Light Fastness of Large Format Ink Jet Media

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Abstract

Large format ink jet media is widely used for graphic arts and display applications. Many large format media are printed with dye-based inks and used for in-door applications. These media are exposed indirectly to sunlight or strong indoor lighting. The color fading rates of these prints in application settings could be different from that predicted according to ΔE in a fadeometer. In this paper, we will compare light fastness test results of ink jet prints in fadeometer and other lighting conditions.

Since faded color prints are not desirable for end-users, various ways to improve light fastness of ink jet prints have been employed by ink and media manufacturers. This paper will also discuss effects of resins and inorganic additives in coatings on light fastness of ink jet prints.

Introduction

Large format ink jet prints are becoming more popular than ever in applications such as graphic arts, displays, posters, and signage. The requirements for large format media are excellent print quality, light fastness and water resistance. Though pigmented inks show improved water fastness and light fastness, pigmented inks, in terms of printing quality, are still not comparable to dye-based inks. Dye-based inks are frequently used in graphic art prints because they give high color density and sharp image. Drawbacks for prints with dye-based inks can include no water resistance and poor light fastness. The former can be solved through laminating over prints. The latter is still to be understood and addressed by ink and media manufacturers.

Large format media typically has ink receptive coatings on substrates such as paper, coated paper and polymeric films. The ink receptive coatings are mainly comprised of water-soluble polymer resins, pigments, mordants, optical brighteners, surfactants, etc. Water-soluble polymer resins used in ink jet coatings include polyvinyl alcohol (PVOH), polyethylene glycol (PEG), polyvinyl pyrrolidone (PVP), cellulose (CEL), polyvinyl acetate (PVA), gelatin (GEL), polyethylene oxide (PEO), poly(2-ethyl-2-oxazoline) (PEOX) and other water-soluble polymers. The pigments could be silica, alumina hydrate, calcium carbonate, polymethylmeth-acrylate (PMMA), starch, polyterefluoro-ethylene (PTFE), titanium dioxide and other particulates. Mordants also are used in ink jet coatings to fix dyes. Commonly used mordants are cationic molecules such as quaternary amines. Dye molecules interact with the chemicals on the image receptive coating. Light fastness of an ink jet print partly depends on the dye-coating interaction. Careful selection of chemicals for ink receptive coatings is needed to improve the light fastness of dye-based ink jet prints.

Light fastness of an image receptive coating can be measured as ΔE by exposing an imaged sample in a fadeometer. Wavelength, light intensity, relative humidity (RH) and temperature in a fadeometer are different from those under real application environments. The present paper will compare light fastness test results in a fadeometer to those in typical end use environments.

Dye fading is a complex mechanism. Poor light fastness for dye-based ink jet prints is largely due to the fact that dyes are present in mono-molecular state and have a very large surface area.[1] The large surface area of dyes provides an efficient light absorption that results in quick degradation of dye molecules. The fading speed depends on the micro-environment of dye molecules. The chemicals in a coating could play an important role in stabilizing dyes if the coating is formulated appropriately.

Experimental

Inks and Printers

Five dye-based ink sets were used in the light fastness experiments. They were GA, GS and GX ink sets from Encad, Inc., HP750C and HP2500CP ink sets from Hewlett Packard, Inc. GA ink set was printed on an Encad Croma 24 printer. GS and GX ink sets were printed on an Encad Novajet 4 printer. HP750C and HP2500CP ink sets were printed on HP750C and HP2500CP Designjet printers, respectively.

Media Coatings

The media coatings used in the experiments included commercial products and experimental media. The experimental media are composed of PVOH, PEOX, PVP and CEL resins or their combination. Lab formulations (10% solids) were coated on 6 mil polyethylene (PE) coated paper with #60 Meyer rod. The coatings were dried in an oven at 250^{o} F for 2 minutes.

Printing

The coated samples were printed with a test pattern containing 0.5x0.5 inch^{2} colored blocks (cyan, magenta, yellow, black, red, green, blue and white). All samples were printed with composite black. The prints were dried at 70^{o} F and 50% RH for 12 hours before testing.

Light Exposure

Indoor: The prints were put on office wall and exposed to office lighting at 70° F and 50% RH for 8 months.

Outdoor: The prints were laminated with 1.7 mil Digiseal laminate film (USI, Inc.) on a USI laminator at 220° F and speed 1. The laminated samples were then put on an outside office window (south facing) to exposed directly to sunlight for 2 weeks in the summer time.

Sunchex: The prints were put in an Atlas Sunchex fadeometer for 40 hours light exposure with a dosage of 0.35 W/M^2 at 340 nm.

Light Fastness Measurement

The light fastness of the samples was measured as ΔE by the following equation:

$$\Delta E=[(L^*_i-L^*_f)^2+(a^*_i-a^*_f)^2+(b^*_i-b^*_f)^2]^{1/2}$$

where L^*_i, a^*_i, b^*_i and L^*_f, a^*_f, b^*_f are the CIELAB coordinates before and after light exposure, respectively. L*a*b* values were measured using an X-Rite 918 illuminate observer. The larger the ΔE, the poorer the light fastness of the color. For over-all evaluation of light fastness, we use a sum of ΔEs for yellow, cyan, magenta, red, green, blue, black and white blocks.

Results and Discussion

Light Fastness vs. Test Condition

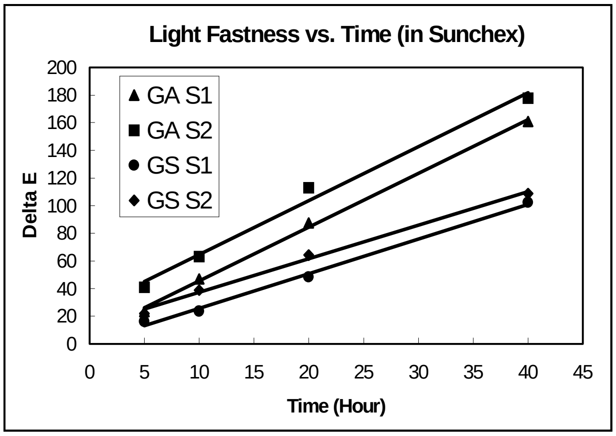

Figure 1. ΔE vs. exposure time in Sunchex

Colors in ink jet prints fade over light exposure time. In most lab experiments, accelerated testing in a fadeometer was used for a quick evaluation of dye stability in an ink jet coating. Figure 1 shows the relationship between ΔE and exposure time in Sunchex. Both coating samples, S1 and S2, are commercial photo-base papers. The ΔEs increased linearly with exposure time in Sunchex with the following equations for S1 sample,

$$\Delta E(GA)=3.89t+6.73 \quad (1)$$

$$\Delta E(GS)=2.52t+0.46 \quad (2)$$

where t is in hours in Sunchex.

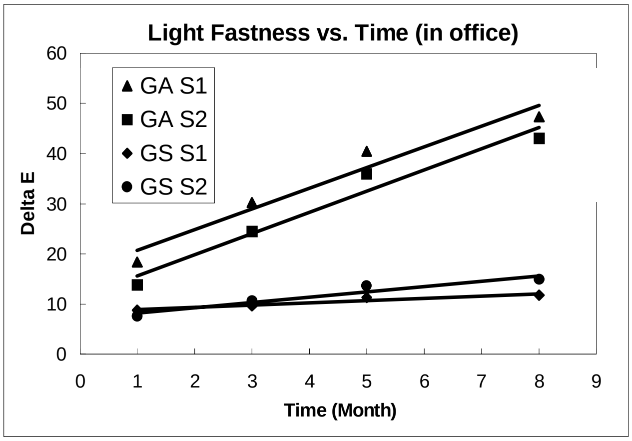

Figure 2. ΔE vs. exposure time in office

Figure 2 shows the relationship between ΔEs and exposure time for samples S1 and S2 under office lighting. The ΔEs for both GA and GS ink prints also increased linearly with time in office with the following equations for S1 sample,

$$\Delta E(GA)=4.12T+16.58 \quad (3)$$

$$\Delta E(GS)=0.45T+8.45 \quad (4)$$

where T is in months in office.

The intercept in equations 1-4 should be zero. It is possible that the inks show thermal degradation as well, thus giving an intercept >o.

The ink jet prints showed comparable fading rates (3.89 in Sunchex and 4.12 in office) for GA ink and quite different fading rates (2.52 in Sunchex and 0.45 in office) for GS ink. The GS print in office is much more stable than predicted according to ΔE in a fadeometer.

Figure 3 shows ΔEs of GA ink prints on sample 3 under the two light sources. Apparently, strong light in Sunchex resulted in quick color fade for magenta color and composite colors containing magenta. Under sunlight, the sample showed color fading pattern similar to that in Sunchex, that is, magenta and magenta containing composite colors faded quickly. To improve light fastness of GA ink prints, an ink jet medium has to stabilize magenta ink.

Figure 4 shows ΔEs of GS ink print on sample S3 after exposure to sunlight and light in Sunchex. In the Sunchex, yellow faded quicker than cyan, black, green and blue colors. While under sunlight, black and green faded quicker than yellow. GS ink responses differently to sunlight and light in Sunchex. There is accelerated fading for composite colors of GS ink under sunlight. To improve light fastness of GS ink prints, there is need to stabilize not only yellow dye, but also cyan and magenta dyes so that the composite dyes will not fade away.

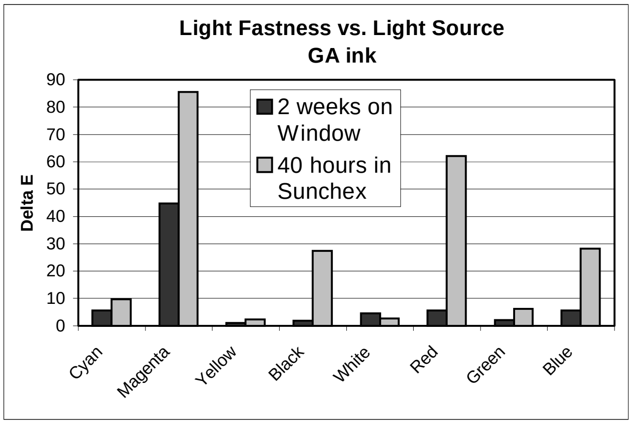

Figure 3. ΔE of GA ink prints

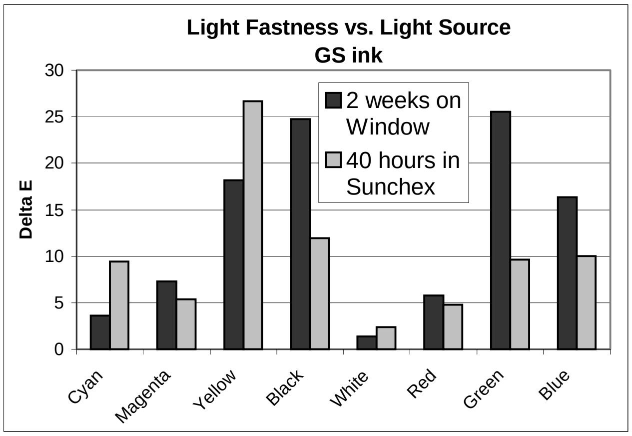

Figure 4. ΔE of GS ink prints

Figure 5 shows ΔE of HP750C ink print on sample S3 after exposure to sunlight and light in Sunchex. The results showed that magenta and yellow faded quicker than composite colors in Sunchex, while composite colors faded quicker than primary colors under sunshine.

The quick color fade for composite colors in GS ink (Fig. 4) and HP750C ink (Fig. 5) under sunlight is possibly due to residual solvents in the printed blocks and dye-dye interaction (dyes acting as photocatalyst).[2] Residual solvents will reduce dye aggregation and therefore accelerate color fade.[3] Dyes in the composite colors can transfer absorbed energy to each other. This also will increase fading for all dyes in composite colors.

The resin or polymeric binder used in an ink jet coating has some effects on the light fastness of the prints. Figure 6 shows ΔE of GA ink prints on different resin coatings. The results show that PVOH and cellulose (CEL) coating systems have better light fastness (smaller ΔE) than that of PVP and PEOX coating systems.

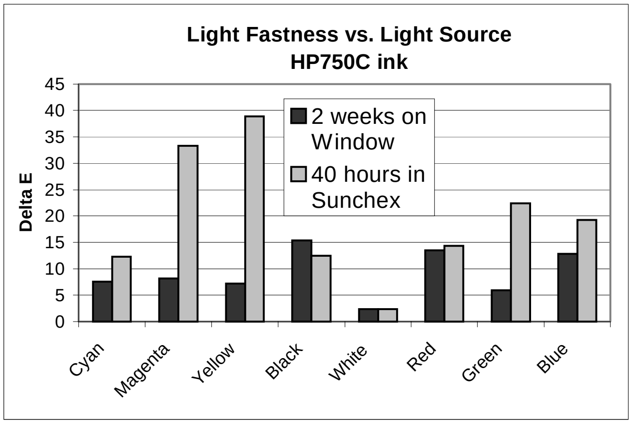

Figure 5. ΔE of HP750C ink prints

Light Fastness vs. Resins

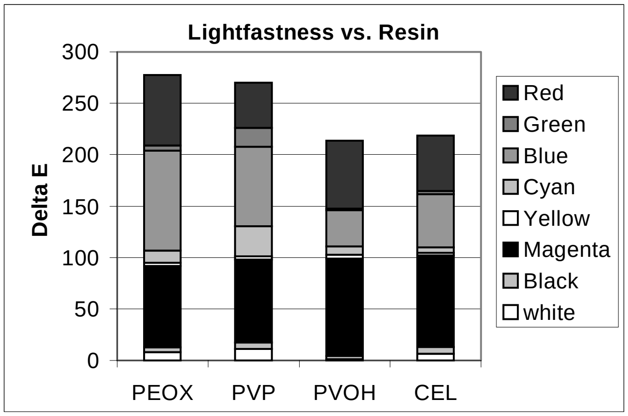

Figure 6. ΔE of GA ink prints after 40 hours in Sunchex

It is known[4] that PVP has poor light fastness. It seems to the authors that nitrogen-containing polymers (PVP, PEOX and vinyl pyrrolidone-containing copolymers) have poor over-all light fastness. This is possibly due to the fact that nitrogen-containing polymers have high fidelity to nitrogen containing dyes. This result in fine distribution of dye molecules in the coating system and less dye aggregation, therefore quick color fade.[3]

Inorganic salts (IS) such as transitional metal salts can stabilize dyes. Figure 7 shows ΔE of GA prints on coatings with and without copper sulfate after 40 hours in the Sunchex. It is clear that copper sulfate can improve light fastness of an ink jet coating by stabilizing dyes in the coating. The coating containing inorganic additives such as PVOH/IS showed smaller ΔE in comparison with the coating without inorganic additives such as PVOH coating.

Figure 8 shows ΔE of various ink prints on samples with and without inorganic salt. Samples S4 and S5 are same coating system, except that S5 contains copper sulfate. Ink jet prints on S5 gave smaller ΔE, indicating better light fastness than prints on S4. The inorganic salt improves light fastness of not only GA ink set, but also of GS, HP750C and HP2500C ink sets. It is known[5] that metal complex dyes are more stable than dyes alone. The addition of transitional metals to coatings can dramatically enhance light fastness of various ink jet prints. The drawback is that transitional metal ions in coatings may produce dull images. Other additives may be needed to increase image sharpness of ink jet coating containing transitional metal ions.

Light Fastness vs. Additives

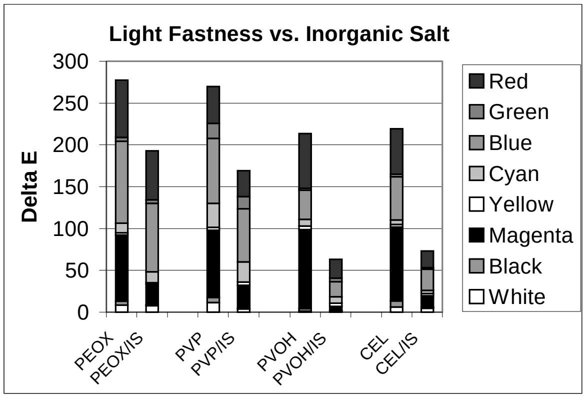

Figure 7. ΔE of GA ink prints after 40 hours in Sunchex

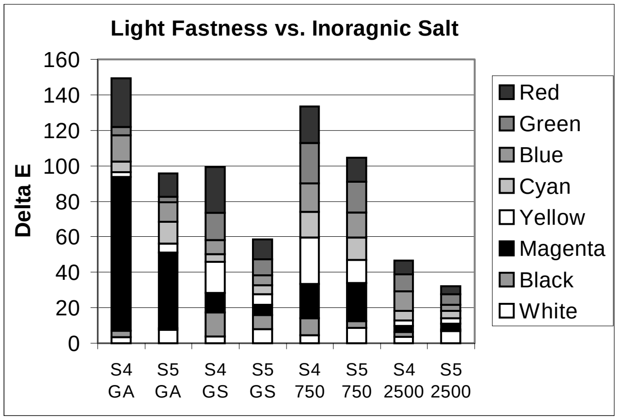

Figure 8. ΔE of various ink prints after 40 hours in Sunchex

Summary

Light fastness of an ink jet print depends on application environment. Light source in an application setting could result in fading rate different from that predicted according to ΔE in a fadeometer.

Some composite dyes have dye-dye interaction that results in quick light fade for composite colors. The coating systems should have additives or polymers to minimize dye-dye interaction and improve over-all light fastness.

Polymeric resins are very important to light fastness of the coatings. Some nitrogen-containing polymers seem to have adverse effect on light fastness.

Inorganic salts can dramatically enhance light fastness of ink jet coatings. The drawback of dull image associated with addition of metal salts has to be addressed.

References

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Biography

John Wang received his B.S. and M.S. degrees in Polymer Physics from the University of Science and Technology of China (USTC) in 1984 and 1987, respectively, and then joined the faculty of USTC. He came to the United States in 1992 and received his Ph.D. degree in Chemistry from Brown University in 1996. Since then he has worked in Arkwright, Inc. He currently is a Group Leader, working on product development in adhesive, ink jet and electro-photographic coatings.