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Abrasion of Digital Reflection Prints: The Abrasiveness of Common Surfaces and the Vulnerability of Print Processes

INTRODUCTION

Very little is currently known about the care and handling of digitally printed materials. Even within the industry the manufacturers know very little about the care of the very things that they produce and sell. As a result, Image Permanence Institute (IPI) undertook its Digital Print Preservation Portal Project (DP3). The purpose of this paper is to describe two aspects of the abrasion studies done as part of the DP3 project and their impact on storage recommendations for digital print collections.

THE DP3 PROJECT

The DP3 project started in late 2007 with the understanding that the digital printing field was still evolving, although by 2007 the industry seemed to be relatively mature in its development. The project is intended to result in a web site dealing with all aspects of stability and care of digitally printed materials. However, rather than addressing the particular stability issues of printing products by brand, this research project looked at stability differences and similarities by generic product type. If necessary, product specification may go as far as an ink type and paper type. Therefore, the web page might be more specific than referencing generic product type alone. If greater specification becomes necessary, the user will have to be able to identify digital print processes.

DIGITAL PRINTS

Within the confines of the DP3 project it was necessary to define what IPI meant by the term "digital print." We have found that many people have different views on what materials this term includes (Burge et al., *Archival Outlook,* 2009), so, for this project, "digital print" refers to both text and images on digital press, inkjet, dye sublimation, electrophotographic, and digitally printed chromogenic prints.

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ABRASION

Initially, the interest in abrasion testing was undertaken because it was one of the most common handling problems found in traditional photographic collections. Remarkably, a survey of the field undertaken as part of the DP3 project in the summer of 2008 showed that abrasion was the number one problem observed in collections of digitally printed materials. Forty-two percent of respondents from libraries, museums, and archives said that they had observed abrasion in their collections of digitally printed materials. Assuming that the survey respondents represented a good cross section of institutions in the field, this result had a maximum error of 7.3% to a 95% confidence. Given that digitally printed materials have been kept in collections for only the past fifteen years or so, 42% is a very serious result (Burge et al., *Archiving*, 2009).

Abrasion differs from scratching in both form and cause. Scratches tend to appear as discrete furrows in the surface of the print from which material has been removed. They are caused by relatively large, sharp objects (large asperities) being pushed across the surface of the print (or *vice versa*, the print may be pushed across the sharp objects). Large, relatively dull objects may also produce a furrow, but in this case the print material will be pressed in and not scraped out. Scratch damage may be reproduced in the lab by scraping a needle or stylus across the surface of the print. Abrasion, on the other hand, results from a material surface with small asperities being pushed across the surface of the print (or *vice versa*).

PRELIMINARY STUDIES

Currently, the International Organization for Standardization (ISO) has no standard abrasion test method for digitally printed images, although there are a variety of scratch tests for traditional photographic materials. In fact, work has just barely started on an abrasion test method standard for images. A test method was determined at IPI that will be presented to ISO for consideration. It is important to note, however, that it is very difficult to characterize any individual storage or transportation situation and, therefore, nearly impossible to relate the absolute results of the lab tests to any real-life situation.

In previous work a variety of abrasion testing devices were considered, and the Sutherland rub tester, a motorized rub tester, was settled on as the best abrading device. This device consists of a base to support the test sample and an arm on which an abrading surface can be mounted. The arm sweeps the abrading material back and forth across the test sample at a programmable speed and for a programmable number of cycles. A number of weights are available so that the abrasion can be varied across a broad range of pressures. A similar manual device was also considered, but it was decided that the electric motor made the Sutherland easier to use and largely eliminated operator differences as a source of noise in the test.

Preliminary tests showed that abrasion manifested itself in several ways: density loss in dark patches as colorant was scraped off, changes in surface gloss, and smearing of colorant from dark patches to adjacent white patches. The objective monitoring of samples for damage would have to track these manifestations of abrasion damage. For example, in samples with smudging it was found that visual ranking of samples correlated well with percent density change and average gray value change in the adjacent white patch with Spearman's rank correlation coefficient values of 0.90 and 0.89 respectively (Salesin et al. 2008). It was interesting to see that other parameters—such as density change in the black patch and gloss change with Spearman's rank correlation values of 0.62 and 0.27 respectively—did not correlate as well to visual evaluation. By far, smudging of colorant into the adjacent white area was the most objectionable effect of abrasion. Even when gloss change values or density change values were quite large, the visual change in the sample was usually not considered to be very significant.

METHOD

The remainder of the paper deals with two aspects of the project: the relative effects of common abrasive surfaces and the relative vulnerability of a range of print types and papers to abrasion. This method section as well as the analysis section will therefore be divided into two parts.

Abrasive Surfaces

Sample materials included the following:

- Digital press on glossy paper (Samples L, M, N)
- Offset printing on glossy paper (Sample O)
- Black-and-white electrophotography (laser prints) on office copy paper (Sample G)
- Color electrophotography on office copy paper (Sample H)
- Solid inkjet on office copy paper (Sample F)
- Dye inkjet on porous-coated and polymer-coated photo papers (Samples A and B)
- Dye inkjet on office copy paper (Sample D)
- Pigment inkjet on photo paper (porous-coated) (Sample C)
- Pigment inkjet on office copy paper (Sample E)
- Dye sublimation, also called dye sub, dye diffusion thermal transfer, or D2T2 (Samples I and J)
- Digitally printed chromogenic photographic paper (Sample K)

Dye sublimation printing requires a mated paper for the printer and therefore has no paper type specified.

Polymer-coated paper, also called swellable paper, has a swellable polymer coating, usually gelatin or a combination of gelatin and polyvinyl alcohol. This type of paper is a direct descendent of traditional photographic paper. It is currently used only for dye-based ink. The ink is absorbed into the coating, causing the coating to swell. This paper has the disadvantage of being slower to reach touch-dryness, as the coating remains sticky until the water and additives in the ink have dried. As a result, printer through-put is necessarily slower.

Porous-coated paper, also called instant-drying paper, is produced by mixing an inorganic material, typically silica or alumina, with a polymer to make a paper coating that contains pores. Macro-porous paper has the largest pores and is only available in a matte surface. Micro- and nano-porous papers can be quite glossy. This paper acts by absorbing the water from ink into the pores and holding the water in a lower layer of the paper. The surface becomes dry to the touch almost instantly, and therefore printer through-put can be quite fast without the risk of stacked prints sticking together (IPI 2008).

In all cases, three replicate specimens were run.

Four common abrading surfaces were used for comparison: the back side of an identical print paper, a typical envelope paper, a typical interleaving paper, and polyester film, such as is used to make sleeves. A very small amount of very fine silica is added to one or both sides of the polyester film as an anti-blocking agent to prevent sleeves from sticking together when they are stacked. This silica has not been found to be a significant cause of abrasion with conventional photographic materials.

The abrading surface was mounted to the moving arm of the Sutherland rub tester, and the test prints were abraded with two pounds of weight on the arm, producing a pressure of 1.7 kPa or 0.25 psi for 100 cycles.

Print Vulnerability

In this part of the experiment a wider range of print types and papers was used. A total of 57 printer/paper combinations were tested including multiple brands representing the following generic combinations:

- Liquid toner digital press on glossy paper
- Solid toner digital press on glossy paper
- Offset lithography on glossy paper
- Black-and-white electrophotography on laser-print-specific office paper
- Black-and-white electrophotography on non-recycled office copy paper
- Black-and-white electrophotograph on 100% recycled copy paper
- Color electrophotography on color laser-print-specific office paper
- Color electrophotography on non-recycled office copy paper
- Color electrophotography on 100% recycled copy paper
- Solid inkjet on color laser-print-specific office paper
- Solid Inkjet on non-recycled office copy paper
- Solid inkjet on 100% recycled copy paper
- Dye inkjet on photo-coated paper
- Pigment inkjet on fine art paper
- Dye inkjet on inkjet-specific office paper
- Dye inkjet on non-recycled office copy paper
- Dye inkjet on 100% recycled copy paper
- Pigment inkjet on inkjet-specific office paper
- Pigment inkjet on non-recycled office copy paper
- Pigment inkjet on 100% recycled copy paper
- Dye sublimation prints
- Digitally printed chromogenic prints

These samples were abraded with envelope paper only using the same pressure and number of cycles as for the abrasive surfaces study. Again, three replicate specimens were run for all printer/paper combinations.

MEASUREMENTS

Objective measurements were made on all specimens using the following three devices:

The BYK Gardener Micro-TRI-Gloss meter measures gloss at three angles to the surface normal. Highly glossy materials are measured with the incident light and detector at 20° to the surface normal. Moderately glossy materials are measured at 60°, and matte surfaces are measured at 85°. The rule of thumb for measurement is that one starts with the 60° angle and if the reading is less than 10, then the surface is matte and 85° should be used. If the 60° reading is greater than 70, then the surface is glossy and 20° should be used.

The GretagMacbeth Spectrolino spectrophotometer was used to make optical density and colorimetric readings. Density measurements conformed to ANSI/ISO status A (ISO 1995a, 1995b).

ImageXpert image analysis software takes a specified area of a scanned image and assigns an eight-bit brightness level to each pixel in the area of interest, ranging from 0 (black) to 255 (white). The average brightness level for all of the pixels in the area of interest is called the *average gray value*. For the one-half inch by one-half inch square used in this project, there were 4,481,689 non-random measurements averaged.

With both the gloss meter and spectrophotometer, three random readings were taken on each of the three replicate specimens before and after abrasion.

ANALYSIS

In all cases, it was assumed that the direction of change in gloss, density, or average gray was not important, but the degree of change was. Therefore, absolute change values for these three measurements were used in the analysis.

Abrasive Surfaces

Analysis was performed in three ways: visual examination, comparison of average change by printer/paper combination per abrader per measurement parameter, statistical calculation using the Whitney-Mann U test or equivalent rank sum test to compare pools of data containing all absolute change values for all printer/paper combinations for each test parameter and abrading surface. One pool might contain absolute change values for gloss measurements with polyester film as the abrading surface. Another might be average gray value change in the black patch with interleaving paper as the abrading surface. This kind of general analysis was potentially problematic for the print verso abrading surface, since the abrader changed with the paper used. Other abrading surfaces remained constant over all of the paper/printer combinations. Comparisons between data pools produced one of three outcomes: the two were equivalent to a 95% confidence, A was worse than B to a 95% confidence, or B was worse than A to a 95% confidence. These paired results were then combined to produce an overall rank order for the abrading surfaces by test parameter.

The general result was that polyester film was less abrasive than envelope paper, interleaving paper, or print verso, and that print verso was apparently the most abrasive surface (table 1). However, the values that went into this result were highly variable by printer/paper combination so the result has to be considered in conjunction with the results from the print vulnerability study (tables 2–4).

Abrading surface	Average gray in black patch	Average gray in white patch (smear)	Gloss
Verso	1	7	3
Polyester	0	0	1
Envelope Paper	1	6	2
Interleaving Paper	0	6	3

Table 1. Average changes in three parameters across all samples for abrasive surfaces study

	Sample														
Abrading surface	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Verso	0	0	3	1	1	1	2	0	0	1	1	0	2	1	0
Polyester	0	0	1	0	0	0	0	0	0	0		0	0	0	0
Envelope paper	0	0	2	1	2	1	1	0	1	0	0	0	3	6	0
Interleaving paper	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0

Table 2. Changes in average gray in the black patch by abrading surface and sample for abrasive surfaces study

	Sample														
Abrading surface	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Verso	0	2	13	40	4	1	33	2	0	1	0	0	1	1	1
Polyester	0	0	0	0	1	1	2	1	0	1	0	0	0	0	0
Envelope paper	3	0	16	33	13	2	17	1	0	0	0	1	2	2	1
Interleaving paper	2	0	5	59	14	1	10	0	0	0	0	1	0	1	1

Table 3. Changes in average gray in the white patch (smear) by abrading surface and sample for abrasive surfaces study

	Sample														
Abrading surface	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Verso	2	0	2	2	1	3	9	1	4	7	4	0	5	2	0
Polyester	1	2	0	0	0	1	0	2	2	3	4	0	0	0	0
Envelope paper	0	7	1	1	1	4	4	0	1	0	2	1	1	5	1
Interleaving paper	11	8	1	2	1	5	4	1	6	0	2	1	0	0	0

Table 4. Changes in gloss by abrading surface and sample for abrasive surfaces study

Print Vulnerability

As with the abrasive surface study, analysis of this part was performed in three ways: visual examination, comparison of average change values by parameter and printer/paper combination, and rank sum test.

Some general conclusions could be drawn from this analysis, although results could vary considerably from paper to paper for the same printer. Pigment inkjet generally performed quite poorly with regard to abrasion, although it was no surprise, since the colorant sits on top of the paper surface. Color electrophotography was one of the best products. On all three papers, it was in the top eight printer/paper combinations. This is also not necessarily a surprising result, even though the image sits on the top surface as the pigment inkjet does. The difference is that, in laser prints, the colorant is bound in a polymer that is melt-extruded into the paper. What was surprising was that the best black-and-white electrophotography/paper combination was worse than the worst color electrophotography/paper combination. Chromogenic, offset lithography, dye sublimation, and liquid digital press rounded out the top-performing processes. Printer/paper combinations that were in the middle were either mediocre

	Average Gray Value Change in Black Patch		Average Gray Value Change in White Patch (Smear)		Gloss Change	
Print Type	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Inkjet fine art 1	2	0.4	36	11.8	2	0.4
Inkjet fine art 2	2	1.0	5	7.1	4	1.7
Inkjet dye office	1	0.5	13	15.9	3	2.9
Inkjet pigment office	2	0.4	21	12.5	3	2.4
Inkjet photo	0	0.2	1	1.3	4	2.8
Inkjet solid	1	0.2	1	0.2	5	1.3
Black-and-white electrophotographic (EP)	1	0.6	9	8.6	4	2.9
Color EP	1	0.9	1	1.3	1	1.0
Dye sublimation	0	0.1	0	0.4	3	2.5
Chromogenic	0	0.0	1	0.5	2	2.4
Digital press liquid	0	0.1	1	0.2	0	0.2
Digital press solid	4	2.3	2	0.9	3	2.2
Offset lithography	0	0.0	1	0.4	1	0.8

Table 5. Average and standard deviation of three parameter changes by generic print type for print vulnerability study

performers in all test parameters or they were excellent in some parameters and poor in other parameters.

However, as with abrasive surface study, results were quite variable and care must be taken before jumping to conclusions based on generalized results (table 5). This table is mostly divided by generic process with measurements averaged over all of the test papers (where used). However, in a couple of cases, specific products were broken out to show differences that were considered to be important. One difference was that digital press with liquid toner was the second-best performer while digital press with solid toner came sixth from the bottom (out of 23). A second difference was that the two fine art papers performed quite differently, although neither was especially resistant to abrasion. All three fine art printers used pigmented inks, but apparently the papers had an impact on how well the pigment adhered to the paper.

RESULTS

From the abrasive surface study, the general conclusion is that polyester film makes the least abrasive surface and the print verso was, relatively speaking, the most abrasive surface overall. As expected, the abrasiveness of the print verso varied quite a bit from printer/paper combination to printer/paper combination, but overall, it was the worst surface for abrasion. However, results were quite variable, so one must consider the results of the print vulnerability study as well.

Results from the abrasive surfaces and print vulnerability studies together led to the following recommendations:

- Archival materials that are quite vulnerable to abrasion damage, such as pigment inkjet prints, should be stored in a polyester enclosure (one print per enclosure) or protected with a polyester cover sheet or interleaving.
- All fine art prints, prints for which even small changes in gloss might be intolerable, should also be stored in polyester enclosures or protected with a polyester cover or interleaving. Care must be taken that no pressure is applied to the polyester.
- Archival materials that are resistant to abrasion damage should be fine if handled and stored with reasonable care. This means that these materials would benefit from a protective enclosure, but a conservation treatment report with images, for example, printed on a color laser printer doesn't need to be rebound with each page in a sheet protector. Similarly, photo books printed on a liquid digital press or chromogenic system probably don't need to be rebound to fit interleaving sheets.

These recommendations are made based on relative rankings of abrasive surfaces and print processes. At this time it is not possible to evaluate the absolute abrasiveness of a print surface or the absolute sensitivity of any digital print process with respect to real life.

The outcome of this research will require that the people charged with the care of these objects be able to identify print processes.

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