Factors to Consider in the Design and Evaluation of Commercial Printing Inks and Substrates for Permanence and Durability

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Abstract

In this paper we describe the various printing technologies, both digital and analog, that are currently being used for commercial printing applications, and the unique aspects of the various marking materials, substrates, and printing systems that influence the resultant permanence and durability of the printed output. The concept of image durability is defined as the combination of image permanence (environmental stability) and print durability (physical stability). Image durability can be thought of as the resistance to degradation of the original image quality of a print or image over time and/or in response to a wide variety of environmental and physical stress factors, individually or in combination. Ultimately, the overall durability of a commercial print will be a function of the ink, the substrate, and any pre- or post-processing steps, all of which need to be carefully co-optimized for the specific handling and other conditions that the print is expected to endure. There are a wide variety of test methods that are available to evaluate the various aspects of image durability. The specific test method and/or test conditions need to be selected with the product-intent application in mind, including any post-printing production processes, as well as final end-use scenarios, in order for the results to be useful for assessing the overall fitness-for-use of the printing technology. Several commercial printing applications will be highlighted as examples of the types of testing that should be carried out in the context of both the expected stress factors and fitness for use for each application.

Introduction

As digital printing technologies begin to approach the productivity and running costs of traditional printing presses, questions are being raised about how digital printing compares to offset in terms of the permanence and durability of the printed output, especially for commercial printing applications [1]. In this paper, we examine the differences among the various printing technologies that can affect print durability, the environmental and physical stresses that affect print durability, and the test procedures that are currently being used to assess print durability. In a separate report we compare various aspects of the actual print durability performance of printed output from both digital and analog printing presses [2].

Commercial printing can be broadly defined as the printing of newspapers, magazines, books, trade publications, direct mail, marketing collaterals, catalogs, and the like. Commercial printing does not generally include package printing, or other industrial applications, such as printed electronics, textiles, décor, product coding, etc. Before discussing in detail the various factors that affect print durability, we will first briefly review the various analog and digital printing technologies used for commercial printing applications, as well as the two key contributors to permanence and durability, ink and paper.

The most common form of commercial printing for the past century is known as offset lithography [3]. Lithography, which is derived from the Greek words for “writing on stone,” dates back to the late 18th century. Offset lithography, which was not invented until over a century later, involves the intermediate transfer of the image to a “blanket” which in turn is transferred to paper. Today’s high speed multicolor offset presses can output thousands of multicolor impressions per hour on either continuous webs or sheets of paper or synthetic substrates. Two other commonly employed analog printing technologies currently used for commercial printing are known as gravure and flexography [4]. Gravure is often used for high quality pictures or illustrations, such as magazines and Sunday inserts. Flexography is used extensively in package and label printing and for applying decorative patterns to anything from toilet paper to gift wrap, and it has also been used for newspaper and magazine printing.

Electrophotography (EP) has been used for selected short-run digital commercial printing applications for over twenty years [5]. The EP printing process employs a photoconductive web or drum which is discharged by exposure to either lasers or light emitting diodes (LEDs) to generate an electrostatic image pattern upon which electrostatically charged dry or liquid ink (toner) is deposited, followed by an electrostatic and/or mechanical transfer to paper. The imaged paper is then fused under heat and pressure to affix the image. More recently, inkjet printing, which involves the deposition of microscopic droplets of ink onto a substrate in response to digital signals [6] has migrated from desktop, wide-format, and/or product-marking applications to production-capable commercial printing systems. The two primary drop generation processes are known as “drop-on-demand” (DOD) and “continuous inkjet” (CIJ). In DOD, the ink is fed into microscopic ejection chambers within a printhead (PH) via capillary pressure, and in response to an electrical signal a drop is ejected “on demand” from the chamber and propelled toward the substrate. In CIJ, on the other hand, streams of ink are continuously ejected

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from an array of microscopic nozzles, and the streams are broken up into droplets by application of high-frequency, low-energy pulses. Once a uniform stream of droplets is formed, print drops are selected and directed to the substrate, and non-print drops are caught in a "gutter" and returned to the ink tank and re-used. The relative movements of the PH and the substrate, and the timing of the firing of the ejector, are controlled in such a way as to result in the precise placement of the droplets on the substrate in an imagewise fashion. In the past several years, high-speed inkjet presses, both sheet-fed and web-fed, have targeted a wide range of commercial printing applications.

One thing that all analog and digital printing technologies have in common is that they place a "marking material", e.g., ink or toner, on a substrate, e.g., paper or plastic, in an imagewise fashion, followed by subsequent drying, fusing, and/or curing steps that are intended to affix the ink to the substrate. Probably the most important factor with respect to print durability is the composition of the marking material itself. With respect to the ink or toner, the primary components that influence permanence and durability are the colorant, the carrier or vehicle, and optional additives, such as binders, viscosifiers, UV inhibitors, anti-oxidants, biocides, and surfactants. The choice of colorant typically has the biggest impact on resistance to fading when subjected to high levels and/or prolonged exposure to light, heat, and air pollution.

After colorant, the other components of the ink are often constrained or determined by the specific printing process. Traditional lithographic inks fall into three general categories: heat set, cold set, and radiation-curable inks. Heat set inks comprise volatile solvents as vehicles which are dried by heating to evaporate the solvent. Cold set inks, on the other hand, use petroleum or vegetable oils as the carrier fluid, and "dry" primarily by absorption of the oil into the substrate. The residual oils that are present in prints produced with cold set inks tend to make them more prone to smudging when subjected to rubbing. For radiation curable inks the carrier fluid comprises a blend of reactive ingredients that polymerize when exposed to strong radiation, such as ultraviolet light (UV) or electron beam (EB). In this case, "drying" occurs by solidification of the ink. One common issue with radiation curable inks on certain types of substrates is relatively poor adhesion of the ink, resulting in poor abrasion resistance unless a pre-coat or primer is applied prior to printing. Dry toner EP uses a solid polymer as the vehicle, which is melted and fused to the substrate, usually under a combination of heat and pressure. Compatibility of the toner polymer with the various commercial substrates and the ability of the polymer to melt and fuse at high speeds are important factors with respect to the ultimate adhesion of the toner to substrate. Inkjet inks that are targeted for commercial printing applications are typically water-based, although there are also examples of radiation-curable, "hot-melt" (aka phase-change), and oil-based inks targeted at specific applications. Aqueous inks have an inherent advantage of lower cost and environmental impact, but offer extra challenges with respect to humidity and water resistance, especially when dyes are used as colorants.

In addition to the ink components, the choice of substrate can have a significant contribution to overall performance. For example, certain inexpensive papers such as news print papers are known to yellow and/or become brittle with age, which will limit the useful life of the print independent of the type of ink [7]. On the other hand, if the print is expected to be immersed in water and/or subjected to certain mechanical stresses, the choice of a plastic or synthetic substrate may be beneficial. Substrate surface treatments have also been used to enhance the adhesion of the ink and improve overall durability of the printed image. For any given combination of ink and substrate, interaction of the two can be greatly impacted by the means with which the ink is chemically and/or physically fixed or bonded to the substrate. In the case of liquid inks, this step typically involves the removal of the ink vehicle via absorption and/or evaporation, followed by chemical and/or physical bonding of the colorant with the substrate. Additives, such as binder polymers, can help form a physical bond to the substrate once the ink vehicle is removed, often with the assistance of heat. Other additives may be used to chemically attach the colorant to the substrate, for example via ionic or hydrogen bonds. An especially challenging ink-substrate combination involves printing pigmented inks on very smooth, glossy coated papers. Recent studies have shown that with the judicious choice of coating pigments and additives, the structure and porosity of the coating can be enhanced while maintaining a relatively smooth, glossy surface [8]. This allows sufficient penetration of the ink pigments into the surface of the coating which greatly improves ink adhesion.

It should also be noted that further protection may be added to the printed article in the form of a protective overcoat or laminate. For some of the most demanding applications, e.g., direct mail, a varnish or other protective overcoat is often routinely applied. The choice of the overcoat material and the application method needs to be carefully matched and optimized to the specific ink, substrate, and printing process in order to ensure satisfactory results. If, for a given application, an overcoat is normally considered integral to the production process, then any evaluation of image permanence and print durability should be conducted with the standard overcoat on the print. However, it is often useful to understand how well the as-printed piece will hold up without the overcoat, as this represents an opportunity for process simplification and obvious cost reduction.

Image Quality and Image Durability

Before we discuss the various stress factors that can impact the permanence and durability of a printed piece, it important to understand the initial condition or quality of the print prior to stressing it (time = 0 condition). In a general sense, the initial condition of the print is characterized by a variety of attributes that, taken together, define the image quality of the printed output. Depending upon the nature of the stress, one or more of the various attributes that make up the overall image or print quality may be affected. A partial list of image quality attributes that may need to be monitored before and after a print is subjected to a test condition includes the following:

- Color reproduction
    - Densitometry
    - Colorimetry
    - Color gamut
- Sharpness and resolution
- Tone scale
- Image artifacts
    - Mottle

- Grain
- Coalescence
- Intercolor bleed
- Differential Gloss
- Banding
- Paper cockle
- Substrate curl
- Show though

Color reproduction and sharpness are typically the most important contributors to perceived image quality. Color quality is characterized by a combination of tools, with densitometry and colorimetry being the most common. Sharpness, resolution, and tone scale are also important image quality attributes that may be degraded by one or more of the stress factors. Metrics such as line width, edge raggedness, the modulation transfer function (MTF), and contrast are often used to characterize resolution, sharpness, and tone scale. In terms of image artifacts, the initial quality goal is to be artifact-free, and it is important to maintain this condition over the intended life of the print. There are specific measurements for each of these that can be used to assess both the initial quality and their degradation in response to the various stress tests.

Image durability can be defined as the change or degradation of the initial image quality over time and/or in response to a specific stress factor. One way to think about image durability is to differentiate between those factors that affect the image permanence from those that impact print durability. Although this may seem like a subtle or semantic distinction, it becomes clearer when you think of image permanence factors as being primarily environmental stresses, and print durability factors as being physical stresses. Environmental stresses include light, heat, humidity, and air quality, and these stresses are constantly and cumulatively acting on the print over its useful like. Physical stresses are more likely to be caused by specific, often one-off interactions of the print with humans or machines. Physical stresses can include the intentional or accidental interaction of the print with water or other fluids, subjecting the print to mechanical forces such as friction, tension, pressure, flexure, etc., or combinations of the above. Physical stresses are often encountered between the time the actual print or image is generated and when it is delivered to the end-user. For example, a mail solicitation piece may be subjected to friction, tension, and flexure as the printed web is transported through the converting equipment, folded and inserted into an envelope, transported through various pieces of equipment used by the postal system to convey and sort the mail, and, finally during the delivery of the mail, it may be further subjected to water in the form of rain, sleet, or snow.

Evaluating Image Durability

Image permanence testing against the effects of light, heat, humidity, and air pollution has been largely driven by the photographic industry over the past several decades, given the importance that consumers, photojournalists, and professional photographers place on the preservation of photographs as family memories, historical documents, and works of art [9]. Historically, the permanence of silver halide photographs has been primarily determined by the effects of long term exposure to light and heat, with the latter given the misnomer of "dark stability" or "dark fastness". In fact, thermally induced fading of the colorants that make up an image and/or yellowing of the substrate happens constantly, regardless of whether the print is in the light or in the dark. More recently, with the advent of digital imaging technologies such as inkjet, the long term effects of air pollution and humidity on image permanence have also been extensively studied. As with light and heat, the result of exposure to air pollutants such as ozone and oxides of nitrogen (NO_x) is typically a combination of colorant fade and substrate yellowing. For dye-based inkjet prints, on the other hand, prolonged exposure to elevated humidity can result in dye migration, which is manifest as a loss of sharpness, a gain in density, and/or a shift in hue.

Image permanence testing generally falls into either comparative or predictive methods. In either case, the test specimen is exposed to an accelerating level of the factor of interest, while the other factors are controlled in such a way as to have a negligible effect on the sample over the duration of the test. For comparative testing, the sample is typically exposed for a fixed duration, and the results are either compared to an internal benchmark or to a standard reference sample. For predictive testing, the accelerated test is run until a specified amount of change, e.g., density loss, is observed, sometimes referred to as an end-point, and using a combination of scientific principles and simplifying assumptions, the length of time required to achieve the same amount of change under a given or assumed long term ambient level for that factor can be calculated.

In the case of light fastness testing, the validity of the predictive test rests on the scientific principle known as "reciprocity", which states that the amount of light induced fade of a colorant, e.g., the loss in optical density (ΔD), is proportional to the total cumulative exposure, expressed as the product of intensity of the light (I) times the duration of the exposure (t). Thus, a relatively short exposure to a high intensity light source can be used to predict a much longer exposure to a much lower ambient light level.

For most purposes comparative testing provides adequate guidance on the suitability of a given printing system for an intended application, or can serve to establish performance expectations relative to a known benchmark. In any event, it is still important to understand the intended ambient use conditions to ensure that the light source used for the accelerated test condition is a reasonable match. As noted above, it is also important that the other environmental factors be held constant at levels that would not be expected to contribute to the observed changes as a result of the accelerated light fade test. For example, a test chamber temperature in the range of 20° – 30° C, relative humidity in the range of 45 –55%, and concentrations of ozone and/or NO_x less that 2 ppb have been shown to be benign for most imaging materials for tests lasting less than about 8 weeks.

For accelerated pollutant stability testing, a very similar methodology to light stability testing is employed, i.e., the test samples are exposed to a much higher than ambient concentration of pollutant gas for a shorter duration, and the cumulative exposure required to reach a specified amount of colorant fade or substrate yellowing can be used to calculate the amount of time to reach the same degree of change at a given ambient concentration of pollutant [10]. Again, the principle of reciprocity is assumed when making predictions based on tests run at high pollutant concentrations. The same caveats apply regarding the potential sources of inaccuracies as with predictive accelerated light fade testing. Again, comparative testing may be a more suitable alternative for demonstrating fitness for use compared to a known benchmark.

Predictive thermal stability testing uses a somewhat different approach, since the concept of reciprocity does not apply to temperature. However, the Swedish chemist Arrhenius discovered that certain types of chemical reactions can be accelerated at several different temperatures above ambient, and that a mathematical relationship between the rates of the reaction at the various elevated temperatures and the inverse of the temperature can be demonstrated. Once the "Arrhenius" equation is derived, it is possible to estimate the rate of the reaction at ambient temperature [11]. As with predictive light and pollutant testing, there are a variety of assumptions and conditions that must be met, but for well-behaved systems this method has been used with great success [12]. Again, a simpler alternative is to conduct comparative tests for a fixed duration at a single elevated temperature. Depending on the temperature that is chosen and the specific degradation process that is at play, this approach can be misleading with respect to actual fitness for use, but it is still useful to screen for potential sensitivity of a particular ink-media combination to prolonged exposure to heat.

As noted above, in addition to colorant fade and substrate yellowing, certain combinations of inks and substrates may also exhibit colorant migration as a function of temperature, leading to loss of sharpness, density gain, and/or shift in hue. In extreme cases, a colorant can actually migrate through a substrate, leading to "ghosting" or show-through on the other side of the print. In other cases, when the prints are in a stack or wound in a roll, prolonged exposure to elevated temperatures can cause a colorant to transfer to the back side of the adjacent substrate, and in the some cases a stack or roll of prints can even be stuck together in a phenomenon known as "blocking". Since image retransfer and blocking are unique to stacked or wound rolls of prints, a separate blocking test is often carried out in which both temperature and pressure are stress variables that can be adjusted to simulate an actual use condition. This will be discussed in more detail below in the context of physical durability testing.

Predictive accelerated high humidity testing is more challenging. As with heat, the principle of reciprocity is not applicable to this environmental factor. For print materials that are sensitive to relative humidity, such as aqueous dye-based inks on certain types of substrates comprising "swellable" surface layers, there is typically a threshold relative humidity below which nothing much happens, but above which dye migration can be significant [13]. If a print experiences brief, intermittent periods of high humidity, the effect can be cumulative, but it is difficult to predict the long-term effect with a single high humidity test condition. One published report has suggested that it might be possible to calculate an "acceleration factor" that could be used to extrapolate the results from a test run for a given period of time at high relative humidity if the long-term statistical distribution of relative humidity in the product-intent environment is known [14].

There are a number of standard methods available for evaluating the various aspects of print durability, driven by both the traditional photographic and commercial printing industries, as well as the office document industry. In some cases there a several test methods that are available for essentially the same phenomenon, for example, dry abrasion of prints [15 – 20]. Most dry abrasion methods have a somewhat common approach, in which the test specimen is rubbed using a back-and-forth motion with a specific reference material, such as an unprinted sample of the same substrate or a standard strip of cloth or paper, while a specified weight or load is applied. The test is continued for either a defined number of cycles or until a pre-determined amount of damage, e.g., loss of colorant, is observed. Variations of this methodology can also be used to evaluated smudge (the tendency of an image to smear or streak onto adjacent areas when rubbed and involves the re-deposition of abraded material), and scuff (a form of abrasion, leading to a change in gloss).

Scratch testing is very similar to dry abrasion testing except that instead of using relatively flat abrasive surface under a known force, scratch testing moves a stylus of specified geometry under a specified load across the surface of the test specimen [21]. In addition to the shape and dimensions of the stylus and the applied load, the angle of the stylus relative to the sample is another important variable to control. Given the wide variety of actual use conditions that can lead to the scratching of a print, the geometry of the stylus and the load used for the test are often selected by trial and error to best match a specific product-intent condition. In one type of scratch test, the degree of damage to the printed image under a set of standard conditions is qualitatively assessed, e.g., no damage, noticeable marring of the surface, complete removal of ink, etc. Alternatively, the load on the stylus may be systematically increased until removal of ink is observed, at which time the test is stopped and the applied load at failure is recorded.

Waterfastness/water resistance and spill/stain resistance fall under the "accidental factors" category, as most commercial prints are not designed or intended to be subjected to direct contact with water or other fluids, and for those applications for which direct contact with liquids is expected, a fluid-impermeable protective overcoat is customary. Nevertheless, it is still of interest to understand how tolerant an unprotected ink-substrate combination will be to these conditions, especially to brief exposure to water, as might occur in the case of direct mail. As with most physical durability tests, there are several variations of waterfastness/water resistance testing that have evolved to evaluate varying use scenarios [22, 23]. In one variation, the print is completely immersed in a tank of water for a specified time, followed by removal and air drying. Changes to the test target in the form of optical density loss from the printed areas, optical density gain into adjacent unprinted areas (image bleed), and/or substrate deformation (paper cockle) are measured and compared to an untreated sample. Another version of this test involves the placement of a known volume of water, usually several drops, on a specific test pattern, allowing the water to completely soak into the substrate and/or evaporate, and then measuring loss of resolution in the treated area. Yet another adaptation of waterfastness testing uses a test target comprising a series of horizontal Dmax bars interlaced with unprinted white space tilted at a 45° angle, and a known volume of water is allowed to flow perpendicular to the test pattern. An increase in optical density in the unprinted white areas is used as a measure of poor water resistance.

Spill/stain resistance refers to the ability of a print to withstand fluids other than plain water, including such things as highly colored materials (red wine, ketchup, mustard, fruit punch, etc.). Again, although most commercial print applications do not anticipate direct contact with such materials as part of their intended usage, we mention it for the sake of completeness, since such test methods are being considered to evaluate the resistance of prints to spills and stains for special-case situations [24].

Fold/crack resistance is used to evaluate the ability of a printed area of the substrate to resist cracking when folded and then unfolded. This situation is primarily experienced with printed forms and statements, which are subsequently folded and inserted into envelopes. Historically, dry toner electrophotography and phase-change inkjet have been prone to this phenomenon, but subsequent improvements in paper and toner/ink formulations, coupled with improved fusing subsystems, have largely eliminated this problem. In this type of test, a machine is used to fold and unfold a print comprising a printed Dmax bar for a fixed number of times, then a brush is used to gently remove any loosened particles or flakes from the area around the fold. A scanning densitometer can be used to measure the width of the resultant crack and/or the loss of density in the area of the crack. Since different responses are often observed as a function of the direction of the fold relative to the grain of the paper, it is important to evaluate the crack resistance in both directions, with the grain and across the grain. Complications can arise with certain coated papers due to the tendency of the coating itself crack and flake off the paper base, independent of the printing process and ink type.

Wet abrasion/wet smudge and highlighter resistance are examples of multifactor durability tests, in which the print is being evaluated for its robustness to two factors simultaneously, i.e., fluid and friction. The ISO waterfastness standard for photographic prints [23] includes a test for wet abrasion in which 0.1 mL of water is placed on a solid density patch, and after 60 seconds a laboratory tissue is sandwiched between the wet patch and a 50-g weight. The weighted tissue is then pulled across the test target. Changes in the optical density of the printed area (wet abrasion) and adjacent unprinted area (wet smudge) are measured and compared before and after treatment.

Highlighter resistance is a special-use practical test that is unique to commercial applications such as text books, and to a lesser extent, trade books. One complication with this type of testing is the wide variability in the highlighter tip construction and design, combined with the diverse chemical compositions and fluid properties of the highlighter inks for the markers that are currently available in the market. Another variable to highlighter resistance testing is the number of "swipes" that are applied across the same line of text. The most common failure mode is the smudging or blurring of the text, similar to what is seen for solid area patches in a wet abrasion test. In the worst cases the entire line of text being highlighted is physically removed. In the extreme, some of the more aggressive highlighters can actually damage the unprinted substrate, especially very absorbent, uncoated ground wood papers often used for trade books. On the other hand, there are now "inkjet friendly" highlighters on the market that are specially engineered for use with aqueous inkjet inks.

Blocking is another example of a multifactor stress test involving the combination of pressure, heat, and/or humidity to a stack of test prints for specified time duration. [25] In addition to the types print degradation noted above as a result of exposure to elevated temperature and humidity, the addition of pressure can cause further degradation modes, such as image retransfer, ferrotyping, or page-to-page adhesion.

Market Application Considerations

Although touched on briefly in several instances above, the life cycle expectations for the permanence and durability of commercial printing vary by market application, sometimes dramatically [1]. From a physical durability perspective, one of the most demanding applications is direct mail. Not only must it survive the finishing and converting process and machinery, it must also endure the vagaries of the postal service [26]. Scratch and dry abrasion resistance are important attributes that must be maintained. Mail must also survive the occasional exposure to inclement weather, so water and wet abrasion resistance are also important features. Because of these demands, it is commonplace for direct mail pieces to be protected with an overcoat regardless of the printing technology. On the other hand, direct mail typically has a very short life expectancy with respect to image permanence, so light, ozone, heat and humidity fastness are relatively less important.

Another particularly demanding application is text book printing. Again, the finishing and converting processes for book assembly and binding involve multiple opportunities for scratch and abrasion, not to mention the physical wear and tear that occurs from subsequent student handling. For books in general, the text and print must be smudge resistant and must not transfer to a reader's moist or sweaty fingers. Many textbooks, especially those used in elementary and high schools, are expected to be re-used for several years, so there is also a greater expectation for resistance to degradation caused by the environmental factors such as heat and humidity. Reference books have an even longer life expectancy. A unique durability requirement of text books, and also for certain types of trade books, is the ability for the text to be highlighted without smearing.

Newspapers, catalogs, and advertising inserts have relatively low image permanence expectations, but they still must have sufficient physical durability to survive the post-printing and fulfillment processes, not to mention smudge resistance inks. A somewhat contradictory expectation for newspapers, catalogs, and similar printed articles is that ease of ink removal is preferred during the recycling phase. Magazines and other periodicals, e.g., comic books, in addition to requiring levels of physical durability performance similar to books, newspapers, and catalogs, have a much higher expectation for image permanence due to their historical and/or collectible potential. Trading cards, fine art reproductions, and the like also fall into this category.

As noted above, it is sometimes necessary based on the demands of a given market application to consider either specially engineered substrates, substrate coatings or pre-treatments, in-line bonding agents, and/or post-treatments to deliver satisfactory permanence and durability for that application. Future improvements in both standard substrates and inks that can minimize or eliminate the need for these extra steps will provide a significant market advantage regardless of the printing technology.

Summary

In this paper we have outlined the various printing technologies, both digital and analog, that are currently being used for commercial printing applications, and the unique aspects of the various inks, substrates, and printing systems that influence the resultant permanence and durability of the printed output. The concept of image durability is defined as the combination of image permanence (environmental stability) and print durability (physical stability). Image durability can be thought of as the resistance to degradation of the original image quality of a print or image over time and/or in response to a wide variety of environmental and physical stress factors, individually or in combination. Ultimately, the overall durability of commercial print output will be a function of the ink, the substrate, and any pre- or post-processing steps, all of which need to be co-optimized for the specific handling and other use conditions that the print is expected to endure. There are a wide variety of test methods available to evaluate the various aspects of image durability, both standardized and non-standardized. The specific test method and/or test conditions need to be selected with the product-intent application in mind, including any post-printing production processes, as well as final end-use scenarios, in order for the results to be relevant to the overall fitness-for-use of the printing technology.

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Douglas Bugner received a Ph.D. in Organic Chemistry from UCLA in 1982. He has spent the past 30 years at Eastman Kodak Company where he is currently Senior Laboratory Head, Ink and Media Design Lab, Commercial Inkjet Writing Systems Division. He holds 60 U.S. Patents, and has authored over 40 scientific publications. Dr. Bugner was awarded the title of Fellow of the Society for Imaging Science and Technology in 2006.