	61.0	-43.3	-40.4	57.6	-42.4	-41.9	3.4	1.7	3.8
		M	49.5	75.5	-27.6	45.9	75.7	-30.1	3.6	2.5	4.4
		Y	90.3	0.7	94.5	86.2	0.4	92.9	4.1	1.6	4.4
		R	50.9	61.0	30.4	47.0	61.2	29.8	3.9	0.6	4.0
		G	63.1	-55.2	42.9	59.5	-55.8	42.3	3.6	0.8	3.7
		B	34.7	16.5	-54.9	30.5	18.8	-58.1	4.2	3.9	5.8
		K	19.5	0.4	1.6	8.3	2.0	-4.3	11.2	6.1	12.8
	Pigment	C	44.9	-15.2	-57.1	40.3	-17.0	-60.1	4.6	3.5	5.8
		M	47.8	67.8	-4.2	41.9	73.0	-7.3	5.9	6.1	8.5
		Y	92.7	-6.9	98.6	88.3	-7.0	101.3	4.4	2.7	5.2
		R	51.0	60.3	38.9	45.6	64.3	43.9	5.4	6.4	8.4
		G	41.0	-49.5	15.6	35.1	-59.7	18.1	5.9	10.5	12.0
		B	27.4	15.2	-42.6	18.4	18.9	-51.4	9.0	9.5	13.1
		K	24.8	0.9	1.3	12.9	1.1	-2.9	11.9	4.2	12.6

Light Fastness Tests

Table 5 displays gamut volume results before and after light exposure. Before light exposure, the adhesive vinyl/pigmented ink/over-laminate combination produced the largest color gamut. After 200 hours exposure, the gamut volume of samples printed with dye-based ink dropped up to 95-99%, and the colors magenta and yellow were visually observed to fade almost completely. Laminated with PVC film did reduce the fading rate slightly, but not effective enough to protect samples from color fading. As expected, pigment-based inks provided better light fastness. At the end of exposure, the gamut volume of samples without laminated dropped about 15-38%. With laminated, the gamut volume of samples dropped only about 2-4%.

Table 5. Gamut volume results before and after exposure.

Display Media	Ink Type		Original	200 Hrs Exposure	Decrease [%] After 200Hrs Exposure
Polypropylene	Dye	Non. Lam.	242,043	2,716	98.9%
		Lam.	247,348	4,961	98.0%
	Pigment	Non. Lam.	438,906	273,707	37.6%
		Lam.	454,083	443,376	2.4%
Adhesive Vinyl	Dye	Non. Lam.	257,393	5,512	97.9%
		Lam.	270,887	11,615	95.7%
	Pigment	Non. Lam.	401,215	336,698	15.7%
		Lam.	505,188	489,143	3.2%

Figure 4 plots ΔE^*_{ab} changes as a function of exposure. As shown in Figure 4, the adhesive vinyl/pigmented ink/over-laminate combination was the most stable, whereas the polypropylene display film/dye-based ink/without laminated combination was the least stable. At the end of exposure, the ΔE^*_{ab} values of samples printed with dye-based ink were over 25.

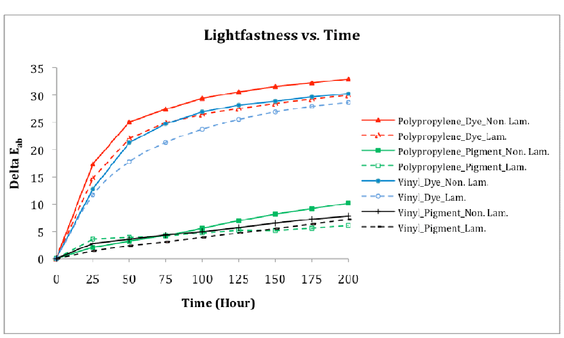


***Figure 4.** Color changes in display media after light exposure for 200 hours.*

Table 5 summarizes the color changes of primary and secondary colors before and after 200 hours exposure. Overall, samples with laminated did reduce the fading rate, even printed with dye-based inks. For the dye-based inks, magenta and yellow inks had poorer light fastness, while cyan ink had better fade resistance. It was also observed visually where magenta and yellow inks faded almost completely at the end of exposure. For the pigmented inks, samples without laminated tended to have poor light fastness with cyan ink, while samples with laminated had worse fade resistance with magenta ink.

Table 6. Summary of primary and secondary color changes before and after light exposure.

Media	Ink Type	Color	Before exposure L*	Before exposure a*	Before exposure b*	After 200 Hours exposure L*	After 200 Hours exposure a*	After 200 Hours exposure b*	ΔL*	ΔC*	ΔE^*_{ab}
Polypropylene	Dye	C	62.2	-44.3	-43.5	74.0	-32.3	-15.0	11.8	30.9	33.1
			58.5	-43.1	-43.9	64.5	-39.6	-19.9	6.0	24.3	25.0
		M	49.2	76.0	-31.7	97.1	1.3	1.5	47.9	81.7	94.7
			46.0	74.0	-32.5	90.0	4.9	3.7	44.0	78.0	89.6
		Y	92.7	-0.8	95.9	96.8	-4.1	23.2	4.1	72.8	72.9
			88.4	-0.5	92.0	92.6	-3.5	22.3	4.2	69.8	69.9
		R	49.9	61.6	28.7	95.8	0.5	10.9	45.9	63.6	78.5
			46.5	59.8	26.8	88.7	5.2	13.4	42.2	56.2	70.3
		G	64.6	-57.4	42.4	84.2	-22.2	5.2	19.6	51.2	54.8
			60.7	-56.8	40.1	74.6	-32.3	-0.7	13.9	47.6	49.6
		B	33.7	14.7	-57.4	72.5	-23.4	-11.5	38.8	59.7	71.2
			29.9	16.0	-59.4	60.7	-28.5	-17.5	30.8	61.1	68.4
	Pigment	C	47.0	-17.1	-59.5	48.9	-24.9	-47.1	1.9	14.6	14.8
			43.0	-16.4	-60.4	40.2	-18.9	-58.1	2.8	3.4	4.4
		M	49.0	70.1	-9.1	50.8	63.0	-4.5	1.8	8.5	8.6
			44.6	71.0	-9.0	43.2	70.1	-0.3	1.4	8.7	8.9
		Y	94.5	-7.1	101.5	94.5	-7.4	88.4	0.0	13.1	13.1
			90.1	-7.0	100.4	89.7	-6.5	104.7	0.4	4.3	4.3
		R	52.8	60.1	37.8	54.4	55.3	27.7	1.6	11.2	11.3
			48.5	61.1	39.2	47.9	61.7	41.6	0.6	2.5	2.5
		G	43.1	-52.3	15.4	46.0	-46.7	8.0	2.9	9.3	9.7
			38.8	-55.4	15.8	36.5	-56.1	15.7	2.3	0.7	2.4
		B	28.5	12.1	-47.2	32.5	3.5	-38.1	4.0	12.5	13.1
			23.1	14.5	-50.1	18.9	12.5	-45.8	4.2	4.7	6.3
Adhesive Vinyl	Dye	C	61.0	-43.3	-40.4	72.2	-30.3	-14.2	11.2	29.2	31.3
			57.6	-42.4	-41.9	63.8	-36.7	-14.9	6.2	27.6	28.3
		M	49.5	75.5	-27.6	90.7	9.0	1.7	41.2	72.7	83.5
			45.9	75.7	-30.1	82.1	15.9	3.1	36.2	68.4	77.4
		Y	90.3	0.7	94.5	95.8	-2.4	10.5	5.5	84.1	84.2
			86.2	0.4	92.9	91.1	-2.8	14.5	4.9	78.5	78.6
		R	50.9	61.0	30.4	86.2	14.5	5.5	35.3	52.7	63.5
			47.0	61.2	29.8	77.7	21.6	6.0	30.7	46.2	55.5
		G	63.1	-55.2	42.9	80.7	-24.5	0.0	17.6	52.8	55.6
			59.5	-55.8	42.3	72.9	-30.8	0.7	13.4	48.5	50.3
		B	34.7	16.5	-54.9	69.6	-12.2	-13.3	34.9	50.5	61.4
			30.5	18.8	-58.1	58.7	-16.4	-14.6	28.2	56.0	62.7
	Pigment	C	44.9	-15.2	-57.1	46.1	-21.1	-49.1	1.2	9.9	10.0
			40.3	-17.0	-60.1	38.6	-21.6	-54.7	1.7	7.1	7.3
		M	47.8	67.8	-4.2	48.7	63.1	-1.5	0.9	5.4	5.5
			41.9	73.0	-7.3	41.1	71.0	0.4	0.8	8.0	8.0
		Y	92.7	-6.9	98.6	92.6	-6.9	92.4	0.1	6.2	6.2
			88.3	-7.0	101.3	87.8	-6.2	103.0	0.5	1.9	1.9
		R	51.0	60.3	38.9	51.7	56.5	34.8	0.7	5.6	5.6
			45.6	64.3	43.9	44.9	63.7	46.0	0.7	2.2	2.3
		G	41.0	-49.5	15.6	42.1	-46.2	14.4	1.1	3.5	3.7
			35.1	-59.7	18.1	33.5	-61.9	18.4	1.6	2.2	2.7
		B	27.4	15.2	-42.6	29.1	9.5	-35.6	1.7	9.0	9.2
			18.4	18.9	-51.4	15.8	14.8	-45.5	2.6	7.2	7.6

Note: Gray field represents sample with laminated.

Figures 5 to 10 present ink color changes (in the a*, b* chroma diagram) with fading for cyan, magenta, yellow red, green, and blue colors, respectively. For the dye-based inks cyan and magenta, with or without laminated, most of the average ΔE^*_{ab}

resulted from both Δa* and Δb* shift, while the b* values of the ink yellow dropped with increasing exposure. Figure 5 and 6 also show that Δa* and Δb* of cyan and magenta shift toward neutral color. Pigmented inks provided good fade resistance. For the pigmented inks cyan and magenta, color shift slightly toward green color, whereas the ink yellow nearly kept its original values with time. For the secondary color red, it was observed that printed with dye-based inks, a* and b* values of the samples respectively dropped and there was a shift toward neutral color, while the b* values of the pigmented ink red dropped with increasing exposure. Figure 9 shows that increasing exposure resulted in a trend to less a* and b* values for the secondary color green. It shows that color changes of dye-based inks were greater than that of pigmented inks. For the secondary color blue, its Δa* and Δb* shift toward green color with increasing exposure.

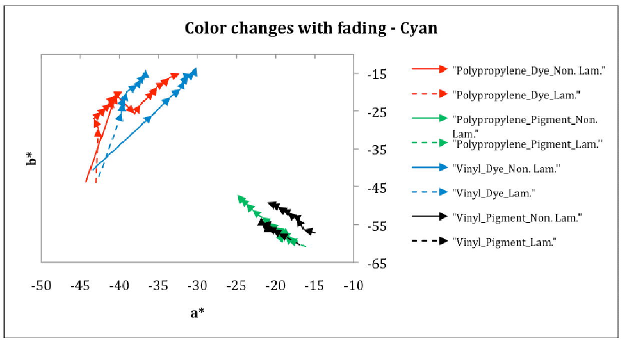


Figure 5. *Color changes with fading for the cyan.*

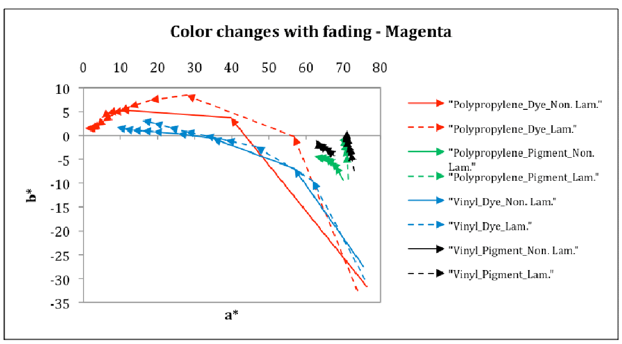


Figure 6. *Color changes with fading for the magenta.*

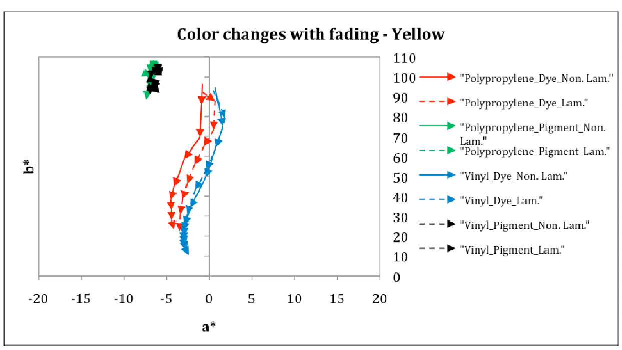


Figure 7. *Color changes with fading for the yellow.*

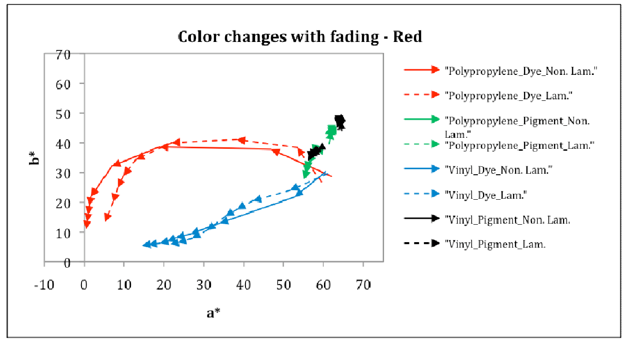


Figure 8. *Color changes with fading for the red.*

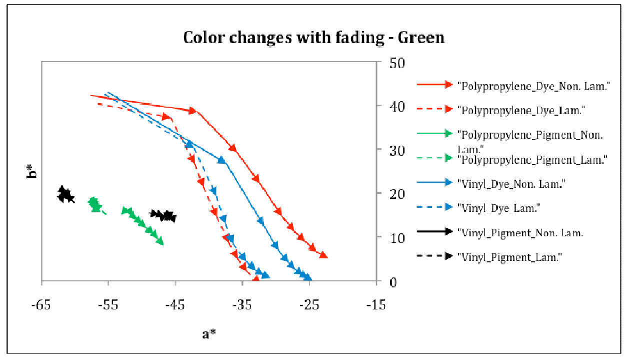


Figure 9. *Color changes with fading for the green.*

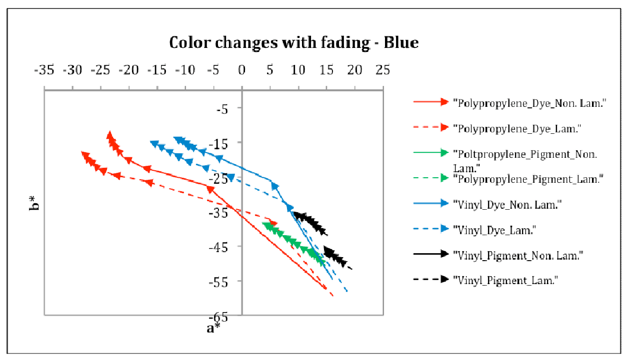


Figure 10. *Color changes with fading for the blue.*

Conclusions

The lamination of display media samples yielded higher optical densities and increased gamut volumes. However, applying lamination also increased the color reproduction variability. The ΔE^*_{ab} values of laminated samples and non-laminated samples varied from 3 to 14. Depending on the display media used, laminated samples with pigmented inks boosted optical densities from 17% to 32%, while laminated samples with dye-based inks increased the optical densities around 6-16%, with exception of black ink density. The lamination increased color gamut about 2-3% for the polypropylene display film, and up to 26% for the adhesive vinyl.

Overall, over-laminating an image increases the gloss level, providing better apparent light-fastness than non-laminated ones. However, it was apparent that using different media and ink type, light fade varies. When printed with dyes, lightfastness improvement by protecting the image using UV-blocking laminates is less than expected. The pigmented ink/over-laminate combination is the best to prevent color fading so that there is a minimum color shift occurs during the lifetime of the prints.

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