5-1-2007

Rub, fold, and abrasion resistance testing of digitally printed documents

Nicholas DiSantis

Rub, Fold, and Abrasion Resistance Testing of Digitally Printed Documents

by Nicholas E. DiSantis

A Thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the School of Print Media
in the College of Imaging Arts and Sciences
of the Rochester Institute of Technology

May 2007

Primary Thesis Advisor: Dr. Franziska Frey
Secondary Thesis Advisor: Dr. Scott Williams

School of Print Media
Rochester Institute of Technology
Rochester, New York

Certificate of Approval

Rub, Fold, and Abrasion Resistance Testing of Digitally Printed Documents

This is to certify that the Master's Thesis of

Nicholas E. DiSantis

has been approved by the Thesis Committee as satisfactory
for the thesis requirement for the Master of Science degree
at the convocation of

May 26, 2007

Thesis Committee:

____
Primary Thesis Advisor

____
Secondary Thesis Advisor

____
Graduate Thesis Coordinator

____
Graduate Program Coordinator

____
Chair, SPM

Rub, Fold, and Abrasion Resistance Testing of Digitally Printed Documents

I, Nicholas E. DiSantis, hereby grant permission to the Wallace Memorial Library of R.I.T. to reproduce my thesis in whole or in part. Any reproduction will not be for commercial use or profit.

Date____________________________ Signature__________________________

In loving memory of Nicholas Myron DiSantis

Founder of Quality Printing Company

Pittsfield, Massachusetts

Acknowledgements

I would like to thank my mother, Judith, and my father, John DiSantis, for their love and support throughout my academic career. These two individuals have provided me with the tools necessary to get as far as I have come today. I would also like to thank my Thesis Committee for giving me the necessary feedback and support that allowed for the completion of this research and creation of this document. Lastly, I thank my sister, Stephanie DiSantis, for her time and skill spent editing this document.

Table of Contents

List of Tables

List of Figures

Abstract

The life cycle of commercially printed digital documents (in particular, marketing and promotional items, direct mailers, business communications, and on-demand color books) was examined to find stress points where potential permanence problems could exist. The stress and life cycle overview covers the stages of processes in printing and finishing, mailing preparation and fulfillment, distribution, usage, and recycling. Stress points found in the different stages of the life cycle, whether physical or chemical, include (but are not limited to) scratching, rubbing, cracking, solvent exposure, light exposure, moisture exposure, heat exposure, and air contamination exposure.

Tests for abrasion resistance, folding resistance, solvent resistance, light-fastness, water-fastness, thermostability, and gas/ozone fastness were researched. Based on a survey given to randomly selected printers, printing press vendors, and print buyers, the tests for abrasion resistance, folding resistance, and rub resistance were selected. Using offset lithography as a benchmark, three commercial digital presses as well as high-speed ink jet technology were included in this testing.

Using a combination of solid circular test targets and the "Three Musicians" test target (an image for visual comparisons), the Taber Abraser testing method, the Sutherland Rub testing method, and a folding procedure outlined in ASTM document F 1351 were used to examine and to compare the five presses in this study (three commercial digital presses, one offset lithographic press, and one high-speed ink jet press). After testing was performed, visual ranking, changes in density, Delta E, and the abrasion resistance index were used as the criteria to evaluate results.

Testing results showed that the high-speed ink jet held up the best in each test performed during this research; however, the image quality of the high-speed ink jet press was less than the image quality of any other press in this study. The second best performer in the testing was the offset lithographic press. The test performance of these particular presses, as compared with the commercial digital presses, was attributed to the different drying methods in each of the different printing technologies. In the ink jet and lithographic presses, the evaporation, absorption, and oxidation drying methods seemed to hold up better to the testing performed than the drying method of toner-based technology. With oxidation and evaporation, the image (i.e., the ink) actually becomes a part of the paper after drying, whereas, in toner technology, the image (i.e., the toner) is fused to the paper and actually sits on top of it. Within the digital printing industry, coatings have been put in place to alleviate some of these problems, but they have not been tested here. This research shows that offset lithography is the dominant technology in terms of offering abrasion and folding resistance of its printed product.

Chapter 1

Introduction

Background

Digital printing is increasingly used today across a wide range of products. Some digital prints are used for marketing, others for books, and still others for lasting keepsakes. Regardless of the intended use, every printed product has a life cycle, and the product is expected to meet or exceed that life cycle. However, based on personal experience and comments from professionals involved in digital printing, some printed products cannot live up to the customer's expectations. This leads users to consider the limitations of digital printing in terms of permanence.

As defined by *Delmar's Dictionary of Digital Printing and Publishing* (1997), permanence is described with relevance to a paper's (i.e., substrate) ability to resist change in its characteristics and properties over a length of time (Romano). In this research, permanence also includes the printed image's ability to resist changes in characteristics and properties over a period of time. The definition of permanence is highly dependent upon the type and purpose of the printed product that one is rating. For example, the Declaration of Independence is an important document archived in Washington, D.C. This document has very different permanence expectations than that of a daily newspaper, which needs to last a mere fraction of the time; thus, the definition of permanence in that case has two different meanings. In this research, permanence is

defined in terms of the appearance of a final printed product, specifically resistance to light exposure, density changes, scratching/abrasion, humidity, water exposure, smearing/rubbing, and chemical exposure (i.e., ozone) (Johnson, 2003).

Independent researchers, educational facilities, manufacturers, vendors, and distributors today are doing much research in the permanence field; however, these researchers have focused more on permanence issues of desktop printing technology (Johnson, 2003). Much less research on the commercial segment of the industry has been conducted.

This document examines the life cycle of marketing and promotional documents, direct mailers, transactional and business documents, and on-demand color books. Its goal is to point out stress points in the life cycle by performing tests to see how certain printing technologies hold up against these stress points.

The Problem

Although Henry Wilhelm, president of Wilhelm Imaging Research, Inc., has conducted much independent research testing permanence of desktop ink jet systems, similar testing in the digital commercial sector is lacking. Press manufacturers and vendors most likely do their own testing, and the Rochester Institute of Technology (RIT) Printing Applications Laboratory has also been approached to conduct testing, yet little research relating to this topic has been published to this researcher's knowledge. In addition, permanence seems to be an issue in the printing industry, regardless of the technology being used.

With the growing popularity of print on demand, variable data, short-run printing, etc., the commercial digital printing sector is in need of permanence performance measures. Based upon an examination of the digital product life cycle and results from specific testing, this research will benefit RIT, as well as printers, print buyers, and vendors in the following ways:

- Printers and print buyers can assimilate the strengths and limitations of current commercial digital printing with their production needs.
- Printers and print buyers can determine what stresses digital products can withstand before the print run begins, rather than after the print run, when it is too late.
- Printing press manufacturers can identify some areas where their products need improvement.

Significance

Raymond Prince of North American Printing Leadership (NAPL) states that rub resistance during the mailing process is of particular concern to many of his current clients (personal communication, 2006). In this research, rub resistance, abrasion resistance, and other categories of stresses that occur during the mailing stages of the product's life cycle are being tested.

Another significant fact is that the markets for direct mailing, variable data, variable imaging, and fulfillment services provided by digital press technology are

growing daily. Direct mailing accounted for over $29 billion, or 11%, of the United States advertising expenditures in 1998 (The Status and Future of Direct Mail, 1999). In 2005, this expenditure increased to $70 billion. With over $70 billion worth of print being mailed, and digital technology gaining market share exponentially, permanence is a major problem. It is a problem that must be dealt with quickly if digital printing is to continue to capture market share (2005 Tech Forecast, 2005). Table 1 identifies by sector some of the markets that digital printing technology is taking over.

Table 1. Areas of printing that digital technology is taking over
(Source: Graphic Arts Marketing Information Service 2004)

FINANCE & BANKING	401K	Investments	Bills	Statements	Accounts	Calendars
RETAIL	Grocery	Coupons	Fliers	Catalogs	Promotional	Labeling
INDUSTRIAL / MANUFACTURING	Trigger mailings	End of lease reminders	Service	Customized statements	New products	Internet
INSURANCE	Customized direct mail services	Marketing	Benefit books	Statements		
TRAVEL / LEISURE / GAMING	Statements / Rewards	Brochures	Customized direct mailings	Membership books	Ticket sales	Children's books
EDUCATION	Report cards	Customized mailers	Personalized mailers	Customized course packets and books	Alumni and fundraising booklets	
PHARMACEUTICAL / HEALTH CARE	Newsletters	Handbooks	Membership cards	Brochures	Programs	
NON-PROFIT / CHARITY	Red Cross	Churches	Schools			
REAL ESTATE	Listings	Post cards				
GOVERNMENT	Lobbying	Government Documents	Government publishing			
OTHER	Restaurants / Bars promotional	Telecommunications				

Reasons for Interest in the Study

Having worked and become certified as a commercial digital press operator before attending RIT, this researcher was drawn by a personal issue to the study of permanence in digital printing. Being involved in a family-owned printing business that has invested in a commercial digital press, this researcher has become aware of the many problems that digital prints have throughout the finishing, distribution, and mailing processes. The prints are susceptible to damage resulting from scratching, rubbing, and

other stresses throughout the products' life cycle. The press manufacturers do not offer many solutions to fix the problem, so this researcher has become interested in finding out how to deal with the problems.

A review of the literature has revealed only a few published resources relating to permanence of commercial digital documents. Problems have been found, not only in the lack of permanence research, but also in the post-printing stage of commercial digital product life cycles. Of particular concern are the problems with digital prints during the mailing process. Some printing cannot withstand the mailing process, which is costing the industry in reprinting costs and dissatisfied customers.

It is up to the press manufacturers to remedy problems with their technology and to offer solutions to problems that are identified in this research. Based on carefully chosen testing to mimic real-world stresses induced on prints, assessments and comparisons are made that can be used to predict the performance of certain documents printed by specific presses, according to their end-use requirements.

Chapter 2

Literature Review

Introduction

With technology expanding at an incredible rate, printing has gone through many changes, the most recent phase being the digital revolution. Digital technology has brought with it more automation and better efficiency, and has made many earlier processes close to obsolete (Cost, 2005). Despite all of these exciting attributes that the digital era brings to the printing industry, it has also created new permanence issues. As defined earlier by *Delmar's Dictionary of Digital Printing and Publishing*, permanence is described with relevance to a paper's ability to resist change in its characteristics and properties over a length of time (Romano, 1997). For the purpose of this research, permanence is anything that alters the appearance of a final printed product, specifically resistance to light exposure, density changes, scratching, humidity, water exposure, smearing, and chemical exposure.

Permanence in digital printing has as much to do with the printing process as with the ink and substrates used. The issue of permanence begins with the printing process, yet many other variables come into play when one takes into consideration finishing methods (i.e., folding, cutting, packaging, etc.) and the product's end use. For example, a

product that is used for a mailing will require different properties than those of another kind of product, such as a map.

The main objective of this study focuses on the life cycle of digital prints and the stress points in each stage of the life cycle that may pose problems in the performance and/or permanence of the digital piece. These stresses, including the chemical and physical stresses, will be discussed from the printing and finishing stages of the product life cycle all the way through the recycling stage.

This study is also limited to the following four categories of digital documents: marketing and promotional pieces, direct mailers, transactional and business documents, and on-demand color books. These four categories have been selected because they have been identified by printing industry leaders as being a major part of the future of digital color print (Frey, 2006). According to Andrew Paparozzi, of NAPL (2005), "Demand for color, design, and customization is growing as clients recognize the power of timely, visually compelling, personalized printing" (n.p.). The documents in this study all stem from this statement by Paparozzi in the NAPL State of the Industry Survey. This belief of the exponential growth expected of digital printing is further discussed by Davis (2005):

> …within all print market segments digital printing is growing faster than traditional ink-on-paper printing. Sales revenues from digital printing has been growing two to four times the rate of growth of traditional ink-on-paper printing over the past couple of years and this trend should continue (p. 7).

Life Cycle Terminology and Focus

According to Frey (2006), life cycle theory:

> …is described as a framework for describing a system in constant change. The change is described as the development that these systems undergo throughout the stages of its life cycle. A stage will therefore require processes that are adjusted to the development of that particular stage. Even though life cycle theory has its origin in biology, it has spread into less organic sectors such as the software industry, the managerial field, electrical engineering, environmental research, and architecture and construction. Due to the diversification of these scientific and industrial areas, divergent life cycle terminologies have been created (n.p).

Secondary research on life cycle theory revealed only findings outlining the transformation from electronic forms to print or microfilms; nothing was found outlining the life cycle of documents within the four categories discussed in this research. Therefore, working backwards, here we define a life cycle that works for this research and apply a similar source to each stage of the life cycle. One life cycle theory that proved promising and fitting relates to the industrial sector, as stated by Järvenpää (2004):

> The industrial cluster is working with very complex entities, which are associated with huge amounts of knowledge. The life cycle theory provides a mental framework for this environment. It claims the different stages of a product or service require different operations performed. The approach emphasizes the complexity of issues and provides an opportunity to define what is important in each stage of the development (p. 6).

Similarly, this research has been confined to the life cycle of digitally printed documents between the printing phase and recycling phase of a document's life cycle. These stages are the printing, finishing, distribution, usage, and recycling stages. This life cycle research refers to the stages of a document's life cycle where stresses, either

physical or chemical, are introduced to the product. However, since we have a set of four different categories of documents being researched here (all of which may differ in production in some way), an overview of certain processes and the stages in its life cycle is provided (Frey, 2006).

Stress Induction on Print

There are many variables among the characteristics of the document types examined in this study, as well as the methods for printing them. For this reason, whether we are using ink jet, dry, or liquid toner, the type of substrate and the formulation of colorants play a role in the type of stress induced on the prints. Toner-based technologies are more susceptible to certain stresses than ink jet technology, and vice versa. Differences are also seen in stresses between dry and liquid toner technologies (Frey, 2006).

Efforts to improve permanence in ink jet technology have been focused on the following six fields: light-fastness, humidity-fastness, thermostability, solvent-fastness, water-fastness, and gas-fastness. Although ink jet does not seem to have many problems with abrasion, the preceding fields still remain problematic. This problem requires changes in not only the ink, but also the substrates that we are printing on (Kitamura, 2003).

Discussing toner technology, Sastri and Sankaran (2003) state, “Print evenness, toner adhesion, and good optical quality is essential…The output should be free of mottled appearance, have uniform optical density, and should be smear free” (p. 619).

Adhesion properties in toner technology are quite important and are dependent upon the following factors: the substrate, the toner type, and the fusing system. Pigments in toner do not show affinity towards the surface of a particular substrate and, therefore, render the resin in the toner the underlying factor in the adhesion process between the toner and substrate. Sipi (2003) describes this problem further:

> There are a few main theories for explaining the principles of adhesion on polymeric materials, but they have not been directly structured for toner adhesion. The general theories entail both mechanical and chemical adhesion. When paper is the receiving layer, both types of adhesion are involved (p. 145).

This adhesion problem with toner technology can wreak havoc on a print run in the post press operations and/or in the distribution process. Mailing can also be particularly harmful to toner-based digital prints. The equipment used by the United States Postal Service (USPS) to sort mail uses spinning wheels that can abrade the surfaces of the print. The heat generated by these wheels can reach and exceed "…[the] glass transition temperature (Tg) of the resin used, which can cause contamination with pigmented toner resin on the next coming papers" (Deprez, 2003, p. 487).

Keeping the preceding factors in mind and bringing in other permanence problems with printing, this researcher has developed Table 2 which shows specific test types that this research will focus on, the specific tests that can be done, and the testing instruments required for each test.

Table 2. Stress types, testing, and instruments
(Source: Frey, 2006)

STRESS	TYPE	TEST	TESTING INSTRUMENT
Scratching / Rubbing	**Physical**	**Abrasion resistance** **Rubbing Resistance**	**-Taber Abrasion Tester** **-Sutherland Rub Tester**
Cracking	**Physical**	**Folding test**	**Fold Tester**
Solvent	**Chemical**	**Solvent resistance test**	**No Specific Instrument**
Light (UV)	**Chemical**	**Light-fastness**	**Fluorescent / Xenon Light Chamber**
Moisture	**Chemical**	**Humidity-fastness** **Water resistance DIN-16524-1**	**No Specific Instrument**
Heat	**Chemical**	**Thermostability**	**Oven**
Air contaminants	**Chemical**	**Gas-fastness, ozone test**	**Ozone Chamber**

Processes in the Printing Stage

Electrophotography

Many of the printing presses used in digital printing use electrophotography, which is much different than conventional printing technologies. This process, combined with digital imaging systems that the presses are equipped with, has provided a niche for cost-effective, short-run, high-quality printing. Unlike conventional offset printing technology, which has long set-up times and uses costly plates to transfer the image to the

substrate, data can now be sent directly to the press from a computer and from the computer file; it can then be printed within minutes with little set-up time. Digital press technology is quite different than that of traditional offset; yet it has become strikingly similar to offset in quality (Digital Offset Introduction, n.d.). With electrophotography, as stated before, the ink sits atop the paper and does not sink into the actual substrate, as other printing processes are designed to do (Fischer, 2005). All three commercial digital presses studied here share this attribute. While this process yields bright and vibrant colors, it also exacerbates the permanence problem because the ink is not actually part of the paper; it is merely fused to it. The finished product from a digital press is susceptible to scratching and can be altered by finishing techniques or other elements, such as mailing, ultraviolet exposure, chemical exposure, and humidity (Krasne, 2002).

Electrophotographic printing is a big business and accounts for approximately 12% of the total paper purchased in 2003. The commercial digital presses in this study all use some form of electrophotography to print. This process uses electricity and positive and negative charges to attract and to repel inks and toner to an image. The image is first exposed to a photoconductive drum or belt using lasers and/or rotating mirrors. Once the image is exposed to the drum, an image area is created which is negatively charged. The drum is then exposed to positively charged toner particles, which cling only to the negatively charged image area on the drum. The image area now contains the toner, which remains positively charged on the drum and is carried around until it contacts the substrate, which also has a minimal charge, allowing the toner to jump from the drum to the substrate, thus creating a printed image. Toners can be either

dry or liquid; once on the substrate, the toners pass through rollers, which, depending on the press and the process, fix the toner to the substrate, using either hot- or cold-setting methods. The end result is the toner (thermoplastic powder or liquid) dries immediately atop the substrate and is ready for finishing or for its particular end use (The Effect of New Printing, 2003).

Ink Jet Technology

Ink jet technology differs from electrophotography, in that the ink does not sit atop the paper; it is absorbed much like it is in offset printing. The ink used in ink jet printers applies ink directly to the substrate in small drops from ink-dispensing nozzles. Because the ink is applied directly from the nozzles to the substrate, the type of paper used is extremely important (Kipphan, 2001).

Instead of being fused, as in electrophotographic technology, ink jet technology uses a combination of evaporation and absorption to print, with water- and solvent-based inks (Kipphan, 2001). In effect, the major difference between toner-based digital printing and ink jet printing is the absorption. Toner does not absorb into the substrate, as the inks do in ink jet printing. Therefore, abrasion and adhesion permanence is not much of an issue when it comes to ink jet. On the other hand, toner-based digital printing has many problems with abrasion resistance and adhesion (Frey, 2006).

Processes in the Finishing Stage

Electrophotographic digital printing, as previously stated, has many problems with abrasion and adhesion. The finishing process that prints are put through, post-press, introduce many of these types of stresses on digital print.

Processes in the finishing stage include folding, stitching, binding, cutting, and die cutting. As Kipphan (2001) explains:

> Folding is the sharp-edged bending of paper webs or sheets under pressure at a prepared or unprepared bending point along a straight line according to specified dimensions and folding layouts (p. 796)…[Stitching is] a for-fit jointing method. With wire-stitching binding, wire staples are pushed through sheets of a block and closed on the underside (p. 839).

Wire comb binding can be split into three different sections: wire-o bound, plastic bound, or spiral bound. In all three cases, a metal or plastic wire is inserted into holes drilled into the sample, and the sample is bound. Perfect binding can be split into two sections: notch binding/tape binding, and flexo-stable binding. Kipphan (2001) describes them both:

> Notch binding: This process (also referred to as perforating binding) occurs in two stages. Firstly the back edge is perforated in the folder using a special punch knife, so that the grooves can be filled with adhesive. Gluing the spine and back stripping of the block takes place in the perfect binder. The spine routing station is put out of action.
> Flexo-stable binding: Flexo-stable binding describes the aim of obtaining maximum perfect binding strength. Here the back edges in the area of the head and foot trim are not routed off. This requires an additional control of the routing unit in the perfect binder. To reinforce the opening hinge and to counter-balance the spine, a felt strip is glued in the area routed off. The join is covered with a backing strip. (p. 832)

Die cutting can be compared to the use of a cookie cutter to punch out large volumes of a substrate at the same time; it is basically the cookie cutter ideology on a

much larger scale for printing. Lastly, Kipphan (2001) describes this process for cutting and trimming: "blocks for hard covers and brochures are cut on one, three, or four sides to the final format, whereby the closed fold edges on the head, foot, and front side of the block are eliminated, if this is intended for the product" (p. 842). Each of these processes exerts stress on the printed product, as seen in Table 3.

Table 3. Stresses induced on a print in the finishing stage of the life cycle
(Source: Frey, 2006)

Process	**Stress Type**	**Stress Type**
Folding	Physical	Cracking
Stitching	Physical	Cracking
Wire comb binding / tape binding	Physical	Scratching, cracking
Die-cutting	Physical	Scratching, cracking
Perfect binding	Physical	Scratching, cracking
Trimming	Physical	Scratching

Processes in the Mail Preparation and Mailing Stage

The mailing process is particularly grueling for all printed pieces, but particularly for digitally printed pieces. Direct mailers created with toner-based, digital printing typically experience more damage than do direct mailers created by any other printing technology. According to C. Clint Bolte (2005), reporting on the PIA/GATF Tech Alert 2005 Conference, "It seems that the various USPS (United States Postal Service) high-speed sorting equipment scrape, scuff, scratch, and rub the digital toners leaving streaks, smears and unsightly cringles at a frustratingly high proportion of the total project run."

(p. 4). Bolte also indicated that press vendors have provided coatings to try to combat this problem, and although it has helped, it has definitely not eliminated the problem.

Companies dealing with direct mailings are usually not concerned with light and ultraviolet radiation fading the prints. Normally, direct mailings are not archived and are more of a marketing tool than anything else; hence, the shelf life of these documents is not very long. However, image quality and the overall look of the final document when it reaches the end user are important in this thriving field of printing. Therefore, humidity, water exposure, temperature, smearing, handling procedures, and scratching are all areas of permanence that a printer needs to be aware of when printing bulk mailers (Bolte, 2005).

Humidity and water exposure can also negatively affect printing. They not only affect the substrate, but distort the inked image on the substrate, as well. This is a much bigger problem during the summer in Northern climates and in the South where humidity and temperature are regularly high. High humidity, coupled with high temperatures, will curl paper and speed up the chemical decomposition of the printed piece. In colder regions, humidity in the winter is of little concern; however, water exposure in all climates is a major concern, especially for bulk mailers. Mail may travel long distances and cover a wide array of climates in a short period of time. It can be exposed to rain, snow, or other weather-related phenomenon. Bulk mailers must be able to withstand this exposure and still look presentable when they reach the end user (Johnson, 2003).

PIA/GATF has teamed up with the USPS, printing press vendors, printers, and digital paper mills to conduct a study to try to pinpoint and to alleviate some of the

problems the industry is having with digital mailers. Their primary objective is to see how the different treatments of ultraviolet coatings, aqueous coatings, or varnishes affect the performance and permanence of the digitally printed piece throughout the mailing process. They soon realized that this would not be the core of their research (Bolte, 2005).

The USPS states that their sorting equipment was primarily designed to handle standard-sized envelopes. The majority of digital mailings are not standard-sized envelopes and are, in fact, quite the opposite with savvy designers getting more and more creative every day. A 2005 mailing study revealed that less than one-third of the mailers arrived at the destination and more than one-quarter were damaged. This leaves much work to be done, as this problem is a high priority for interested parties. Since more and more mail is printed digitally, this problem needs to be addressed and solved immediately. As of June 21, 2006, the final results of the PIA/GATF joint study have not been released (Bolte, 2005).

Processes in the Fulfillment Stage

Mailing and fulfillment are usually tied together because sometimes fulfillment can include mailing. Whatever the case, fulfillment is viewed as a value-added service, which more and more printing companies today claim to be involved in. According to Twyla Cummings' *Industry Trends in Fulfillment, Finishing and Distribution* (2004), fulfillment is defined as "the storing and distribution of products directly to end users, after the initial job has been printed and mailed" (p. 10). This simple definition clearly

states what fulfillment is all about: the customer. As competition in the printing industry increases, this simple definition continues to mean much more (Cummings and Chhita, 2004).

Fulfillment services have grown from simple operations to multifaceted, real-time, Internet-based programs that customers can work and monitor directly. These interfaces can monitor and allow the customer to interact with storage, management, and distribution concerns of their products at the click of a button. Print buyers want a "one-stop shop for it all," and fulfillment houses are supplying just that (Cummings and Chhita, 2004).

According to Cummings and Chhita, the three types of fulfillment are literature fulfillment, product fulfillment, and Internet fulfillment or e-fulfillment. They state:

> [Literature fulfillment is the]…physical distribution of company information such as brochures, point-of-purchase (POP) displays, and product catalogs. Typically, the customers request the assistance of the printer in designing, printing the informational document, product finishing, warehousing, and ultimately distribution to individuals and businesses.
>
> [Product fulfillment is the]…distribution of goods such as magazines, CDs, audiotapes, free samples, and premiums to retail outlets, subscribers or consumers. Typically, for example, the printer would assemble kits containing printed postcards, booklets, and other promotional items and then ship them directly to the customers.
>
> [Internet fulfillment or e-fulfillment is the]…electronic distribution of a requested product such as coupons and certificates or company information or literature such as newsletters, brochures or flyers. This type of fulfillment is least utilized by printers, since the value proposition is still being explored (p. 10).

Fulfillment incorporates many stages in a product's life cycle; therefore, it is a significant area to study. Internet fulfillment obviously has no bearing on the product life-cycle stresses because there is no printed product; however, literature and product fulfillment cover a wide array of stresses. These two categories carry with them the stresses induced by printing, finishing, and distribution (Cummings and Chhita, 2004), which are covered in the next section.

Processes in the Distribution Stage

Distribution normally takes place after finishing, when a printed product is sent directly to the customer, end user, distributor, warehouse, or database (Kipphan, 2001). For printing companies or third parties handling distribution, the following factors are of utmost concern: costs, handling procedures, storage, and safety. Because of these factors, distribution is a key part of the digital print life cycle; in most cases, it is the final stage before the printed product reaches the end user. A vital shift in distribution trends has occurred in the past few years, addressing the concerns of the distributors. Historically, printing companies followed a print-and-distribute business model. This involved physically printing the product in one location, then delivering it directly to where it needed to go. A distribute-and-print business model has become increasingly popular. This model is derived from electronically distributing the files to be printed at a location closer to the original destination of the product, which dramatically reduces the stresses that are invoked by the distribution process and is a breakthrough in cost-efficiency, as well as in storage and safety (Cummings and Chhita, 2004).

Both the traditional and technologically advanced methods of distribution burden the print with stresses. The distribute-and-print model minimizes as much of the stresses as possible; however, stresses still include scratching, cracking, moisture, heat, and air contaminants. These stresses, as well as the stresses from mail preparation and mailing, fulfillment, and distribution are outlined more specifically in Table 4.

Table 4. Processes in the mail preparation and mailing, fulfillment, and distribution stages
(Source: Frey, 2006)

PROCESS	**DOCUMENT CATEGORY**	**STRESS CATEGORY**	**STRESS TYPE**
Collating	Direct Mail, Marketing & Promotional Materials, and Transactional & Business Communications	Physical	Scratching, cracking
Inserting	Direct Mail, Marketing & Promotional Materials, and Transactional & Business Communications	Physical	Scratching, cracking
Wrapping/packing	All	Physical/Chemical	Scratching, heat
Addressing	Direct Mail, Marketing & Promotional Materials, and Transactional & Business Communications	Physical/Chemical	Scratching, light, heat
Sorting	Direct Mail, Marketing & Promotional Materials, and Transactional & Business Communications	Physical/Chemical	Scratching, cracking, heat
Postage application	Direct Mail, Marketing & Promotional Materials, and Transactional & Business Communications	Physical/Chemical	Scratching, cracking, heat
Warehousing/storage	All	Physical/Chemical	Scratching, air contaminants
Transportation	All	Physical/Chemical	Scratching, cracking, moisture, heat
Delivery	All	Physical/Chemical	Scratching, cracking, moisture, heat

Processes in the Usage Stage

Although it is difficult to find literature on the user stages of the product life cycle in digital printing, the users are unique to the product. Permanence issues, quality, and archivability are, as mentioned previously, product dependent. Therefore, permanence can, in some cases, have many different meanings and interpretations (Johnson, 2003).

As discussed earlier, the principal categories of documents focused on in this study include: marketing and promotional materials, direct mail, transactional and business communications, and on-demand color books. These are all vastly different products, with different life expectancies, and with different user expectations of these life expectancies.

Normally, marketing and promotional materials do not have a long shelf life. They are, however, expected to be very presentable when they get to the end user. Because of their short shelf life, they do not need to excel in the archiving field, but must last long enough to survive the printing process, finishing process, and distribution process—all while maintaining a superior quality. With digitally printed products, this superior quality can be tough to sustain, more so than with products printed using other printing technologies.

Direct mail holds the same qualities as do the marketing and promotional materials. They do not have a long shelf life, but are expected to survive the grueling stages of printing, finishing, and distribution stages, and still look great when they reach the end user.

On the other hand, transactional and business documents follow a different suit. These documents usually hold some legal or contractual qualities; therefore, they are expected to last. These types of documents are commonly filed and kept for years. This means that this type of printing must be able to withstand all the aforementioned processes, yet also retain some archiving ability.

Lastly, on-demand color books do not hold as much value as the transactional and business documents; however, user expectations are the same. Books are meant to be read and are sometimes abused, but also they are often viewed as lasting keepsakes. These printed materials go though the harshest of conditions throughout their life cycle. They must deal with the printing, finishing, and distribution stages, as well as continuous use and prolonged exposure to the elements. This may be the only type of printed product discussed in this research that is exposed to every type of stress mentioned. Table 5 outlines the stresses in the user stage of the life cycle.

Table 5. Processes in the user stage
(Source: Frey, 2006)

PROCESS	**DOCUMENT CATEGORY**	**STRESS CATEGORY**	**STRESS TYPE**
Usage	Marketing & Promotional, Direct Mail	Physical/Chemical	Scratching, cracking, moisture, heat
	Transactional/Business Com.	Physical/Chemical	All but solvents
	On-Demand Color Books	Physical/Chemical	All

Processes in the Recycling Stage

The last stage in a digitally printed product's life cycle is recycling, i.e., the breaking down of ink and paper to be reused. This seemingly simple process, one that has been going on for years, has seen some complications in the digital era.

Conventionally, the recycling process begins in the flotation stage, where the de-inking of printing occurs. To improve and to aid in the ink release process, chemicals (such as caustic soda, sodium silicate, hydrogen peroxide, and soap) are introduced in the pulping stage, making slurry (Carre, Magnin, and Ayala, n.d.). In this process, the slurry of paper is subjected to rising air bubbles, which carry the ink particles from the paper to the top of the slurry. Once the ink particles have risen, due to the hydrophobic properties of the ink, they can easily be targeted and removed. However, most non-impact printing processes are difficult to process in this way. According to Bolanca, Agic, and Bauer (n.d.), non-impact printing inks,

> …unlike conventional printing inks, [toners] contain synthetic binders based on polyester or polymers of styrene with acrylates, methacrylates, or butadiene. The toners contain 90-95% resin, 3-5% colorant, 1-3% charge control agents and other technical additives (p. 2).

These binders make it difficult to complete the recycling process. During the first stage of the process, the toner tends to break up into very large particles, unlike conventional printing inks, some of which are too large to be removed in the processes (Bolanca, Agic, and Bauer, n.d.).

Other recycling techniques include screening, cleaning, washing, and dispersion. Screening consists of exactly what it implies: the pulp is screened through openings in a

fine web. This process is primarily used to remove large contaminants from the pulp. Washing is similar to screening, in that it removes unwanted contaminants through a screen with the addition of water. However, this process is seldom used, unless there is a need to remove mineral fillers for certain products, such as paper. Cleaning can be used to remove large or small contaminants in somewhat of a washing machine approach. As Carre, Magnin, and Ayala (n.d.) describe,

> Cleaning is based on particle separation in a centrifugal flow field. A swirling motion is created by the tangential inlet flow. The vortex motion creates centrifugal forces which causes the particles heavier than the stock to migrate to the outside of the cleaner, while the lightweight particles migrate toward the vortex core (p. 2).

Finally, dispersion is used to reduce residual contaminants. With the addition of heat, this process is used to rid the old product of adhesives, varnishes, toners, or coatings that may have been left over from previous recycling processes (Carre, Magnin, and Ayala, n.d.).

Areas that seem to be particularly problematic with recycling processes include use of ultraviolet inks, liquid toner, hot-melt ink jet prints, home and office ink jet prints using water-based pigment inks, and ultraviolet coatings. These specific printing types create problems in recycled paper with speck contamination, sticky deposits, low brightness, and pronounced color shade (Carre, Magnin, and Ayala, n.d.).

For the recycling process to be economical and able to create quality recycled papers, the toners must be almost completely removed from the pulp. With digital printing taking more and more of the market share away from traditional offset lithography, this could pose a serious problem in the future. However, testing has

indicated that the recycled paper produced from digital prints is just as good as that produced from offset prints. The recycled papers showed a

> …deterioration of properties such as burst strength, tensile strength, stretching and double fold…[however the] use of recycled fibers leads to an improvement in properties such as stiffness, tear resistance, porosity, opacity, and light scattering coefficient, because of the loss of swelling ability and fiber bending (Bolanca, Agic, and Bauer, n.d., p. 70).

Work still needs to be done on how to recycle digitally printed products more efficiently because they have the ability to produce equal quality recycled papers as offset; however, we do not currently have the technology to recycle it as well.

Summary and Conclusion

This chapter has reviewed literature outlining the life cycle of digitally printed marketing and promotional materials, transactional and business communications, direct mail, and on-demand color books. Focusing on the stresses involved in each stage of the life cycles, the goal of this research is to identify areas in digital print production and distribution that require more attention and research. No formal document was found outlining the full life cycle of digitally printed products, so the secondary research was observed through life cycle theory, based on the concepts of Järvenpää.

Digital printing is projected to be the fastest growing service over the next two years. As such, it is imperative that time and money be spent researching the subject. On-demand and variable data printing, only available on truly digital presses without a fixed image carrier, have proven to be valuable for consumers, provide opportunities for printers, and be extremely profitable for press vendors.

It is for this reason that this research examines the life cycle of digital printing: to discuss the strengths and weaknesses in this new era of print. In this research, the life cycle has been examined in the stages between the printing processes and recycling, namely, the stages of printing and finishing, mailing and fulfillment, distribution, usage, and recycling.

Each stress has been examined in every stage of the life cycle where it was found in the printing and finishing stages. No stress was involved in the actual printing; however, physical scratching and cracking occurred during finishing. During the mailing and fulfillment stages, scratching, cracking, heat, light, and air contaminants were seen as stresses induced on the printing. Similarly, scratching, cracking, heat, and moisture were seen as stress problems in the distribution stage. In the user stage, the printing was subjected to every type of stress found in Table 2. Lastly, the products were turned back into pulp in the recycling stage to produce recycled papers, where stresses were deemed irrelevant.

There is no secondary literature that this researcher could find on print life cycles, performance measures, or performance predictions of digitally printed materials using a full life cycle approach. With one-to-one marketing, variable data, and print-on-demand becoming so popular, this research is necessary for all professionals in all of the segments of the printing industry. If the expanding projections of digital printing hold true, these problems must be solved to help accommodate the digital transition.

Chapter 3

Research Questions

The primary objectives of this research are summarized in the following research questions:

1. What different types of stresses are associated with digitally printed products throughout their life cycle?

2. What are the concerns of a sample of printers, print buyers, and vendors with regard to digital print permanence?

3. How do the specific technologies (toner-based digital, lithographic, and ink jet digital) compare to each other with respect to abrasion resistance, rub resistance, and folding resistance testing?

Chapter 4

Project Methodology

Overview

The testing for this research involved Miami Systems in Cincinnati, Ohio; the Center for Integrated Manufacturing Studies (CIMS) facility at the Rochester Institute of Technology (RIT); the Printing Applications Laboratory (PAL) at RIT; the Print/Postal Hub at RIT; and the Imaging Products Laboratory (IPL) at RIT. Samples were printed on the three commercial digital presses, a high-speed ink jet press, and an offset lithographic press (Table 6).

Table 6. Materials used to print the test targets

PRESS	TECHNOLOGY	STOCK WEIGHT	SPECIFICS
Ink Jet	High Speed Ink Jet (HSIJ)	50#	Weyerhauser HSIJ treated, uncoated
Offset Litho	Lithographic	50#	Finch uncoated
Digital A	Electrophotography	80#	Xerox Color Xpressions Text
Digital B	Electrophotography	70#	UPM High Definition uncoated
Digital C	Electrophotography	70#	UPM High Definition uncoated

Testing capabilities in the IPL include ozone, folding, light-fastness with xenon light, water-fastness, rub testing, and abrasion testing. Research actually performed for this thesis consists of rub resistance, abrasion resistance, and folding resistance.

The commercial digital presses involved in this research and testing are all sheet-fed. Digital press samples are compared with the high-speed ink jet press, as well as the offset lithographic press, which is used as the industry benchmark.

Primary research stemming from the missing pieces in the literature review had the following objectives:

1. Interviews to identify what problems printing companies, vendors, and consumers are facing in terms of permanence. This, in effect, covers the life cycle from an industry perspective. (Interview questions and full responses are located in Appendix A.)

2. Define testing (based on existing testing models) that can be done to help predict the performance (i.e., folding, abrasion, water-fastness, light-fastness, pollutants, etc.) of digitally printed materials.

   Perform testing on printed samples with test targets. Test targets are provided by the IPL and have been modified by the researcher to fit the testing models. A circular, solid test target was retrieved from IPL and from this, five targets are made one each of cyan, magenta, yellow, process black, and solid black. Also, the "Three Musicians" test target was used for visual comparisons of testing. (Appendix C shows the actual test targets printed in a scaled-down version.)

3. Conclusions will be reached, assessing performance measures created for digital printing technologies and their particular use with certain products. The end product will include comparisons between three main commercial digital presses, high-speed ink jet, and offset lithography with regard to the specific testing performed.

Testing Methodology

Particular attention has been paid to the stresses involved in each step of the digital product life cycle, thus far, to determine problem areas. Standardized tests were selected in an attempt to simulate these stresses. The tests were performed in a controlled environment that allowed for comparisons to be made with a relative degree of confidence. The tests chosen are some of the best methods, to this researcher's knowledge, to simulate the stresses induced on a commercial digital print and, therefore, this research can be used as a guide for information on permanence of commercial digital printing only.

The standards documents that were chosen are from both the International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM). It is important to note that many companies outside of the educational realm of research provide testing, some of which could apply to this research; however, the testing facilities at RIT proved to be sufficient for completion of this researcher's goals.

Note that before any of the targets are cut to suit specific testing requirements, the machine direction and cross machine direction was documented using ASTM D 528, the

standard test method for machine direction of paper and paperboard. Within this standard, the wetting technique was used, where each sheet is cut into a perfect square and dropped into a pan of water. After the sample was dropped into the water, it was quickly removed and observed to see in which direction the sample curled. Along the base of the curl (i.e., in the valley) was the machine direction. If along the whole base of the valley was the machine direction, the opposite was documented, the cross machine direction ("Standard Test Method," 1997/2002). This must be noted in certain testing methodologies, so it was deemed appropriate to derive first. Figure 1 shows the actual samples cut and tested to determine machine direction and cross machine direction.

Figure 1. Actual results from the wetting technique used to determine machine and cross machine direction

The following are detailed descriptions of testing, the instruments (if any) used, and the standard procedures of the tests as put forth by ISO or ASTM. Of these tests, the ones highlighted in yellow in Table 7 were actually performed. The decision to run

certain tests was based upon preliminary interviews with printers, print buyers, and print press vendors to decide which tests are the most important to the industry. (The results of this survey can be seen in Appendix A.) Table 7 is a summary of test types researched, instruments needed, length of tests, samples necessary, and specifications. After interviewing a sample of printers, press vendors, and print buyers, it was concluded to test for folding and abrasion resistance. (See Chapter 5 for a description of the interviews.)

Table 7. Testing summaries

Test Type	Instruments Needed	Length of Test	Samples Per Press	Total Samples	Sample Specifications
Abrasion Resistance	Taber Abraser	Approximately 2-3 hours	6	30	10.5 cm samples
	Sutherland Rub Tester	Approximately 3-4 hours	6	30 printed + 30 non-printed	7.6cm x 15.2 cm samples
Folding Resistance	ASTM F 1351-96	Approximately 2-3 hours	6	60 (30 md + 30 cmd)	21.6cm x 21.6cm samples
	Image Xpert	Approximately 3-4 hours	1	10 (5 md + 5 cmd)	Image Xpert Test Target
Solvent Resistance	*See Table 7*	7 days maximum	1	60	*See procedure*
Light Fastness	Xenon Light Chamber		2	10	
	Fluorescent Light Chamber		2	10	
Water Fastness	*See Procedure*	Approximately 5-6 hours	4	20	35mm x 35mm squares
Thermo-Stability	Temperature Controlled Oven	At least 12 months	5	25	
Gas/Ozone Fastness	Ozone Chamber	9 days	8	40	

Abrasion Resistance

Typical abrasion resistance was tested by two methods approved by the ASTM standards organization. The Taber Abraser method was outlined similarly to the research being conducted at RIT by ASTM F 1478-95. The other method outlined in this report uses the Sutherland Rub Tester and is outlined by ASTM D 5264-98.

Taber Method. ASTM F 1478 is the standard test method for determining the abrasion resistance of prints from copiers and printers using, specifically, the Taber Abraser. This test is used specifically to measure, record, and observe how much of an image is abraded from the surface of the samples. The Taber Abraser has rough wheels which grind and rub the surface of the print during the test. Circular, solid test targets are used in this testing for ease of using the machine and measuring results. (The circular test targets can be seen in Appendix C and include cyan, magenta, yellow, process black, and solid black inks.) The targets were cut to approximately 10.5 centimeters in diameter. This measurement does not have to be exact. Also, a small hole must be punched out of the center of the sample to accommodate the testing instrument's mounting procedure. This hole only needs to be as large as a standard 3-hole punch. The "Three Musician" test target may be cut in the same manner as the circular solid targets and tested to be used strictly as a visual comparison, using an image. ASTM has a specific test target to be used in their standard testing method; however, the targets used in this research allow for the same measurements to be taken.

Results of this test simulate some of the stresses that a printed piece is subject to in the mailing, distribution, and fulfillment phase of a document's life cycle (i.e.

automated sorting and handling machines, shipping environments, etc.). (The full testing procedure appears in Appendix B.)

Sutherland Rub Tester. ASTM D 5264 is the standard method for testing the abrasion resistance of prints using, specifically, the Sutherland Rub Tester. This test can be used, just as the Taber Abraser, to simulate stresses imposed on a printed product through mailing, distribution, or fulfillment services. This method can simulate stresses from abrasion/rubbing from another substrate or from handling on its own, while the Taber Abraser uses strictly abrasive wheels. The samples for the testing used the same circular targets and the "Three Musician" test target as did the Taber Abraser testing. The Sutherland Rub Tester does not require the printed samples to be cut to any specific size. However, blank stock must be cut to approximately 7.6 centimeters by 15.2 centimeters to be mounted on the Sutherland Rub Tester.

This testing was done at IPL, under laboratory conditions that were recorded at the time of testing. Many different factors affect a typical product in the distribution stage of its life cycle; those factors are not taken into account here (i.e., temperature, humidity, precipitation, etc.). As with any testing, this procedure has its limitations. (The full testing procedure is located in Appendix B.)

Folding Resistance

Folding resistance can be tested using ASTM F 1351-96. This document articulates the standard practice for determining the effect that hard creasing paper has on printed images. Before getting into specifics, a hard crease, according to this document,

is a “paper folded 180 degrees (back to back, face to face, long grain, short grain) with a uniform force applied to the fold” (Standard Practice for Determination, 1970/1996, p. 12). This standard was originally developed for business imaging systems (i.e., copiers, fax machines, printers, typewriters, etc.). Therefore, it has not been developed with commercial digital presses, offset lithography, or even ink jet in mind. With this caveat in mind, this researcher will perform the tests as per ASTM F 1351-96 and report this fact as a possible source of error. ISO 18908 is also a standard for fold testing, but the ASTM standard was deemed sufficient for this research.

The ASTM F 1351 document describes a simplistic instrument to be used in testing for folding/hard creasing resistance of digital prints. This test was performed in the IPL on the RIT campus where the specific testing instrument resides. (The testing procedure, as per ASTM F 1351, for fold testing is located in Appendix B.)

Chapter 5

Results

Introduction

To decide which tests were to be performed in this research, a survey consisting of four questions was conducted with printers, print buyers, and printing press vendors who were randomly selected by this researcher. The four questions asked of the respondents were as follows:

1. How would you compare digital printing to the offset lithography with regards to permanence issues and problems?

2. Do you see any problems with digitally printed products compared to any other printing you are involved with?

3. Do you find any permanence problems in the finishing stages or mailing process of digitally printed products that are of particular concern?

4. Rank from 1-7 (1 being the highest and 7 being the lowest) the following permanence tests which results you deem most necessary: abrasion, folding endurance, solvent resistance, light-fastness, water-fastness, thermostability, and gas/ozone fastness.

From the interviews conducted with printers in the Northeast, marketers and advertisers, and digital printing press vendors, it was quite clear that their largest concerns were cracking of toner in commercial digital printing. The average secondary concern was abrasion resistance; hence, the testing actually done in this document covers folding and abrasion resistance. It is interesting to note, however, that printers had issues with the products that they had to finish and distribute. They seemed to choose abrasion, cracking, and water exposure as concerns which are in line with the same stresses induced to print in their finishing and distribution processes. On the other hand, the primary concern of print press vendors was folding. One would think that press vendors' and printers' goals and concerns would be aligned, but in this case, they are not. Similarly, print buyers (marketers and advertisers) could not offer a ranking, as they did not know the process well enough. There was a real disconnect between the printers, press vendors, and print buyers when in actuality, they should all be working towards the same goals. (Actual results from the survey can be found in Appendix A.)

Because of the disconnect between printers, print buyers, and press vendors, the idea of developing a sample kit containing original samples and samples after testing came up. When interviewing, a visual sample would be quite helpful when asking questions about permanence issues; the visual sample may be able to get people in the printing industry looking at the issues in the same way or at least able to respond to the questions. This sample kit is put forward as an area for further research.

Results from the Taber Abrasion Test, Sutherland Rub Test, and folding test were evaluated in a number of ways. A visual assessment of rank from 1 to 5 (with 1 being the

least resistant to the stress or stresses put forth by the test and 5 being the most resistant to the stress or stresses put forth by the test) was done. Testing results were also based on objective evaluation, including density changes, Delta E (ΔE), and an abrasion resistance index introduced in ASTM F 1478. In the evaluation of the data and calculations, the lower the density change, the better; the lower the ΔE (distance between two colors), the better; and the higher the abrasion resistance index, the better.

Before the testing was performed, samples that are not to be tested are laid out with the machine direction noted for the sake of visual referencing back to the original samples after the testing. Certain testing standards require the notation of grain direction during the testing. Also, samples to be used in the testing are cut and shaped, as noted in the procedures section, in preparation for use with the testing instruments. Original, untested samples are shown in Figure 2.

Figure 2. Original samples with machine direction noted

Using the GretagMacbeth SpectroEye, which is shown in Figure 3, density values and L*a*b* colorimetric values are taken before and after the testing to allow for the preceding calculations to be made. As measurements were taken, they were exported to a Microsoft Excel spreadsheet for ease of evaluation and documentation, both during and after the testing.

Figure 3. GretagMacbeth SpectroEye

Settings for the SpectroEye are critical for accurate measurements and reproduction of the testing. In discussions with a professor at RIT, settings for the Spectrophotometer were agreed upon for this research. Table 8 shows the settings that were chosen before testing.

Table 8. Settings for the GretagMacbeth SpectroEye

GretagMacbeth SpectroEye Spectrophotometer Settings	
Density Standard	ANSI T
Observer angle	2 degrees
Illuminant	D50
White Base	Absolute
Physical Filter	No

Samples to be tested are kept in the same environmental conditions for at least 24 hours prior to testing. Immediately before the testing, the temperature and humidity are recorded at an average of 70.5° Fahrenheit and 30% Relative Humidity throughout the tests. While these readings are close to the temperature and humidity readings specified in the Sutherland Rub testing procedure, this was a possible source of error. The actual

temperature tolerance specified in the rub testing procedure was between 71.4° and 75.4° Fahrenheit, and the humidity tolerance was between 48% and 52% humidity. The conditions at IPL at the time of testing and before testing do not meet this specification. However, since the samples are being examined directly before testing and then compared to themselves after the testing, in the same conditions, this factor was deemed acceptable for this research.

Figure 4 shows the last step that was taken before actual testing began. Measurements (density and L*a*b* values) were taken on each sample immediately before the test that is to be performed. The sample that was used as a reference had an initial density of 1.72 before testing.

Figure 4. Actual density reading on the GretagMacbeth SpectroEye before an abrasion test

Taber Abrasion Test Results

Ranking of the Taber Abrasion results is apparent, both in the visual and the objective assessment. The actual Taber Abraser testing instrument is shown in Figure 5.

Figure 5. Taber Abraser testing instrument

Visually, the ranking, from 1 being the least abrasion resistant through 5 being the most abrasion resistant, is:

1. Commercial Digital Press B
2. Commercial Digital Press C
3. Commercial Digital Press A
4. Offset Lithography
5. High-speed Ink Jet

Commercial Digital Press B showed a density change at an average of 0.42, a ΔE of 20.8, and an abrasion resistance index of 71.5. The only press that had a higher density change was Commercial Digital Press A, which posted a 0.44 change in density. Figure 6 shows a sample from Commercial Digital Press B (cut from the "Three Musician" test target) after the Taber Abrasion Test.

Figure 6. Commercial Digital Press B sample run on the Taber Abraser

As seen in Figure 6, the wheels from the Taber Abraser significantly change/abrade the image. The Taber Abraser can be used to simulate wheels on folding machines used in the finishing process as well as wheels in the Unites States Postal Service high-speed sorting equipment. Defining endpoints that describe the acceptable change have not been defined in this industry. However, the result obtained should be unacceptable to most printers, print buyers, and printing press vendors.

The high-speed ink jet, however, performs very well, showing visually nothing abraded on the sample, which looks completely intact. It shows the lowest change in density at 0.02, the lowest ΔE at 1.78 and the highest abrasion resistance index at 98.73. (Appendix D contains the complete list of Microsoft Excel data and calculations.) Figures 7-9 offer a visual assessment of the Excel data and calculations for each press's performance during the Taber Abrasion Test.

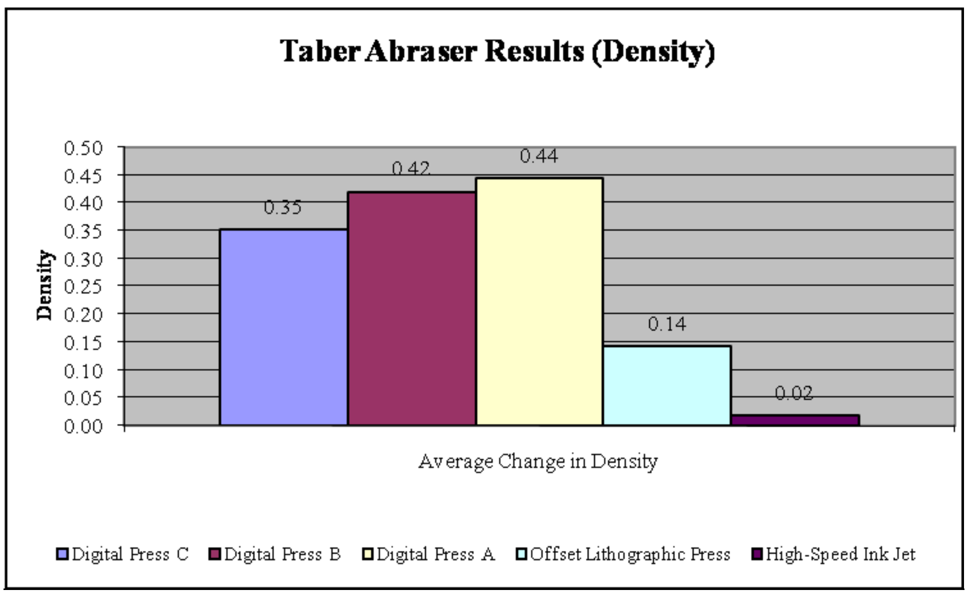

Figure 7. Taber Abrasion test—average change in density per press

The three commercial digital presses (the dry toner-based, as well as the liquid toner-based) show the most density change of the three technologies compared here. The offset lithographic and the high-speed ink jet do not have much of an issue with density changes. The high-speed ink jet performs exceptionally well during this test.

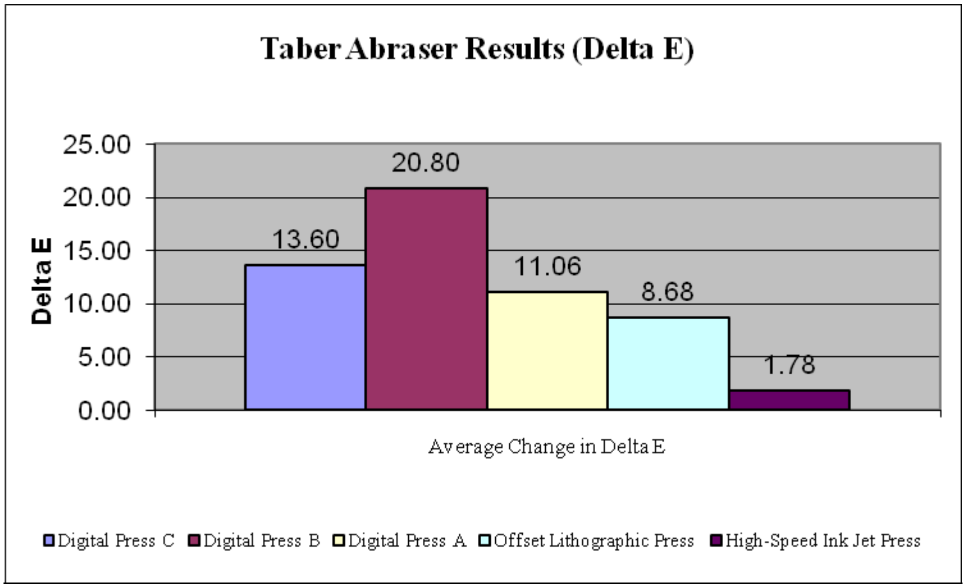

Figure 8. Taber Abrasion test—average change in Delta E per press

ΔE refers to the distance between two colors or points in the L*a*b* color space. (Delta-E, 2005). Therefore, for the testing involved in this research, you can infer that the larger the ΔE, the further the color is from the original sample. A large number for ΔE is not good, and Press B tops the list in the above chart with a very large ΔE of 20.80. Here again, the three commercial digital toner-based presses are on the high end of the ΔE. The high-speed ink jet performs the best again; posting a 1.78 ΔE on the Taber Abraser Test. (Figure 8 shows these results.)

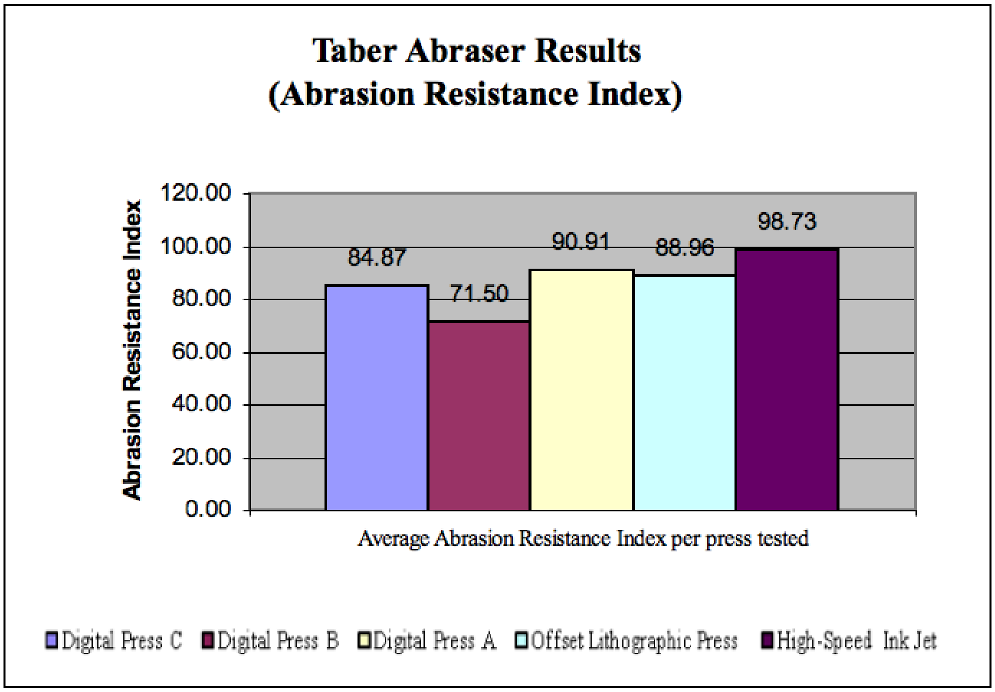

Figure 9. Taber Abrasion test—average change in the Abrasion Resistance Index

The abrasion resistance index is found in ASTM F 1478. Equation 1:

$$A_I = 100 - (2[R_f - R_i]) \quad (1)$$

Where:

- A_I = Abrasion Resistance Index
- R_f = Final reflectance measurement after abrasion test
- R_i = Initial reflectance measurement before abrasion test

Reflectance in this case is calculated as percent reflectance. The abrasion resistance index number is dimensionless and can only be used to rank one sample against another. Using the index, a larger number means that the sample was more resistant to change caused by abrasive forces. With this in mind, one can note that the

high-speed ink jet showed better results within the Taber Abrasion testing over the other presses in the study.

The Taber Abraser is a good simulation of wheels abrading the surface of a print product during the finishing operation at a printing plant (i.e., folding, etc.), as well as going through the high-speed sorting equipment used in the USPS. The results of this testing are very useful for printers, print buyers, and print vendors.

Sutherland Rub Test Results

Evaluation of the Sutherland Rub Tester (shown in Figure 10) results used very much the same criteria as that of the Taber Abrasion testing.

Figure 10. Sutherland Rub Tester

Measurements (density and L*a*b*) are taken before and after the testing, and comparisons are made. Also, as in the Taber testing, visual assessments are made using

the “Three Musicians” test target. The visual assessment, using the same scale as in the Taber testing, is:

1. Commercial Digital Press C
2. Commercial Digital Press A
3. Commercial Digital Press B
4. Offset Lithography
5. High-speed Ink Jet

As the Sutherland Rub Tester abrades the surface of the test target with an unprinted sheet, as can be seen in Figure 11, the image starts to deteriorate.

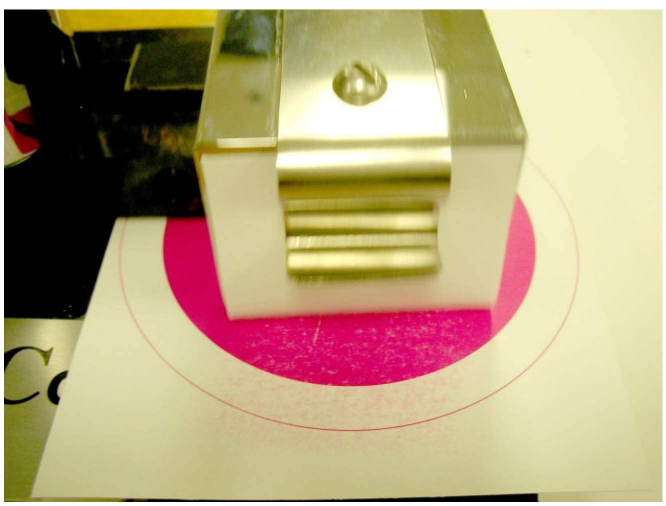

Figure 11. Sutherland Rub Tester in action with a sample from Press C

Press C seems to be the only press that struggles in this abrasion test. The other presses in the study seem to be quite similar in abrasion resistance throughout each of the readings and calculations. (Figures 12, 13, and 14 show the visual comparison of the data collected in Excel.)

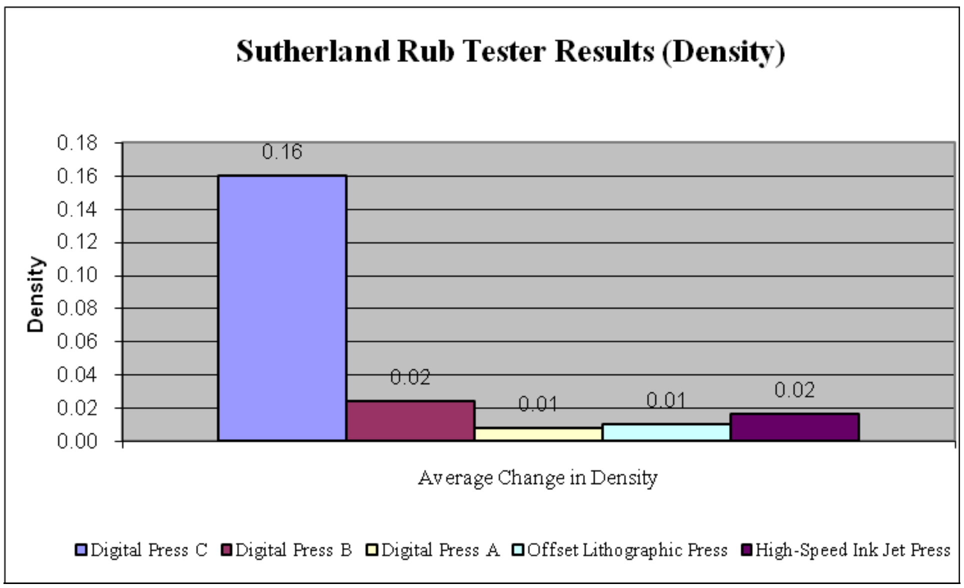

Figure 12. Sutherland Rub Test—average change in density per press

Figure 12 clearly shows the stability and similarity between Press A, Press B, offset lithography, and the high-speed ink jet press. It also illustrates how much worse Press C performs in terms of density throughout the Sutherland Rub testing.

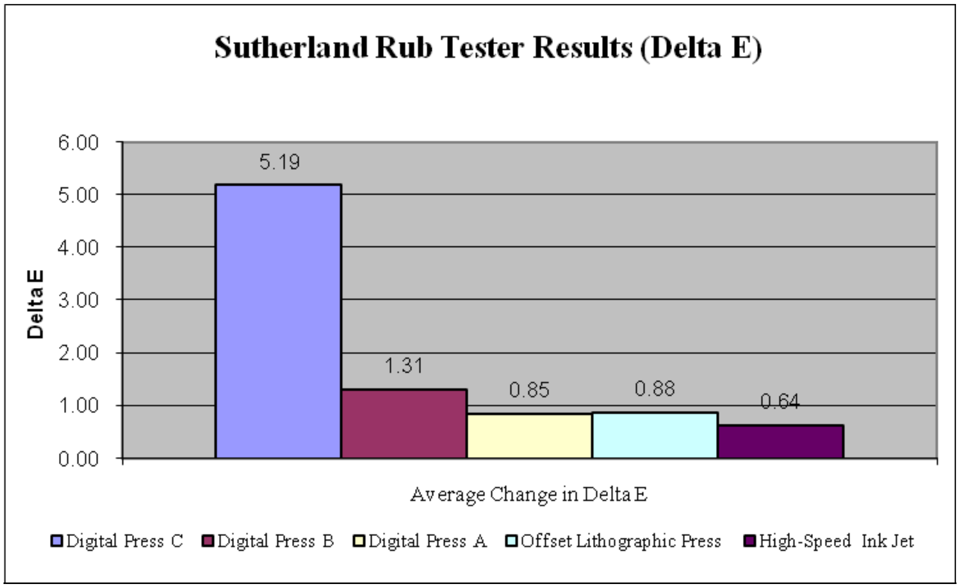

Figure 13. Sutherland Rub Test: average change in ΔE per press

Figure 13 further illustrates the difference in performance among Press C and the other samples in this study. The color shift in Press C was higher than the others.

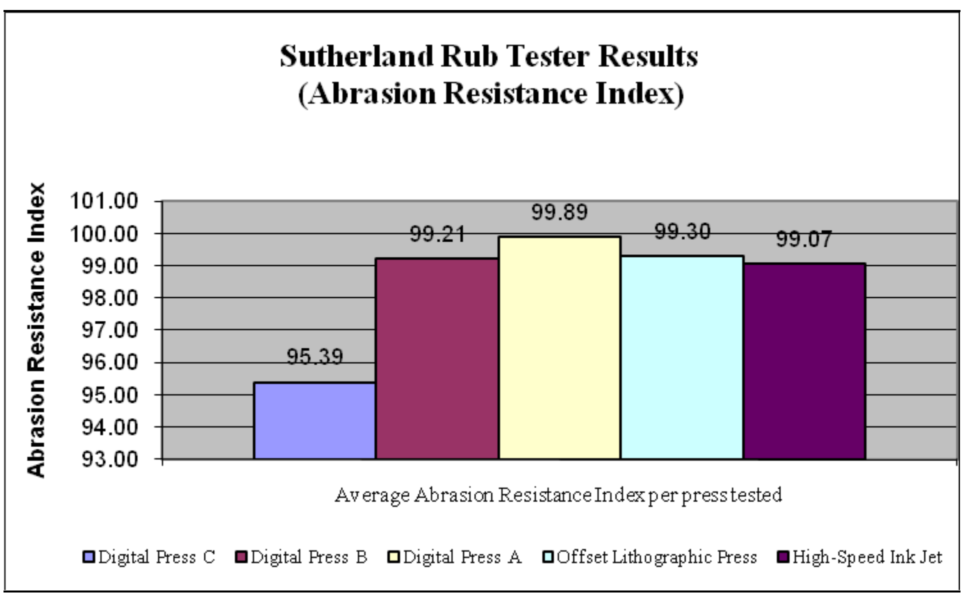

Figure 14. Sutherland Rub Test—average of the abrasion resistance index per press

As illustrated in Figure 14, the abrasion resistance index confirms the lower abrasion/rubbing tolerance that press C has, compared with the other toner presses, ink jet, and offset lithographic technology tested in this research.

The high-speed ink jet continues its excellent performance in testing, and Press A seems to come out on top, followed closely by the offset lithography. This test is a good simulation for print that is packaged in bulk to be shipped; these results could be very useful for printers, print buyers, and vendors.

Folding Test Results

The fold testing for the research in this document was done using a simplistic instrument outlined in ASTM F 1351; this testing is shown in Figure 15.

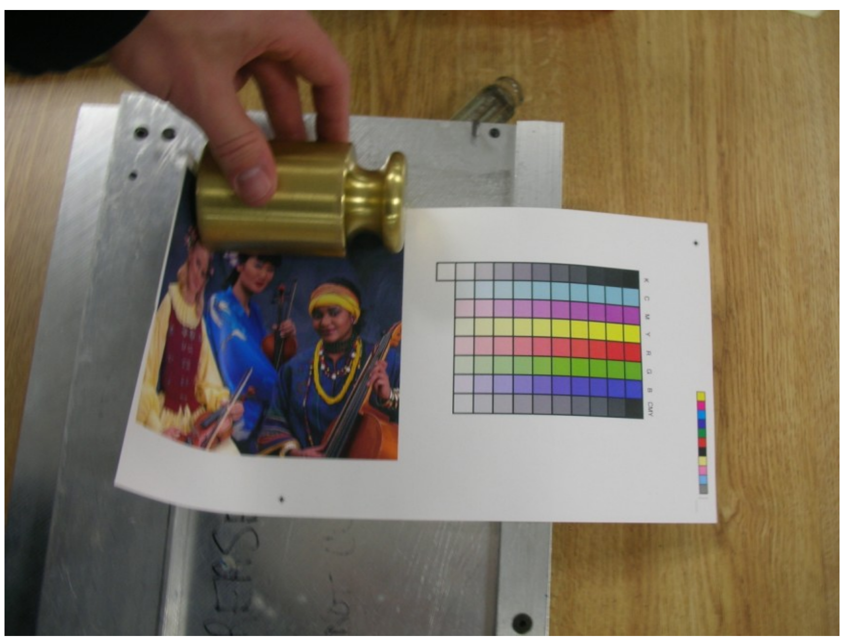

Figure 15. Folding instrument complete with angled steel board and 2kg weight

After the testing is completed, the samples are visually inspected with a loupe. With the loupe, this researcher is looking for cracking, white space, and distortion of the image and/or the substrate. With this analysis, a ranking is compiled in exactly the same manner as in the case of the Taber Abrasion Test and the Sutherland Rub Test. Using 1 as the worst performance and 5 as the best performance through the folding test, the results are:

1. Commercial Digital Press A
2. Commercial Digital Press C
3. Commercial Digital Press B
4. Offset Lithography
5. High-speed Ink Jet

Out of all of the presses, Press A showed the worst cracking and white space. Also, Press B and Press C showed slight cracking and white space. Press B did show the least cracking of all the toner-based presses. Since Press A and Press C are both dry toner-based, and Press B is liquid toner-based, this researcher believes and the data shows that a correlation can be made with toner technology and fold permanence resistance. The offset lithographic press and the high-speed ink jet press both showed no cracking or visual damage from the fold at all. This is to be expected because of the oxidation and evaporation technology versus the toner-based adhesion/fusion technology. Toner-based inks, which are merely fused to a substrate, cannot be expected to perform as well as an

ink jet or offset lithographic product, which uses evaporation or oxidation as a drying method, to soak into and to become a part of the sheet. Regardless, this is pertinent knowledge for printers, print buyers, and print vendors of all types.

Chapter 6

Summary and Conclusions

The objectives of this research were outlined earlier in three research questions. The first question inquired about the different type of stresses that were found within a digitally printed products' life cycle. Examining the life cycle of marketing and promotional documents, direct mailers, transactional and business documents, and on-demand color books, revealed that there are very different stresses, which are induced on the printed documents through each step in the life cycle. No stress was involved in the printing stage of the product life cycle, but many stresses were found in the finishing, mail preparation and mailing, fulfillment, distribution, user, and recycling stages of the product life cycle. Stresses in the finishing stage included scratching and cracking. Stresses in the mail preparation, mailing, fulfillment, and distribution stages included scratching, cracking, heat, air contamination, and moisture. It was determined that every stress type was present in the user stage of the life cycle. Lastly, the recycling stage of the life cycle was deemed irrelevant with regard to stress points because this is the stage where the product is broken down.

The second research question outlined in this document asked about the concerns printers, print buyers, and press vendors had with regard to digital print permanence. An exploratory survey was developed and sent to different printers, print buyers, and press vendors. Five printers, two press vendors, and one print buyer responded to this survey. The results showed that printers were mostly concerned about folding endurance and abrasion resistance. Press vendors were most interested in light-fastness, water-fastness, and folding endurance. The print buyer did not feel comfortable enough with the technology and was unable to answer the majority of the questions. Based on interviews, it was decided that rub resistance, abrasion resistance, and fold resistance testing would be done. The results are discussed in the next section.

The last research question posed in this document dealt with the ability of toner-based digital, lithographic, and ink jet digital technology to resist abrasion testing, rub testing, and fold testing. Test results showed that offset lithography and ink jet performed better in terms of abrasion, rub, and fold testing than the toner-based digital presses. Because of the dry and liquid toners being fused to the substrate in commercial digital presses, they are more susceptible to abrasive forces than are offset and ink jet, which rely on oxidation or evaporation as a drying method. Technologies using evaporation or oxidation allow the image (i.e., ink) to become part of the paper rather than just sitting atop the paper, as in toner-based technologies. This fact allows the evaporation/oxidation-based presses to be more permanent resistant in the abrasion, rub, and folding tests.

The commercial digital presses examined in this study showed problems with permanence in each of the three tests (the Taber Abrasion Test, the Sutherland Rub Test, and the fold test) performed in this study. Press manufacturers are in the process of introducing coatings and other features to alleviate the problems.

Recommendations for Further Research

An exploratory industry survey showed that a disconnect between printers, press vendors, and print buyers exists when it comes to permanence issues with digital printing. Many print buyers (marketers and advertisers) could not respond to the survey conducted through this research simply because they did not know enough about printing. Printers and press vendors seem to be very knowledgeable about the problems that they have seen firsthand. However, as a whole, the industry is not thoroughly educated enough on the subject of permanence issues with commercial digital printing. One topic for further research could be to expand on the survey conducted in this research, and find out why this disconnect occurs, and what can be done to overcome it.

Light-fastness, thermostability, solvent resistance, water-fastness, and gas/ozone fastness are all areas of permanence that have gone largely unpublished in the commercial digital printing sector. Performing these tests would add to the findings in this thesis, as well as the sample kit, described in Chapter 5. Lastly, with the test samples run for this research, it would be easy to create a document that could be used as a "cheat sheet" for print buyers. This would help them choose the best technology to suit their product needs before printing and not find out that they have chosen the wrong technology for the end-use requirements of their products after it has been printed. The "cheat sheet" would be a very useful document for many people and would certainly aid in the education of print buyers.

Lastly, the establishment of endpoints at which point permanence tests fail or are deemed a success are not currently available in the industry. Performing research to describe and illustrate these endpoints from an industry perspective would be very useful.

Bibliography

Bibliography

Bolanca, Z., Agic, D., & Bauer, K. (n.d.). *Possibilities of recycling digital prints* (Rep. No. 1.6). Croatia: University of Zagreb.

Bolte, C. C. (2005, February). *Application shortcuts on key technologies.* Chambersburg, PA: C. Clint Bolte & Associates. Abstract obtained from *PIA/GATF Tech Alert 2005 Conference.*

Carre, B., Magnin, L., & Ayala, C. (n.d.). *Digital prints: A survey of the various deinkability behaviors*. Grenoble, France: Center for Technical Papers.

Cost, F. (2005). *The new medium of print: Material communication in the Internet Age*. Rochester, NY: RIT Cary Graphic Arts Press.

Cummings, T.J., & Chhita, K. (2004). *Industry trends in fulfillment, finishing and distribution* [Monograph]. *No. PICRM-2004-02.*

Davis, R. H. (2005, February). Over the horizon: An environmental scan for 2005 and 2006. *GATF World 2005 Technology Forecast*. 1(17), 5-8.

Defining and Segmenting Commercial Printing. (1999). Alexandria, VA: Graphic Arts Marketing Information Service.

Delta-E Explained. (2005). Retrieved February 16, 2007, from MacDermid ColorSpan Inc. Web site: http://colorspan.com/support/tools/deltae.asp

Deprez, L., Op de Beeck, W. (2003). Digital production printing with uv-curable dry toners for paper and flexible packaging. *Proceedings of the IS&T NIP19: 2003 International Conference on Digital Printing Technologies, USA,* 486-491.

Digital Offset Introduction. (n.d.). Retrieved September 26, 2005, from Graphic Comm Central Drupa 2000 Web site: http://teched.vt.edu/gcc/Drupa2000/DigitalOffset/DigitalOffestIntro.html

The effect of new printing technologies on the performance requirements for paper substrates. (2003). Alexandria, VA: Graphic Arts Marketing Information Service.

Fischer, C. (2005, July). *HP Indigo 3050 Press Operator Training Course Presentation.* PowerPoint and handout presented at HP Invent, Littleton, MA.

Frey, F., Christensen, H., & DiSantis, N. (2006). *Investigation of the life cycle of digital printed documents.* (Research monograph at the Printing Industry Center at Rochester Institute of Technology). Rochester, USA: Rochester Institute of Technology.

International Standard (Third Edition ed., Vols. ISO 2836:2004(E). (2004). Geneva, Switzerland: ISO. (Original work published 1999).

Järvenpää, E. (2004, Spring). *Life cycle terminologies and definitions* (Literature review at the Laboratory of Work Psychology and Leadership). Helsinki, Finland: Helsinki Institute of Technology.

Johnson, H. (2003). *Mastering digital printing*. Cincinnati, OH: Muska and Lipman Publishing.

Kapecki, J. A. (2006, May 10). *T19 image permanence: Understanding, measuring, and predicting print life*. PowerPoint presented at Rochester Institute of Technology, Rochester, NY.

Kipphan, H. (2001). *Handbook of print media: Technologies and production methods*. Berlin: Springer Verlag.

Kitamura, K., Oki, Y., Kanada, H., Hayashi, H. (2003). A study of fading property indoors without glass frame from an ozone accelerated test. *Proceedings of the IS&T NIP19: 2003 International Conference on Digital Printing Technologies, USA,* 415-419.

Krasne, A. (2002, January). Secrets to print longevity revealed. *PC World Magazine*, 86.

Paparozzi, A. (2005, October). *The state of the printing industry*. Presented at the School of Print Media, Rochester Institute of Technology, Rochester, USA.

Prince, R. (2006). *Commercial digital printing permanence issues*. Electronic mail.

Romano, F. (Ed.). (1997). *Delmar's dictionary of digital printing and publishing.* Albany, NY: Delmar Publishers. 2005 Tech Forecast.

Sastri, B., Sankaran, V. (2003). Media/toner interactions in laser printing. *Proceedings of the IS&T NIP19: 2003 International Conference on Digital Printing Technologies, USA,* 619-622.

Sipi, K. M. (2001). Toner layer structure and toner adhesion on coated paper. *Proceedings of the IS&T NIP17: 2001 International Conference on Digital Printing Technologies,* USA, 145-150.

Standard practice for abrasion resistance of printed materials by the Sutherland Rub Tester. (1998). In *Annual Book of ASTM Standards* (Vol. v.15.09, d 5264-98). Philadelphia: ASTM International. (Original work published 1970).

Standard practice for determination of the effect of hard creasing paper on images produced by business imaging systems. (1996). In *Annual Book of ASTM Standards* (Vol. v.15.09, pp. 1183-1184). Philadelphia: ASTM International. (Original work published 1970).

Standard practice for determining the water-fastness of images produced by ink jet printers utilizing four different test methods-drip, spray, submersion and rub. (2003). In *Annual Book of ASTM Standards* (Vol. v.15.09, pp. 1624-1626). Philadelphia: ASTM International. (Original work published 1970).

Standard test method for determination of abrasion resistance of images produced from copiers and printers (Taber Method). (1995). In *Annual Book of ASTM Standards* (Vol. v.15.09, pp. 1395-1399). Philadelphia: ASTM International. (Original work published 1970).

Standard test method for machine direction of paper and paperboard. (2002). *ASTMInternational* (D 528-97). West Conshohocken, PA: ASTM . (Original work published 1997)

The status and future of direct mail. (1999). Alexandria, VA: Graphic Arts Marketing Information Service.

Testa, R. P. (2006). *Longevity testing of digital proofing materials*. Unpublished Master's Thesis, Rochester Institute of Technology, Rochester, NY.

2005 Tech Forecast. (2005) *GATF World, 11*.

Variable data imaging opportunities with digital printing presses. (2004). Alexandria, VA: Graphic Arts Marketing Information Service.

List of References

List of References

Standard practice for accelerated testing of light-fastness of ink jet prints exposed to indoor fluorescent lighting and window-filtered daylight. (2004). In *Annual Book of ASTM Standards* (Vol. v.15.09, pp. 1524-1525). Philadelphia: ASTM International. (Original work published 1970).

Standard practice for determining the light-fastness of ink jet prints exposed to indoor fluorescent lighting. (1998). In *Annual Book of ASTM Standards* (Vol. v.15.09, pp. 1521-1523). Philadelphia: ASTM International. (Original work published 1970).

Appendix A

Assessment of Digital Printing Permanence Issues Actual Survey and Results

Appendix A

Assessment of Digital Printing Permanence Issues Actual Survey and Results

1. How would you compare digital printing to the offset lithography with regards to permanence issues and problems?

Table 9. Response to question #1

Response to question #1
Printer A: No response.
Printer B: Digital printing is problematic compared to offset. Most digital products fail the tape test.
Printer C: Digital inks are better than standard offset inks. It is the dye vs. pigment issue.
Printer D: Quality is image dependent with digital printing. Marking and cracking can also be an issue, especially when going through USPS and up time on equipment is a major production issue.
Bindery E: No response.
Vendor F: New opportunities exist with variable data and very short runs with digital printing. Higher color gamut than offset but much slower. Also, less open to different substrates than offset. Much more stable, close to a proofing device if run correctly. No real make ready time.
Vendor G: It would depend on the application, not necessarily the print technology. I think digital overall, has lower permanence than offset, I think the more interesting question is what is the actual requirement of the application.
Advertiser H: Seems very close to offset.

2. Do you see any problems with digitally printed products compared to any other printing you are involved with?

Table 10. Response to question #2

Response to question #2
Printer A: No.
Printer B: Digital printing is problematic compared to offset. Most digital products fail the tape test.
Printer C: No. Electrophotographic (EP) digital images are different than offset, ink jet or thermal. EP is more susceptible to streaking and marking than offset.
Printer D: Quality is image dependent with digital printing. Marking and cracking can also be an issue, especially when going through USPS and up time on equipment is a major production issue.
Bindery E: Problems with coatings, laminations, and quality.
Vendor F: Mainly scratching on the Indigo. Some (non-Indigo) devices have a waxy feel to it. Xerography experiences that especially on uncoated paper. Also, size limitations.
Vendor G: Yes. I think every print technology brings a unique set of problems / opportunities.
Advertiser H: You run into the same problems, just on a smaller scale.

3. Do you find any permanence problems in the finishing stages or mailing process of digitally printed products that are of particular concern?

Table 11. Response to question #3

Response to question #3
Printer A: Image quality differences (less sharp), serviceability, and marketability.
Printer B: Scuffing in the mail and bindery processes and having to coat to eliminate the scuffing.
Printer C: No response.
Printer D: No response.
Bindery E: No.
Vendor F: Scratches easily (Indigo) needs coating. Xerography based machines do not require coating but look less "offset-like."
Vendor G: No (almost). Our digital print has not run into any permanence issues with folding, abrasion, etc. There was an issue at one installation having to do with the moisture used to wet the envelopes—this was overcome easily once the appropriate paper for our technology was used.
Advertiser H: Size restraints.

4. Rank from 1-7 (1 being the highest and 7 being the lowest) the following permanence tests which results you deem most necessary: abrasion, folding endurance, solvent resistance, light-fastness, water-fastness, thermostability, and gas/ozone fastness. *(Note: The following table includes the actual results from 1-3. Many respondents were uncertain, but most responded to at least 1-3.*

Table 12. Response to question #4

Company	Business	Concerns		
		1	2	3
Printer A	*Sheetfed Printing*	Folding endurance	Light-fastness	Water-fastness
Printer B	*Sheetfed Printing/Digital Printing*	Folding endurance	Abrasion	Water-fastness
Printer C	*Digital Printing*	Folding endurance	Abrasion	Light-fastness
Printer D	*Sheetfed Printing/Digital Printing*	Gas/ozone fastness	Solvent resistance	Light-fastness
Bindery E	*Print Finishing*	Folding endurance	Light-fastness	Solvent resistance
Vendor F	*Digital Print Vendor*	Light-fastness	Solvent resistance	Folding endurance
Vendor G	*Digital Print Vendor*	Water-fastness	Folding endurance	Abrasion
Advertiser H	*Marketing/Advertising*	n/a	n/a	n/a

Appendix B

Testing Procedures Performed

Appendix B

Testing Procedures Performed

Taber Abraser Testing Procedure

- Procedure
    - Calibrate the Taber Abraser.
        - Dress wheels according to the standard.
            - Run the abraser 40 cycles using sandpaper as your sample to dress wheels.
        - Place weights on swing arms (500 g).
        - Set and attach vacuum.
        - Blow wheels off after every test.
        - Dress wheels after every 4 samples.
    - Monitor and control environment (i.e. temperature, humidity, etc.).
        - Note the temperature and humidity at the time of the testing.
    - Samples should be cut to approximately 10.5cm diameter circles (the center hole should be punched out).
        - Cut larger than 10.5 cm not smaller if possible.
        - Using a spectrophotometer, measurements should be taken prior to testing (density and L*a*b*).
    - Mount a sample to the abrasion sample holder (secure with plate, nut, and clamp).
    - Lower the arms and vacuum.
        - Start the vacuum and abrade the sample for 20 cycles or revolutions.
    - Remove the sample and blow the loose particles off of the sample and the wheels with compressed air.
    - Take reflection density measurements and L*a*b* measurements after the test, record, and compare to initial measurements.
    - Repeat for at least 5 samples per press.

- Calculate the abrasion resistance index as follows: A=100-(2[Rf-Ri])

  Where: A = abrasion resistance index
  Rf = final reflectance
  Ri = initial reflectance

  This number can be used to rank samples in order of resistance factors. The higher the abrasion resistance index, the greater the resistance the sample is to abrasion.

- Evaluation
  - Using the abrasion resistance index coupled with a visual analysis and ΔE, a ranking of the best sample from each set of samples per press will be announced.
    - Visual comparisons will be made comparing the abraded sample to an original and ranked on a scale from 1-5 (1 being the least abrasion resistant and 5 being the most abrasion resistant).
    - Observations and ranks should include image removal, smudge, surface degradation, etc. ("Standard Test Method," 1970/1995, p. 12).

Sutherland Rub Tester Testing Procedure

- Procedure
  - Sample preparation
    - For this test 5 samples from each press are needed and 5 identical samples are also needed of the same substrate, unprinted.
    - Samples (unprinted) must be cut to 7.6cm x 15.2cm.
    - Do not get fingerprints on samples.
    - Make sure to set up samples so that the rub is across the machine direction.
    - Samples must be conditioned at testing room's temperature for 24 hours prior to testing.
  - Preparation of Sutherland Rub Tester
    - Room must be between (22 and 24 degrees Celsius or 71.4 and 75.4 degrees Fahrenheit).
    - Room must be between 48 and 52% humidity.
    - Decide how many strokes to set the Rub Tester at and record. The testing instrument in IPL is set to 40 rubs, which will be used in this research.

- Test
  - Mount 7.6cm x 15.2cm rubber pads to the top and bottom bases of the machine (mount to receptor blocks).
  - Attach sample to the rubber pad on the base with the printed surface exposed (option of choosing a small or large weight, determinant upon how severe shipping and handling simulations you want to create).
  - Attach receptor to the receptor block.
  - Brush sample and receptor with an anti-static brush removing any particles from the surface of each.
  - Place receptor block in the holder.
  - Set the dial on the Sutherland Rub Tester to the decided upon number of strokes (40) and record.
  - Turn the machine on and it will automatically perform the test and shut off when it is finished.
  - Repeat the process for each sample to be tested.

- Evaluation
  - Record the testing conditions (i.e. temperature, humidity, etc.).
  - Record changes in receptor (i.e. rub off, ink transfer, discoloration, etc.)
  - Record any changes in samples as compared to the original.
  - Record L*a*b* values and compare to the original measurements.
  - Take measure reflectance densities and compare to original sample densities and record the differences ("Standard Practice for Abrasion," 1970/1998, p. 12).

Fold Testing Procedure

- ASTM Procedure

  - The testing environment must have stable atmospheric conditions such as temperature and humidity, both of which will be recorded at the time of the testing.
    - The documents to be tested must be in this stable environment for at least 24 hours before the test is conducted.

  - The 12 test samples per press are suggested to be cut 8 ½ x 8 ½ inches (or 21.6cm x 21.6cm) but any size will work.

    - 6 samples will be cut in the machine direction and 6 samples will be cut in the cross-machine direction of the print.
  - Carefully bend test sample so that the image will face inward (machine direction).
    - Be careful not to fold it.
  - Slowly roll the 2 kg weight across the sample so that it creases/folds the paper.
  - Make two folds per sample (1 front to back, 1 back to front).
  - Repeat steps in the machine direction for 4 samples and in the cross-machine direction for the remaining 4 samples.

- Evaluation
  - Compare samples to each other and to the non-creased/unfolded samples (a loupe or magnifying glass may help in the observation).
    - Look for cracking, peeling, separation, etc.
    - Note whether the damage has been done to the coating, ink, and/or substrate.
  - Rub images along the fold to check for loose ink or anything else that may have loosened during the test.
  - Record all observations and rank order each sample per case of testing ("Standard Practice for Determination," 1970/1996, p. 12).

Appendix C

Actual Test Targets Run for Testing

APPENDIX C

Actual Test Targets Run for Testing

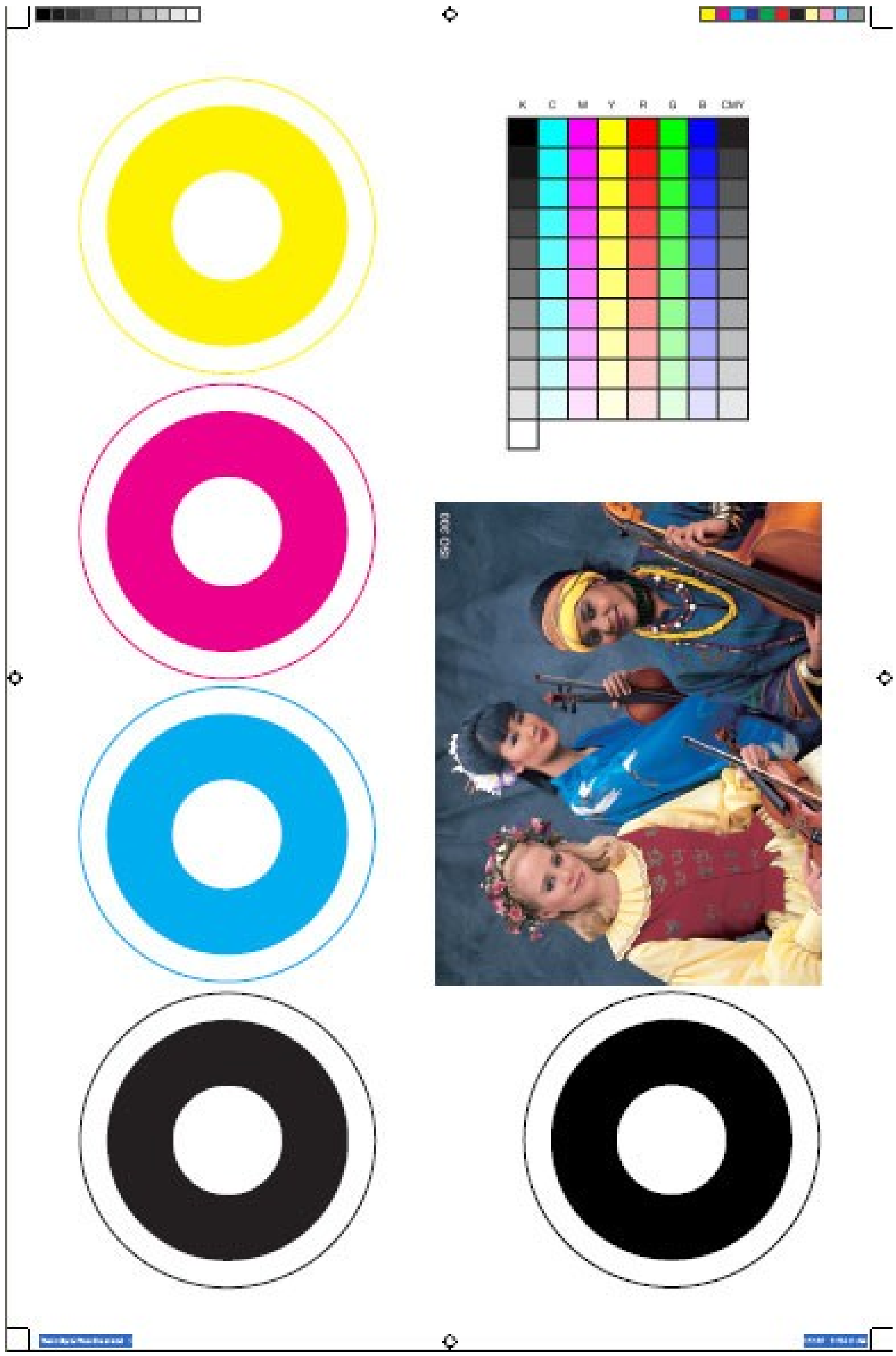

Figure 16. Digital press sheet run

Appendix D

Microsoft Excel Data and Calculations

Appendix D
Microsoft Excel Data and Calculations

Table 13. Taber Abrasion test data

Taber Abraser Abrasion Test	**Cyan**	**Magenta**	**Yellow**	**Black *built***	**Black *solid***	**Mean**	**Median**
Commercial Digital Press C							
Sample before test							
Density	1.10	1.28	1.12	1.51	1.28	1.26	1.27
L	57.15	48.79	91.11	18.59	25.74	48.28	48.53
a	-27.75	73.08	-11.88	0.72	0.63	6.96	0.68
b	-53.85	-2.80	85.71	1.27	-0.27	6.01	0.50
Sample after test							
Density	0.79	0.82	0.85	1.28	0.79	0.91	0.84
L	63.21	56.74	91.27	25.08	43.95	56.05	56.40
a	-22.19	57.71	-10.97	0.32	0.76	5.13	0.54
b	-46.48	-5.31	71.32	-0.33	-2.60	3.32	-1.47
Change in Density	0.31	0.46	0.27	0.23	0.49	0.35	0.33
Delta E	11.04	17.49	14.42	6.70	18.36	13.60	14.01
Ri	7.94	5.25	7.59	3.09	5.25	5.82	5.54
Rf	16.22	15.14	14.13	5.25	16.22	13.39	14.63
Rf-Ri (Absolute Value)	8.27	9.89	6.54	2.16	10.97	7.57	7.92
2 * (Rf-Ri)	16.55	19.78	13.08	4.32	21.94	15.13	15.84
100 - 2 * (Rf-Ri)	83.45	80.22	86.92	95.68	78.06	84.87	84.16
Abrasion Resistance Index	83.45	80.22	86.92	95.68	78.06	84.87	84.16
Commercial Digital Press B							
Sample before test							
Density	0.95	0.99	0.96	1.42	1.07	1.08	1.03
L	62.15	56.04	90.53	21.83	32.08	52.53	54.28
a	-30.19	68.06	-6.59	1.06	0.59	6.59	0.83
b	-47.76	-7.24	78.65	0.34	0.92	4.98	0.63
Sample after test							
Density	0.62	0.59	0.52	0.96	0.60	0.66	0.61
L	68.86	65.49	90.94	36.21	53.49	63.00	64.24
a	-20.59	47.77	-5.08	4.87	0.63	5.52	2.75
b	-39.71	-7.17	48.53	4.51	-3.07	0.62	-1.23
Change in Density	0.33	0.40	0.44	0.46	0.47	0.42	0.43
Delta E	14.21	22.38	30.16	15.45	21.78	20.80	21.29
Ri	11.22	10.23	10.96	3.80	8.51	8.95	9.59
Rf	23.99	25.70	30.20	10.96	25.12	23.20	24.55
Rf-Ri (Absolute Value)	12.77	15.47	19.23	7.16	16.61	14.25	14.86
2 * (Rf-Ri)	25.54	30.94	38.47	14.33	33.21	28.50	29.72
100 - 2 * (Rf-Ri)	74.46	69.06	61.53	85.67	66.79	71.50	70.28

Abrasion Resistance Index	74.46	69.06	61.53	85.67	66.79	71.50	70.28
Commercial Digital Press A							
Sample before test							
Density	1.42	1.62	1.61	1.63	1.68	1.59	1.62
L	54.27	51.19	89.24	15.33	16.63	45.33	48.26
a	-37.29	82.34	-1.62	1.39	1.72	9.31	1.56
b	-46.38	-11.33	97.32	1.17	1.79	8.51	1.48
Sample after test							
Density	1.12	1.10	1.12	1.15	1.25	1.15	1.13
L	56.89	56.18	90.25	30.35	26.83	52.10	54.14
a	-32.43	72.65	-1.77	1.06	1.11	8.12	1.09
b	-44.12	-10.67	84.27	0.33	0.54	6.07	0.44
Change in Density	0.30	0.52	0.49	0.48	0.43	0.44	0.46
Delta E	5.97	10.92	13.09	15.05	10.29	11.06	10.99
Ri	3.80	2.40	2.45	2.34	2.09	2.62	2.43
Rf	7.59	7.94	7.59	7.08	5.62	7.16	7.37
Rf-Ri (Absolute Value)	3.78	5.54	5.13	4.74	3.53	4.55	4.64
2 * (Rf-Ri)	7.57	11.09	10.26	9.47	7.07	9.09	9.28
100 - 2 * (Rf-Ri)	92.43	88.91	89.74	90.53	92.93	90.91	90.72
Abrasion Resistance Index	92.43	88.91	89.74	90.53	92.93	90.91	90.72
Offset Lithographic Press							
Sample before test							
Density	0.75	0.76	0.83	0.89	1.12	0.87	0.85
L	63.88	58.52	90.40	39.07	30.19	56.41	57.47
a	-23.46	56.31	-6.64	2.01	0.67	5.78	1.34
b	-42.40	-7.99	66.26	2.00	1.18	3.81	1.59
Sample after test							
Density	0.62	0.61	0.66	0.76	0.99	0.73	0.69
L	66.50	62.11	89.39	45.00	35.13	59.63	60.87
a	-19.18	46.33	-6.32	1.23	0.35	4.48	0.79
b	-34.86	-7.79	54.20	-0.43	-0.37	2.15	-0.40
Change in Density	0.13	0.15	0.17	0.13	0.13	0.14	0.14
Delta E	9.06	10.61	12.11	6.46	5.19	8.68	8.87
Ri	17.78	17.38	14.79	12.88	7.59	14.08	14.44
Rf	23.99	24.55	21.88	17.38	10.23	19.60	20.74
Rf-Ri (Absolute Value)	6.21	7.17	7.09	4.50	2.65	5.52	5.86
2 * (Rf-Ri)	12.41	14.34	14.17	8.99	5.29	11.04	11.73
100 - 2 * (Rf-Ri)	87.59	85.66	85.83	91.01	94.71	88.96	88.27
Abrasion Resistance Index	87.59	85.66	85.83	91.01	94.71	88.96	88.27
High Speed Ink Jet Press							
Sample before test							
Density	0.80	0.81	0.83	0.93	0.98	0.87	0.85
L	66.28	56.38	89.63	37.44	36.19	57.18	56.78
a	-30.63	53.62	-1.32	-3.35	-0.17	3.63	-0.75
b	-34.94	-3.15	65.74	-0.71	-4.12	4.56	-1.93
Sample after test							

Density	0.78	0.78	0.80	0.92	0.98	0.85	0.83
L	66.31	58.13	89.84	38.60	35.98	57.77	57.95
a	-30.38	51.33	-1.63	-3.95	-0.72	2.93	-1.18
b	-35.14	-4.70	62.98	-1.74	-4.74	3.33	-3.22
Change in Density	0.02	0.03	0.03	0.01	0.00	0.02	0.02
Delta E	0.32	3.27	2.79	1.66	0.85	1.78	1.72
Ri	15.85	15.49	14.79	11.75	10.47	13.67	14.23
Rf	16.60	16.60	15.85	12.02	10.47	14.31	15.08
Rf-Ri (Absolute Value)	0.75	1.11	1.06	0.27	0.00	0.64	0.69
2 * (Rf-Ri)	1.49	2.22	2.12	0.55	0.00	1.27	1.38
100 - 2 * (Rf-Ri)	98.51	97.78	97.88	99.45	100.00	98.73	98.62
Abrasion Resistance Index	98.51	97.78	97.88	99.45	100.00	98.73	98.62

Table 14. Sutherland Rub test data

<u>Sutherland Rub Tester</u> **Abrasion Test**	**Cyan**	**Magenta**	**Yellow**	**Black *built***	**Black *solid***	**<u>Mean</u>**	**<u>Median</u>**
Commercial Digital Press C							
Sample before test							
Density	1.21	1.35	1.15	1.28	1.55	1.31	1.28
L	56.86	47.99	91.17	26.50	18.20	48.14	47.99
a	-28.44	74.52	-11.92	0.65	0.72	7.11	0.65
b	-54.32	-2.58	86.55	-0.19	1.25	6.14	-0.19
Sample after test							
Density	1.04	1.17	1.01	1.11	1.41	1.15	1.11
L	59.67	51.23	91.51	31.94	21.92	51.25	51.23
a	-26.56	69.37	-11.81	0.56	0.19	6.35	0.19
b	-51.37	-4.77	80.87	-1.04	0.72	4.88	-1.04
Change in Density	0.17	0.18	0.14	0.17	0.14	0.16	0.17
Delta E	4.49	6.47	5.69	5.51	3.79	5.19	5.51
Ri	6.17	4.47	7.08	5.25	2.82	5.16	5.25
Rf	9.12	6.76	9.77	7.76	3.89	7.46	7.76
Rf-Ri	2.95	2.29	2.69	2.51	1.07	2.31	2.51
2 * Rf-Ri	5.91	4.59	5.39	5.03	2.14	4.61	5.03
100 - (2*Rf-Ri)	94.09	95.41	94.61	94.97	97.86	95.39	94.97
Abrasion Resistance Index	94.09	95.41	94.61	94.97	97.86	95.39	94.97
Commercial Digital Press B							
Sample before test							
Density	0.99	1.01	0.95	1.09	1.40	1.09	1.01
L	62.20	56.14	90.44	32.58	21.05	52.48	56.14
a	-29.98	67.76	-6.72	0.60	0.92	6.52	0.60
b	-47.75	-7.71	78.97	1.00	0.39	4.98	0.39
Sample after test							
Density	0.98	0.98	0.94	1.08	1.34	1.06	0.98
L	62.19	56.85	90.37	32.85	23.93	53.24	56.85
a	-29.75	65.76	-6.78	0.55	1.80	6.32	0.55
b	-47.63	-6.88	78.65	0.84	1.91	5.38	0.84
Change in Density	0.01	0.03	0.01	0.01	0.06	0.02	0.01
Delta E	0.26	2.28	0.33	0.32	3.37	1.31	0.33
Ri	10.23	9.77	11.22	8.13	3.98	8.67	9.77
Rf	10.47	10.47	11.48	8.32	4.57	9.06	10.47

Rf-Ri	0.24	0.70	0.26	0.19	0.59	0.40	0.26
2 * Rf-Ri	0.48	1.40	0.52	0.38	1.18	0.79	0.52
100 - (2*Rf-Ri)	99.52	98.60	99.48	99.62	98.82	99.21	99.48
Abrasion Resistance Index	99.52	98.60	99.48	99.62	98.82	99.21	99.48
Commercial Digital Press A							
Sample before test							
Density	1.43	1.56	1.61	1.63	1.64	1.57	1.61
L	53.65	51.10	89.84	15.86	15.81	45.25	51.10
a	-37.08	81.72	-2.97	1.80	1.41	8.98	1.41
b	-47.96	-11.67	98.01	1.80	1.39	8.31	1.39
Sample after test							
Density	1.42	1.59	1.60	1.56	1.66	1.57	1.59
L	53.82	51.07	89.98	17.78	15.20	45.57	51.07
a	-37.52	82.08	-2.83	1.64	1.52	8.98	1.52
b	-47.27	-11.56	97.63	1.45	1.31	8.31	1.31
Change in Density	0.01	-0.03	0.01	0.07	-0.02	0.01	0.01
Delta E	0.84	0.38	0.43	1.96	0.62	0.85	0.62
Ri	3.72	2.75	2.45	2.34	2.29	2.71	2.45
Rf	3.80	2.57	2.51	2.75	2.19	2.77	2.57
Rf-Ri	0.09	-0.18	0.06	0.41	-0.10	0.05	0.06
2 * Rf-Ri	0.17	-0.37	0.11	0.82	-0.21	0.11	0.11
100 - (2*Rf-Ri)	99.83	100.37	99.89	99.18	100.21	99.89	99.89
Abrasion Resistance Index	99.83	100.37	99.89	99.18	100.21	99.89	99.89
Offset Lithographic Press							
Sample before test							
Density	0.78	0.79	0.81	0.94	1.15	0.89	0.81
L	65.16	58.50	90.12	39.01	31.22	56.80	58.50
a	-23.41	55.88	-6.76	2.01	1.14	5.77	1.14
b	-41.50	-8.33	65.84	1.84	0.82	3.73	0.82
Sample after test							
Density	0.77	0.79	0.78	0.93	1.15	0.88	0.79
L	64.47	58.77	90.32	38.45	30.39	56.48	58.77
a	-23.02	55.63	-6.91	1.87	0.50	5.61	0.50
b	-41.68	-7.93	64.53	1.54	0.86	3.46	0.86
Change in Density	0.01	0.00	0.03	0.01	0.00	0.01	0.01
Delta E	0.81	0.54	1.33	0.65	1.05	0.88	0.81
Ri	16.60	16.22	15.49	11.48	7.08	13.37	15.49
Rf	16.98	16.22	16.60	11.75	7.08	13.72	16.22
Rf-Ri	0.39	0.00	1.11	0.27	0.00	0.35	0.27

2 * Rf-Ri	0.77	0.00	2.22	0.53	0.00	0.70	0.53
100 - (2*Rf-Ri)	99.23	100.00	97.78	99.47	100.00	99.30	99.47
Abrasion Resistance Index	99.23	100.00	97.78	99.47	100.00	99.30	99.47
High Speed Ink Jet Press							
Sample before test							
Density	0.83	0.83	0.80	1.01	1.04	0.90	0.83
L	65.59	57.84	89.47	36.13	34.91	56.79	57.84
a	-30.57	52.55	-2.33	-3.40	-0.52	3.15	-2.33
b	-36.43	-4.34	63.60	-1.29	-4.21	3.47	-4.21
Sample after test							
Density	0.81	0.83	0.78	1.00	1.01	0.89	0.83
L	66.16	57.18	89.60	36.27	35.07	56.86	57.18
a	-29.87	52.84	-2.21	-3.14	-0.41	3.44	-2.21
b	-35.65	-3.75	63.90	-1.43	-3.84	3.85	-3.75
Change in Density	0.02	0.00	0.02	0.01	0.03	0.02	0.02
Delta E	1.19	0.93	0.35	0.33	0.42	0.64	0.42
Ri	14.79	14.79	15.85	9.77	9.12	12.86	14.79
Rf	15.49	14.79	16.60	10.00	9.77	13.33	14.79
Rf-Ri	0.70	0.00	0.75	0.23	0.65	0.46	0.65
2 * Rf-Ri	1.39	0.00	1.49	0.46	1.30	0.93	1.30
100 - (2*Rf-Ri)	98.61	100.00	98.51	99.54	98.70	99.07	98.70
Abrasion Resistance Index	98.61	100.00	98.51	99.54	98.70	99.07	98.70