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Lightfastness Studies of Water-based Inkjet Inks on Coated and Uncoated Papers

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Abstract

Instrumental color (i.e. L*A*B*) and optical density measurements were performed on coated and uncoated papers printed with water based inkjet inks using continuous binary array inkjet equipment. Lightfastness tests were performed in a QUV test chamber with Cool White Fluorescent lamps, Q-SUN Xenon Arc Test Chamber with a Window Glass Filter, and under glass at a Florida outdoor benchmark location (Q-Lab Weathering Research Service). These results were compared with two indoor exposure locations. Rank order was used to show good correlation between the various exposure methods. The results of this study generated data indicating that the lightfastness of water-based inkjet inks can be complex and dictated by the type of coated or uncoated paper used. This study also shows that inks printed on coated substrates are more susceptible to UV degradation than those printed on a bond or uncoated substrate. The development of a light stability test protocol is intended to simulate the conditions of the actual service environment. Meaningful data can be produced to better evaluate the "archivability" or predict durability of inkjet inks and substrates.

Introduction

Printing of documents by inkjet technology has occurred commercially for over 10 years. With the advent of sheet feed desktop printing, papers have been formulated with coatings and additives to enhance and improve the lightfastness of color office documents. Many studies have been completed showing the benefits of additives and pigment inks in protecting image quality at various light exposure conditions. There is work underway within the ANSI IT9.3 Stability of Color Images Subcommittee to write test standards for indoor light stability and outdoor durability. In addition, the subcommittee is developing standards addressing humidity-fastness, ozone fade and thermal degradation/dark stability.

More recently, full color inkjet technologies have been implemented in statement, billing and data center printing. In these document printing businesses, low cost papers must be used to meet running cost requirements. In addition, azo type dyes are required to meet the high speed up time demands of high speed digital printing equipment. Overall, there is lower demand for long term lightfastness for transactional documents and billing statements when compared to full color photo quality images printed by desktop inkjet units. However, long-term archivability is necessary for certain documents.

Based on this new direction for inkjet printing, a fundamental study was required to determine the relative lightfastness of uncoated or bond type papers versus lower cost coated papers. In this study, we report lightfastness results of uncoated and coated papers printed with full color Scitex Digital Printing VersaMark™ Printing Systems. A progressive fade rate comparison is made with a xenon arc light source and compared to Florida sunlight as well as indoor exposure of sunlight through a window. These results are compared to results with a Cool White light source and a pure fluorescent office light environment.

Q-LAB

Fluorescent Lamps

Historically, light stability tests using high output cool white fluorescent lamps have been used for color photographs (ANSI IT9.9)1. For example, the standard test condition of a low-watt cool white fluorescent light at 450 lux/12 hour day, 60% RH & 70 F ambient room temperature is not accurate in approximating the variety of end-use environment of computer-generated images printed with inkjet inks. While the output of cool white fluorescent lamps may somewhat reproduce low light or museum environments, the spectrum of these lamps is limited. In essence, the output of these lamps do not match the spectral power distribution of sunlight through window glass. Cool white fluorescent lamps are useful for testing products whose primary end use is in lighted display cases or pure indoor fluorescent lit areas. However, making service life predictions with this lamp type for images displayed in typical indoor environments (i.e. home or office) is imprecise. Images displayed near windows, sliding glass doors, skylights, etc. can receive up to 50,000 lux of full spectrum sunlight (i.e. UV, Visible & IR) in the morning hours on a clear day. The cool white fluorescent lamp spectral output compared to sunlight through window glass is shown in Figure 1.

Xenon Arc Lamps

The xenon arc was adapted for accelerated weathering in Germany in 1954. Xenon arc testers, such as the Q-SUN Xenon Test Chamber, are appropriate for photostability of materials because they provide the best available simulation of full spectrum sunlight: UV, Visible & IR light. Xenon arcs use filters to achieve the appropriate spectrum (e.g., outdoor sunlight or sunlight filtered through window glass).

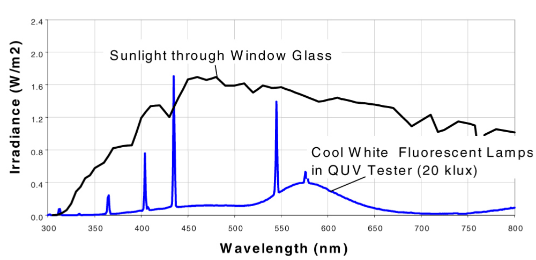

Figure 1 - Cool White Fluorescent Lamp vs. Sunlight Through Window Glass

Xenon arcs require a combination of filters to reduce unwanted radiation. The "Window Glass" Filter simulates sunlight through window glass. It is typically used to test products whose primary service life will be indoors. Figure 2 shows the Spectral Power Distribution of noon summer sunlight behind glass compared to a xenon arc with a Window Glass Filter.

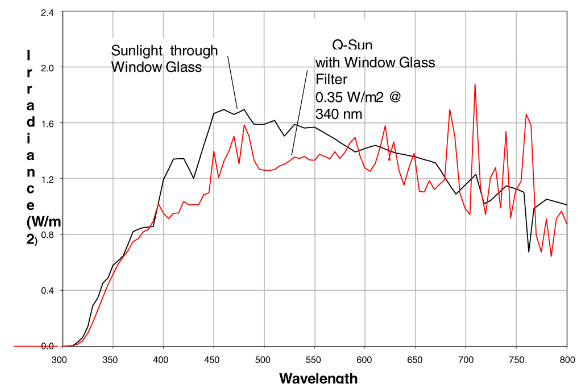

Figure 2 - Q-SUN Chamber Xenon vs. Sunlight Through Window Glass

Experimental

Materials. The materials used in this study were supplied by a variety of paper companies in the United States, Europe and Japan. These papers were categorized as coated paper (CP) or uncoated paper (UC). CP1 and CP2 are coated papers at a 54 (80 g/m^2) and 72 (107 g/m^2) pound per ream book basis weights (Book Weight or BW), respectively. The CP1 paper has a lower coating weight than CP2 and is distinguished from CP2 by the coating type used. CP3 is a coated one-side (C1S) glossy paper at 50 BW (74 g/m^2). UC1 and UC2 are uncoated papers at 50 BW (74 g/m^2) and 60 BW (89 g/m^2), respectively. UC1 is a basic bond paper and UC2 is specially formulated paper for increased inkjet ink permanence when exposed to water. UC3 is machine finished 60 BW (90 g/m^2) paper that is treated for better inkjet image quality.

The inkjet inks used in this study were Cyan #6092001, Magenta #6092002, Black #6092003 and Yellow #6092004 from Scitex Digital Printing, Inc. These inks are water based and were prepared with azo-type dyes except for the Cyan dye that was prepared from a phthalocyanine base. These dyes are known to have relatively good lightfastness properties for inkjet images as communicated by the manufacturers. The inks were formulated with other components to run in Scitex continuous inkjet printers and had viscosities of 1.1 centipoise.

Printing. All papers and inks were printed on a Scitex Digital Printing, Inc. VersaMark™ Business Color Press ™ at 500 feet per minute. The continuous inkjet print heads used to print the inks were nine inch wide 9500 Series Printheads and PS-90 Print Stations and Fluid Systems. All the images were printed on one side with an ink saturation level (linearization level) sufficiently high enough for the "best" image quality but not to cause ink to penetrate completely through the paper causing a show through condition on the unprinted side. The images printed for this study were 0.5 centimeter square images.

Natural and Accelerated Exposure Testing. Natural and accelerated exposure tests were performed by Q-Lab Weathering Research Service. Instrumental color and densitometer readings on four sample areas were taken every 10 hours. Three replicates of six sample types (18 samples) of printed coated & uncoated papers were tested as follows:

I. Outdoor Under Glass Exposure in a ventilated exposure cabinet at 45°S in Florida for 72 hours (three days).

II. Cool White Fluorescent Exposure in a QUV Accelerated Weathering Tester per ASTM G154.2 Irradiance level was 0.060 W/m^2 at 420 nm, chamber temperature at 31-35° C for 40 light hours.

III. Xenon Arc with Window Glass Filter Exposure in a Q-SUN Xenon Arc Test Chamber per ASTM G155.3 Irradiance level was 0.35 W/m^2 at 340 nm, chamber temperature at 63°C Black Panel Temperature per ASTM D3424, Method 3.[4]

IV. Scitex Digital Printing, Inc., business document exposure was completed in an interior building hallway (Indoor Hall) with both fluorescent light and daylight exposure up to 30 weeks or 5000 hours.

V. Scitex Digital Printing, Inc., interior room (Indoor Fluorescent) with only fluorescent light exposure for up to 2000 hours.

LAB and Delta E Measurements. All L*A*B* measurements were made with a Gretag SPM 50 Spectrophotometer in accordance to ASTM D2244 Illuminant D65, 10° Observer, Specular included. Measurements were made at the indicated time intervals on three replicate samples for each process color image on each paper. Delta E calculations were derived from LAB measurements on images after printing with minimal light exposure.

Density Measurements. Density measurements were completed on a Macbeth TR927 Densitometer. The R,G, B, and Othro filter were used for Cyan, Magenta, Yellow and Black printed images, respectively.

Results and Discussion

Exposure Test Results. Exposure to the Q-SUN Xenon Arc initially revealed that there were large Delta E values for the coated papers (CP). As is well known in the dye and inkjet industries, both the magenta and yellow inks showed a high level of fade up to 40 hours of Xenon Arc light exposure as shown in Figure 3. For CP1 and CP3, the Delta E values for the fade of the cyan ink was comparably lower than the magenta and yellow ink fade with the black ink showing the lowest Delta E or fade under Xenon Arc. Values for CP2 fell in between those of CP1 and CP3. A value of Delta E above 10 indicates a significant level of ink or dye fade.

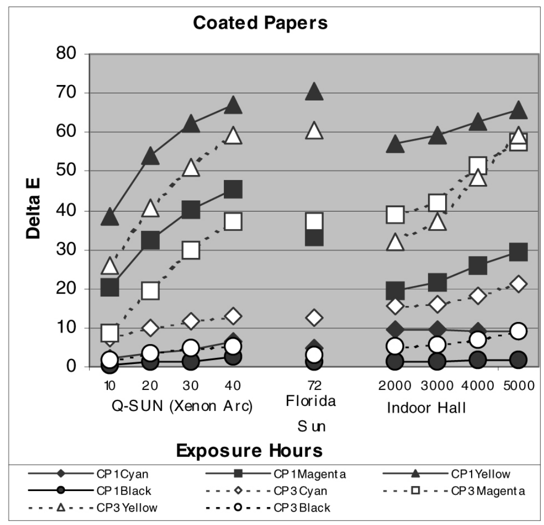

Figure 3 - Fade of Coated Papers by UV Light Sources

These values for Delta E were also compared to the 72 Hour Delta E values for Florida Sun outdoor exposure under glass. As can been seen in Figure 3, these values are comparable to the Delta E values for the 40 Hour Xenon Arc. In order to get a further comparison, these values were compared in Figure 3 to 2000 hour through 5000 hour exposures to natural indoor light and fluorescent exposure in an Indoor Hall. Again, the Delta E values for the Indoor Hall exposures are on the same order as the 40 hour Xenon Arc and 72 hour Florida Sun exposures.

Further exposures were completed with uncoated papers (UC) shown in Figure 4. With UC1 and UC2, it is observed that the Delta E and values and relative fade is much lower. In most cases of the cyan, magenta and yellow inks the Delta E values are less than 50 percent than that for the coated paper in Figure 3. These differences are particular noteworthy for the Florida Sun and the Indoor Hall exposures. For the uncoated papers in the Indoor Hall exposure, all inks except for the yellow ink exhibited Delta E values under 10 after 5000 hours.

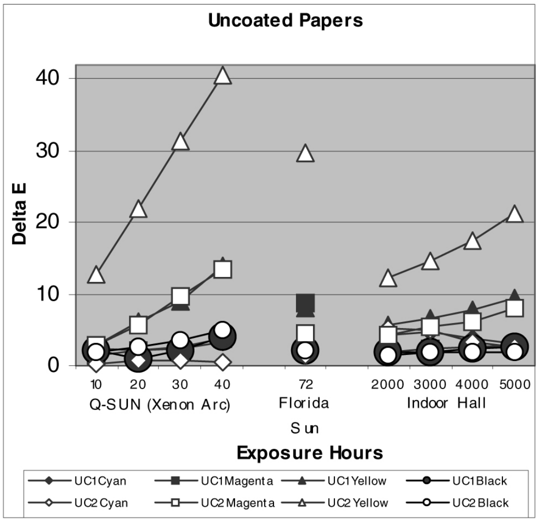

Figure 4 - Fade of Uncoated Papers by UV Light Sources

During this study, the main focus was directed toward an understanding of the higher level of fade for the coated papers versus the uncoated papers at the same exposure times with the different light sources. The primary factor considered was the higher initial density of the coated papers when compared to the uncoated papers as shown in Table 1. As can be seen, the coated papers (CP) have a higher initial density compared to uncoated papers (UC) for most colors. This difference in density can be attributed to the fact that ink is primarily absorbed in the surface layer of the coated papers.[5] Coated papers are typically coated with coatings that contain titanium dioxide, calcium carbonate and other materials that quickly absorb ink components and hold the dye on the surface of the paper increasing the optical density of the ink and dye colors. CP2, with the heaviest coating, shows the highest optical density values except for magenta. In comparison, when low viscosity water based inkjet ink is printed on uncoated or bond paper, the ink and dye will quickly absorb into the internal structure of the paper and result in low optical densities. This can be seen with UC1, a basic bond paper. UC2 and UC3 have achine-finished treatments that increase optical density over UC1 except for black.

Papers	Cyan	Magenta	Yellow	Black
CP1	1.23	0.73	0.89	1.53
CP2	1.53	0.83	1.16	1.70
CP3	1.42	0.92	1.16	1.40
UC1	0.72	0.51	0.65	1.36
UC2	1.01	0.78	0.92	1.25
UC3	1.07	0.85	0.98	1.19

Table 1 - Initial Density Values for Coated and Uncoated Papers

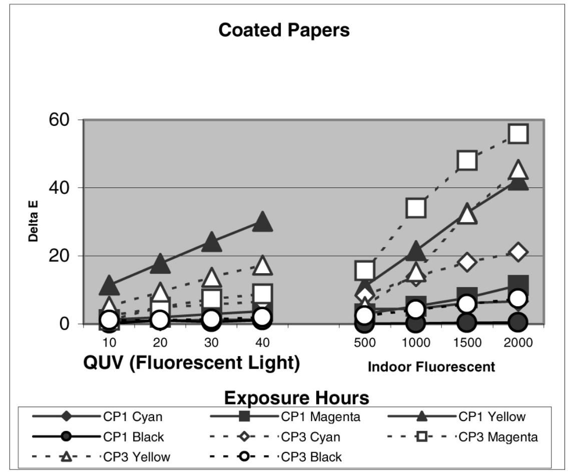

Figure 5 - Fade of Coated Papers by Fluorescent Light Sources

Since the fade results for Xenon Arc exposures are substantially higher for the variety of coated papers compared to the uncoated papers it can be concluded that initial optical density is a factor. This factor can be attributed to the fact that more dye molecules will be on the surface of the coated papers. Thus, these dye molecules are more directly exposed to the light source. In the case of the uncoated paper, higher concentrations of the dye molecules are absorbed into the bulk of the paper. Therefore, the paper fibers and formulation components protect a certain portion of the dye directly from the light source.

Cool white fluorescent exposures completed in a QUV Tester are shown in Figures 5 and 6. As can be seen in Figure 5, the level of fade for the coated paper after 40 hours of exposure to QUV fluorescent light is above 10 Delta E for the yellow ink. The values are compared to Indoor Fluorescent lighting typically used in an office environment. For CP3, the magenta ink exhibited a high level of fade in this lighting. When compared to Xenon Arc fade in Figure 3, the fluorescent light fade results are substantially lower except when comparing to the Indoor Hall (up to 5000 Hours) which also contained fluorescent lighting owing to a close result for the CP1 Yellow, CP3 Yellow and CP3 Magenta up to the 2000 hour level. Values for CP2 are between CP1 and CP3 with Black at comparable levels.

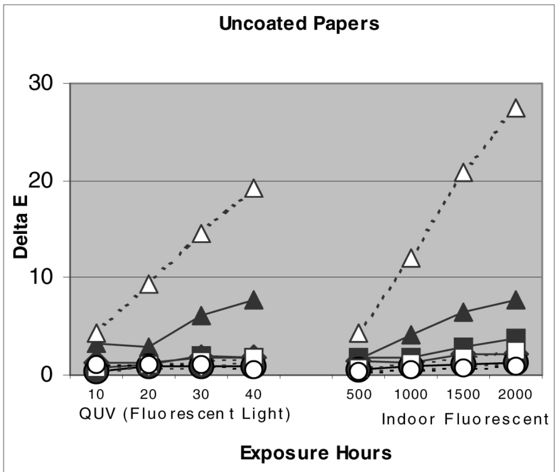

Figure 6 - Fade of Uncoated Papers by Fluorescent Light Sources

For the uncoated papers in Figure 6, the fluorescent light shows very low levels of fade except again for the UC3 Yellow. This result at 2000 hour is comparable to the Delta E at about 30 for UC3 in the Indoor Hall (not shown) at a Delta E of 38.63 at 2000 hours. The fade of the Black dye under fluorescent light was considered very low. Values for UC2 are between UC1 and UC3 with the Black at comparable levels.

Rank Order Correlation. For most materials, it is very difficult to correlate real time (natural) exposure with laboratory results (X hrs natural exposure = Y hrs Accelerated laboratory exposure). One of the few useful methods is a comparison of relative rank orders. Spearman Rank Order is a statistical measure that provides a value for a set of performance rankings. For example, if two sets of data are being compared, rank order indicates how closely the rankings match one another. Perfect correlation is represented by a value of 1.0. Random correlation is represented by a value of 0. Negative correlation is represented by a value of –1.0. Spearman rank correlation coefficients (rs) are commonly used for relating weathering tests. See Table 2 below.

Material	Rank: Test 1	Test 2	Test 3	Test 4
A	1	1	2	6
B	2	2	6	5
C	3	3	3	4
D	4	4	4	3
E	5	5	1	2
F	6	6	5	1
R_s to Test 1	--	1.0 Perfect Correlation	0 Random	-1.0 Negative Correlation

Table 2 - Example of Rank Performance

In correlating accelerated and real exposure tests, the rank performance of the materials exposed to both environments is compared, and the strength of the association between the tests is therefore established.

Rank Order Discussion of Specific Test Results. Instrumental color measurements were taken on all test specimens before and after exposure. The color change in Delta E units was recorded for each specimen. Rank order correlation was performed by comparing Delta E readings taken from one exposure of individual C,M,Y and K (Black) values for one substrate sample type to Delta E readings of the same sample type from another exposure. For example, the Delta E reading for the "Y" value of sample type CP1 after exposure in Florida behind glass was compared to the CP1 "Y" value after 40 hours exposure in a Q-SUN Xenon Arc Test Chamber.

Delta E measurements for each of the six paper substrates and ink colors were compared to each other from one exposure type to another (e.g., Indoor Hall vs. QUV Cool White Fluorescent lamp exposure). Spearman rank was then performed on meaningful data sets. Examples of these rankings are shown in Figures 7 – 10.

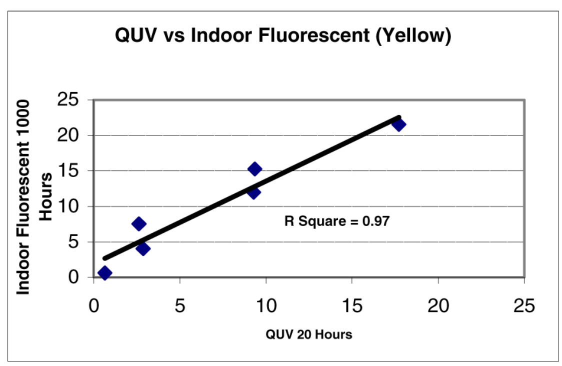

Figure 7 - Rank Order of QUV vs Indoor Fluorescent for Yellow Printed Papers

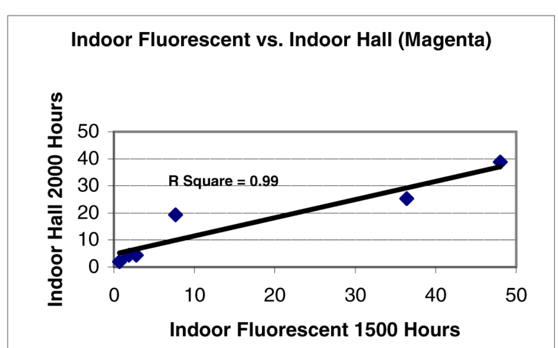

Figure 8 - Rank Order of Indoor Fluorescent vs Indoor Hall for Magenta Printed Papers

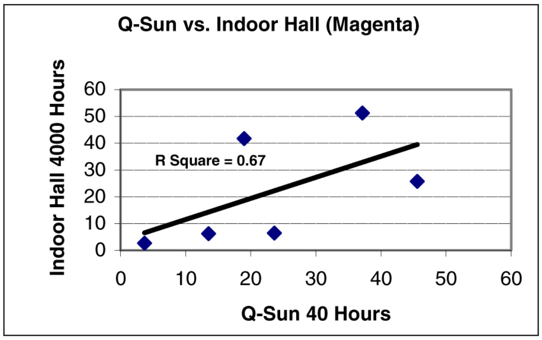

Figure 9 - Rank Order of Q-SUN Chamber vs Indoor Hall for Magenta Printed Papers

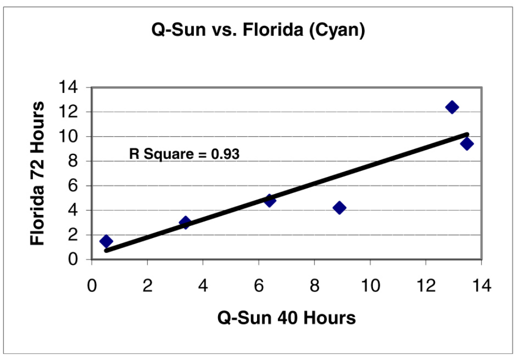

Figure 10 - Rank Order of Q-SUN Chamber vs Florida Outdoor Behind Glass for Cyan Printed Papers

Figure 7 shows excellent correlation between the QUV tester results and the Indoor Fluorescent fade results indicating a usefulness of the QUV tester to determine fade print durability in an indoor office environment. Figure 8 indicated that the strong fade behavior of the magenta dye is independent of the light source. The differences in Figure 9, may be explained by differences in temperature between the Q-SUN chamber and typical indoor office environments. However in Figure 10, a high rank order correlation indicates the usefulness of Xenon Arc and Florida under glass exposure for inkjet imaging materials.

Testing Issues. There are a number of issues that must be considered when testing for lightfastness: Light Intensity, Temperature, Temperature Sensitivity of Materials, Humidity, Dark Stability, Linearity of Degradation, Reciprocity Failure, Gas (Ozone) Fading, Paper Yellow and Lux vs. Watts per Square Meter. Because of these parameters, there can be variability in lightfastness test results with ink jet printed papers. Therefore, until these parameters are fully investigated, service life predictions cannot be made with certainty.

Conclusions

Results from this study indicate that inkjet inks printed on coated substrates are more susceptible to UV degradation than those printed on a bond or uncoated substrate.

Xenon arc with Window Glass Filter can be used as a predictive test for inks/substrates whose end use is intended for indoor environments with windows. Additionally, the QUV model with cool white fluorescent lamps can be used to simulate the accelerated effects of indoor environments, for inkjet inks and substrates used to create business documents for indoor office or retail environments. Florida behind glass natural exposure can be used as an accelerated test to simulate indoor environments with windows. Variations in this study could be related to differences in temperature or humidity levels.

There was excellent rank order correlation between several of the Indoor Hall and Indoor Fluorescent and accelerated laboratory exposures (Q-SUN and QUV testers) along with Florida behind glass exposures. Both natural and accelerated tests were able to distinguish between good and bad performers.

This study indicates that Black inkjet inks are minimally affected by both natural and accelerated light stability tests. The Black inks should provide excellent archivability on uncoated and coated papers.

Future tests for inkjet inks, coated and uncoated substrates should include simulating the ambient effects of humidity, temperature and ozone. Presently, the repeatability and reproducibility of the various exposure methods is unknown. Variability resulting from specimen preparation and color measurement techniques is also unknown. It would be useful to determine an appropriate benchmark exposure based upon actual, real world service conditions for future studies. One research option would be to select a reference material with known durability and expose it along with the test specimens to a predetermined change. The test specimen data could then be normalized against the reference material's performance.

Acknowledgements

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References

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2. ASTM G154, Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Non-Metallic Materials.
3. ASTM G155, Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials.
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5. Laboratory studies carried out at Scitex Digital Printing using an EMCO DPM 30 to measure ultrasonic transmission of inkjet inks penetrating into coated and uncoated paper.

Biography

Russell H. Tobias received his B.S. degree in Chemistry from the University of California at Santa Barbara in 1978 and a Ph.D. in Polymer Science from The University of Akron in 1982. Since 2000, he has worked for Scitex Digital Printing, Inc. in Dayton, Ohio. His work has focused on the development of novel inkjet inks and substrates for high-speed inkjet printing in continuous binary array inkjet printers. He is a member of the IS&T and the American Chemical Society.

Eric T. Everett received his B.A. from Baldwin-Wallace College in 1987 and an M.A. from Case Western Reserve University in 1989. Since 1998 he has worked for Q-Panel Lab Products Company in Cleveland, Ohio. His work focuses on standards development and administration. He is a member of nine ANSI, ASTM, ISO and SAE Committees dealing with weathering and testing of color images, packaging, textiles and other materials.

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