Multi-Variant Analysis of Real-World Environmental Variables Affecting Image Fading on an Outdoor Synthetic Inkjet Substrate

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Abstract

The permanence of large format, outdoor inkjet signs is a concern for many museums and companies creating signs that will be displayed for years or months either on the side of a museum or by the side of the road. The permanence industry has focused their research on using equipment to simulate the outdoor conditions these prints face to gauge their fading properties. The research conducted here took a more direct approach by placing the prints in an actual outdoor environment situation with no protection, tracking the rate of color change (DE), and the fluctuation of the environmental variables. A multiple regression analysis of the data that was collected was then used to create prediction formulas and to eliminate environmental variables that did not affect the fading.

The multiple regression analysis was able to create a prediction formula for only two of the color patches tested on the uncoated vinyl substrate. The test included an uncoated vinyl substrate patch and nine printed color patches (cyan, magenta, yellow, black, red, green, blue, and two grays). The successful formulas created were for the measured substrate patch and the cyan patch. The formula showed that the substrate patch was affected by the average high and low temperatures and by the amount of time exposed in weeks. A second formula showed that the cyan patch was affected by the UV (ultra violet) index and the amount of time exposed in weeks.

The prediction formulas act as more of a guideline for museums or printers to base their decisions about which substrates to use and to provide an idea about what environmental factors can be expected to affect the fading. This can in turn aid future research into the permanence of synthetic inkjet substrates by allowing researchers to conduct a preliminary short term study to narrow down the different variables they will be using for a more in-depth study. This research has shown that it is possible to conduct a short-term study of several variables to be used as a basis for later, more advanced research of the same material but with fewer variables, or for accelerated testing.

Introduction

Outdoor inkjet signs are subject to harsh and changing conditions, causing them to fade at higher rates than an indoor inkjet sign or photograph. These outdoor inkjet signs undergo stress caused by changing environments from factors such as rain, humidity, sunlight, ozone, UV exposure, etc. Most often the type of testing that is conducted on both indoor and outdoor inkjet signs centers around accelerated fade testing [2].

Accelerated testing offers the benefit of retrieving data quickly and efficiently but has limits from problems such as reciprocity failure, and the amount of variables that can be tested at one time. Accelerated testing has clear benefits and disadvantages that have been proven by many different researchers. Adding data to supplement accelerated fade testing based upon a short term real-world exposure would benefit the information that can be derived from both accelerated fade testing and real-world testing. The additional information that would be gained would enable researchers to make more future advancements and knowledge about the prints [1].

The use of a multiple regression analysis conducted on a real-world exposure test allows for variables to be ruled out and thus indicates which variables researchers using accelerated fade testing should focus on. It can also be used to give an indicator of which types of inkjet substrates should be used given a specific situation, such as a banner being hung outside of a museum announcing a new exhibit or an advertising sign at a baseball park. This type of information will allow for a more informed decision to be made resulting in better permanence when creating large format outdoor inkjet signs.

Experiment Setup

The experiment was conducted on a synthetic substrate (uncoated vinyl) for large format inkjet printing. A test target of nine squares of color (C, M, Y, K, R, G, B, Gr (CMY), and Gr (CMYK) and one square of plain substrate. The patches of color were created in Adobe Illustrator CS2 by using the CMYK sliders. For pure CMYK patches, 100% was chosen for each color. For RGB, the combinations of the two colors that create the actual color were chosen; for example, 100% Y and 100% M for red. The file was then saved as an EPS file.

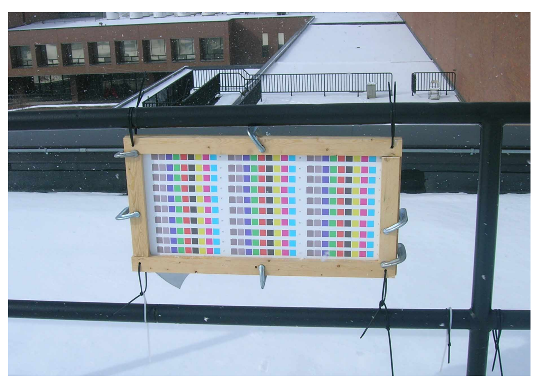

Figure 1. Prints during exposure on roof.

A test print was created with the test target printed thirty times on the test substrate (uncoated vinyl) with a large format eco-solvent inkjet printer using the manufacturer's inks and substrates. It was printed using the profile that came with the manufacturer's software and was listed as the profile for uncoated vinyl. After printing the test print was allowed to dry for twenty-four hours on a table at ambient room temperature and humidity before being measured for LAB values. LAB was chosen as the color space for this study because it is a perceptual color space

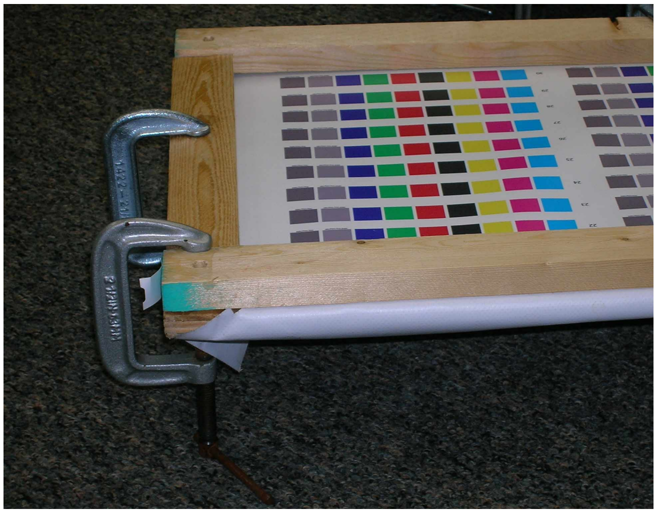

Figure 2. Test print mounted in wooden frame

which replicates mathematically what the human eye observes [3].

The test print was mounted in a wooden frame with wooden backing held together with C-clamps. It was placed on a railing on the roof of a four story building on a 90-degree angle with no protection from the environment facing eastward. The building on which the test print was placed was building #7 located on the Rochester Institute of Technology campus, in Henrietta, New York, a suburb of Rochester. A wooden backing was used to allow for more exposure to moisture to compensate for the 90-degree angle [1].

For the following sixteen weeks (November to February) the prints were removed once a week (same time every week) and measured for LAB values. When the test print was removed it was allowed to dry for one hour before measurement and if there was snow it was shaken off, not brushed off. These LAB values were then used to calculate DE (Delta E_{ab}). Prior to placing the test print on the roof it was measured for LAB values, those values were used as the reference values to determine the DE.

Figure 3. LAB Measurement setup

The LAB measurements were made with an X-Rite spectrophotometer that was calibrated prior to use every week. The same spectrophotometer was used for all the measurements to eliminate instrument variation and a cable used to directly import the data into Excel was used to reduce the possibility of human error.

The environmental variables were tracked and averaged for their weekly values using a common weather monitoring website that is easily accessible (www.weather.com). The area code for the address of Rochester Institute of Technology (14623) was entered to obtain the environmental variable data. The following environmental variables were tracked: UV Index, Average low and high temperature for the day, Precipitation Amount, and Average Humidity for the day.

A multiple regression analysis was conducted on the data collected to draw correlations between the environmental variables and the change in DE. Environmental variables that did not affect the change in DE of the different patches tested were discarded until only the variables affecting the change in DE remained. A prediction formula was then produced with the multiple regression analysis indicating which variables affected the fading or change in DE and at what rate it could be expected that they would affect a print on a similar substrate exposed to similar environmental variables.

Results

A multiple regression analysis was conducted on the DE results and environmental variable results for the sixteen weeks. The multiple regression analysis assumed a normal distribution of the samples measured and used a ninety-five percent confidence level. DE is not normally distributed because the equation does not allow for a negative value and will be skewed to the right. The use of this type of statistical method to analyze DE has been conducted previously in other research and has become accepted as a norm in this type of research using DE [4].

Table 1. *Results from multiple regression analysis showing correlation of DE with environmental variables.*

	R^2	Std. Error	Co-efficient	Time	Low Temp.
Substrate	0.882	0.167	0.386	0.095	-0.010
Cyan	0.900	0.263	0.444	0.163	x
Magenta	0.730	0.373	1.489	0.152	0.009
Blue	0.741	0.613	1.091	0.234	x
	High Temp.	**Hum.**	**Precip.**	**UV Index**	
Substrate	0.0042	x	x	x	
Cyan	x	x	x	0.077	
Magenta	x	-1.226	x	-0.200	
Blue	x	x	x	-0.106	

In Table 1 the results from the multiple regression analysis the variables that were eliminated have an "x" in that column next to the patch for which they were eliminated. Only the patches of Cyan (C), Magenta (M), blue (B) and substrate were chosen for the multiple regression analysis because they showed the most noticeable change in DE. The only variable, which correlated with all of the color patches, was time, although it did not always correlate in a linear manner. R^2 reflects how much of the data fell into the correlation, any variable that had a R^2 less than 0.85 was discarded. The standard error is the amount of deviation of the coefficient from the correlation, any variable with a standard error higher than 0.30 was discarded.

The substrate patch showed a correlation between DE, time, low temperature, and high temperature. It was unaffected by humidity, UV index and precipitation. The R^2 was 0.88 and the standard error 0.17, so it can be assumed the regression is a good representation of the variables affecting the substrate patch. Low temperature showed a negative coefficient, meaning that the low temperature inversely affected the DE. Thus the color is changing in the opposite direction in the colorspace when the temperature is lower then when the temperature is higher. The prediction formula for the rate of fading for the substrate patch on uncoated vinyl is:

y hat=0.3865+(0.0951*Week)-(0.0107*Low Temp.)+(0.0042*High Temp.)
where week = time in weeks
where low temp. = average low temperature in Fahrenheit for one week
where high temp. = average high temperature in Fahrenheit for one week

The cyan patch showed a correlation to the time and UV index variables. The R^2 was 0.90 and the standard error was 0.26 indicating that that the regression is a good representation of the variables affecting the cyan patch on uncoated vinyl. The prediction formula for the rate of fading for the cyan patch on uncoated vinyl is:

y hat=0.4441+(0.1635*Week)+(0.0776*UV Index)
where week = time in weeks
where UV Index = average of the UV Index for the week

The patches of magenta and blue had an R^2 that was too low and a standard error that was too high indicating that the regression was not a good representation of the variables affecting these two patches.

The data that is entered into the two formulas that were created to make a prediction cannot exceed the data that was used to create the prediction formula. An example of data that would be within the limits of this study would be a sign that was going to be displayed during the winter months in Rochester, New York. An example of a sign that was going to be displayed which would not be allowed to use these prediction formulas would be one that is to be displayed during the summer months in Rochester, New York. Due to this limitation of the prediction formula it should be used more as a suggestion as to which variables will affect the change in DE of the print for further study or to give a customer an idea about which environmental variables will react with their sign.

The prediction formulas give a consumer an idea about how long before they have to replace their large format inkjet sign and how to choose the material best suited for their intended use. For example, if a museum went to a sign shop that used a large format inkjet printer and asked for a recommendation on what type of material they should use for a large banner advertising a new exhibit that will be on the front of the museum for 10 weeks. The printer would then obtain some more information about the conditions it was going to be displayed in. They would find out the sign is going to be exposed to a high temperature of 90 degrees Fahrenheit, a low temperature of 32 degrees Fahrenheit, and an average UV index of 1.5 for 10 weeks with no protection from the environment. They would recommend uncoated vinyl because the high and low temperatures will counteract the color shifts of each other and could tell the client to expect a change in the substrate DE of 1.4 and a change in the cyan ink DE of 2.2. Thus the museum will be prepared for a possible slight shift in the cyan ink but that it will be barely be noticeable especially from the viewing distance at which the sign will be displayed.

Conclusions

The regression analysis was useful in creating a prediction formula for two of the color patches, substrate and cyan on an uncoated vinyl substrate. The rest of the regression analyses for the other color patches were discarded for poor correlations. However, the two prediction formulas that were created from the data can be used as a starting point for future research on the environmental variables that affect uncoated vinyl substrates. They provide information to consumers on what to avoid in specific conditions and what behaviors may be expected from the uncoated vinyl substrate when exposed to specific environmental variables. This study produced a methodology to both measure and to analyze data regarding real-world permanence. Researchers conducting accelerated fade testing can then use this data for testing the environmental variables in a more controlled environment to gain better insight to what is causing the change in DE and to analyze how to better prevent it.

The influence of certain environmental variables, UV index, high and low temperature, and time, on the uncoated vinyl substrate have a profound impact when deciding upon whether or not to use that substrate. A museum can make an approximation as to the rate of fading with the prediction formula to gain an idea about how the material would behave in a specific climate. This allows for a museum creating outdoor inkjet signs to make better decisions on what to expect from the inkjet sign and to have more knowledge about how long until their sign needs to be replaced. The prediction formula should be used as a guideline for deciding upon whether or not to use an uncoated vinyl substrate with the knowledge of what environmental variables the sign will be facing for the duration of its use. Additional researchers can use the prediction formulas as the basis of where to begin their testing of the same material but with fewer variables or for accelerated fade testing.

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