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Imaging materials — Evaluation of image permanence of photographic colour prints in consumer home applications

Support d'image — Évaluation de la permanence de l'image de tirages couleur photographiques dans les applications domestiques grand public

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 42, *Photography*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Reflection colour photographic-indoor stability specifications for consumer home have been discussed (Physical properties and image permanence of photographic materials). Many matters have been discussed about environmental data, psychophysically based end of test, nominal use case conditions, and mechanics of rating system, reciprocity issues, and experimental testing issues in the meetings.

This document describes cumulated information, data and knowledge work over the last 15 years as 'Guidelines for print-life-estimations'. Furthermore, it describes the background and the history of the discussion in TC 42/WG 5.

The purpose of this document provides data, information, and indicating the guidelines for evaluation of image permanence. These data and information were introduced and discussed and were quoted from the papers reported in conferences by TC 42/WG 5 members. Furthermore, detailed information and understanding are available in the references listed in the Bibliography in this paper.

It describes four important environmental stressors (heat, light, atmospheric pollutants, and humidity) in main body of this document. Ozone was chosen as the model system for atmospheric pollutant, but SO_x, NO_x and other atmospheric pollutants are present in the indoor environment. In addition, it includes an Annex A about accidental stressor (water, abrasion and others), examples of many topics and useful data collections and information.

Information about the stability of colour photographs toward these various factors can be obtained by accelerated stability tests. The starting assumption for indoor use cases is that the various environmental factors (heat, light, atmospheric pollutants, and humidity) each act independently on the photograph, i.e., there are no synergistic interactions taking place between these factors under typical storage and display conditions. While interactions most certainly do take place in the real world, modelling and testing for interactions is extremely difficult. The accelerated tests are therefore designed such that only one factor (heat, light, atmospheric pollutants and humidity) is varied at a time. The other factors not under investigation are controlled or held at a level that will induce only negligible changes in the image during the course of the accelerated test.

In accelerated testing, high levels or "loads" are required for each of the factors in test in order to complete the tests in a reasonable amount of time. The validity of accelerated testing for light and pollutants assumes that equal change will occur for the same cumulative exposure, i.e., one assumes reciprocity for the dose. However, for some systems "reciprocity failure" has been observed. When applied to light-induced fading and staining of colour images, reciprocity failure refers to the failure of many colorants to fade, or to form stain, equally when irradiated with high-intensity versus low-intensity light, even though the total light exposure (intensity × time) is kept constant through appropriate adjustments in exposure duration. This concept can be applied to any accelerated test where the same cumulative exposure can be obtained by different intensities or concentrations and time. Note, however, that this concept cannot be applied to accelerate testing for heat or humidity where special test procedures are required. This concept does hold for ozone stability testing, where the ozone concentration can be high or low. The extent of colorant fading, colorant migration, and stain formation can be greater or smaller under accelerated conditions, depending on the chemical reactions involved in the colorant degradation, on the kind of colorant dispersion, on the nature of the binder material, and on other variables. For example, the supply of oxygen that can diffuse into a photograph's image-containing layers from the surrounding atmosphere may be restricted in an accelerated test (dry gelatine, for example, is an oxygen barrier). This may change the rate of colorant fading relative to the fading that would occur under normal display conditions. The magnitude of reciprocity failure may also be influenced by the temperature and moisture content of the test specimen. Comparisons between products will more accurately reflect observed differences when accelerated aging conditions are close to actual use conditions.

The following International Standards describe test methods relating to indoor stability. These Standards provide procedures for reporting technical data.

A test method for thermal stability is described in ISO 18936. A test method for humidity fastness is described in ISO 18946. A test method for indoor light stability is described in ISO 18937. A test method for ozone gas fading stability is described in ISO 18941. A test method for stability under low humidity conditions in ISO 18949.

Imaging materials — Evaluation of image permanence of photographic colour prints in consumer home applications

1 Scope

This document provides data and information related to evaluation of image permanence of photographic colour prints in consumer home applications. This document characterizes the test methods, the end of test criteria, the environmental factors, and the reporting. It also provides the background and the history of those.

This document describes guidelines and limitations for print life estimates, i.e. translation of the test results to the performance in actual usage as well as limitations of such a translation.

The photographic colour prints printed digitally described in this document can be generated with dyes or pigments by several processes, including ink jet, chromogenic (silver halide), thermal dye transfer processes, and electro photography, excluding lithographic printing, screen printing and other non-digital printing.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18913, *Imaging materials — Permanence — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18913 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
test load
cumulative dose, which is the product of a stress level and exposure time

3.2
specimen aim temperature
controlled aim value temperature of the specimen by configuring the light exposure equipment

4 Overview

4.1 General

This document describes approaches for the evaluation of image permanence of photographic colour prints in consumer home applications. The use profile “consumer home” is defined with two sub-cases i) display and ii) storage. In addition, variants of the use profile due to “partial protection” are introduced.

Then, suitable accelerated test methods representing single factor testing of the four leading environmental factors are described, which are considered important for characterization of image permanence in this use profile. Limitations of these laboratory tests are set into perspective.

Different approaches of collecting and reporting test data are presented. In addition, the advanced reporting level based on eventual translation of test data into print life expectations is introduced together with limitations of such predictions.

The definition of end of test and the interdependence of their meaning with test target design and evaluation metrics are discussed.

4.2 Use case

Within the consumer home use profile, there are two main use cases for colour photographic images, namely display and dark storage, in which the four leading environmental stress factors heat, light, atmospheric pollutants and humidity have different weights. In both, additional (partial) protection against some environmental factors may be introduced by suitable enclosures that create a “micro-environment”, in which the level of one or several environmental factors is reduced. For example, framing of displayed colour prints with glass, plastic, or other materials can introduce additional protection against degradation caused by light or pollutants or both. In dark storage, light-tight enclosures, such as “shoe box” and albums, first of all will help to reduce the level of light exposure as well as help to reduce the level of active atmospheric pollutants due to the lack of air exchange inside the box. Levels of heat and humidity could only be reduced by air-conditioned environments as shown in Table 1.

Table 1 — Major and minor stressors for various storage and display use cases

	Heat	Light	Atmospheric Pollutants	Humidity
Dark Storage Protected	Major	Not a factor	Minor	Major
Dark Storage Unprotected	Major	Not a factor	Major	Major
Display Protected	Major	Major	Not a factor	Minor
Display Unprotected	Major	Major	Major	Major

NOTE 1 Additional protection in storage and display environments can be provided as follows:

a) In the dark environment by enclosures which limit air exchange;

b) In the light environment by framing with UV absorbing glass which reduces damaging light and also limits air exchange.

NOTE 2 The “Display Protected” category is considered to be “Not a Factor” for atmospheric pollutants only if the protecting frame is sealed to prevent any exchange of air. Atmospheric pollutants, such as ozone, are extremely reactive and are not retained in closed (protected) spaces, while humidity can penetrate into the enclosure and remains for a long period.

NOTE 3 Dark storage protected and display protected provides protection against short-term humidity excursions.

Typical ranges of environmental factors in the use profiles “consumer home” are given in Clause 8.

4.3 Single factor tests and their limitations

A typical approach for image permanence testing for indoor use profiles is based on single factor accelerated test methods that assess the susceptibility of the print to degrade for each of the four leading environmental factors one at a time. Prints are exposed to one of the factors heat, light, humidity and atmospheric pollutants and the other stress factors are set to zero or a ‘neutral’ level. Ozone was chosen as model system for atmospheric pollutant, acknowledging that SO_x, NO_x and other atmospheric pollutants are also present in the indoor environment and that exposure to these may result in different image fading results[1][2]. A considerable level of acceleration is needed in the test methods for the evaluation of degradation by heat, light, ozone, and humidity, because the degradation of many modern colour print images by these stress factors is too slow to yield timely information about their long-term effects.

For example, in assessing the image degradation of a reflection print due to exposure to light, the accelerated test method in ISO 18937 specifies that the test be conducted under air that contains <2 nl/l ozone at an air temperature and relative humidity of 21 °C to 27 °C for control specimen aim temperature and 50 % ± 5 % RH, respectively. These conditions ensure that any image degradation observed will be due primarily to light exposure and not to ozone, thermal, or humidity. These are designed to minimize the contribution from each other.

An overview of the single factor test methods and their setting for the other environmental factors is described in Table 2. Users can set conditions by controlling their testing equipment.

Table 2 — Test conditions described in test methods International Standards

	Reference ISO	Heat	Light	Ozone	Humidity
Thermal stability	ISO 18936	main factor	dark	<2 nl/l	50 % RH
Light stability	ISO 18937	21 °C–27 °C	main factor	<2 nl/l	50 % RH
Ozone stability	ISO 19841	23 °C	dark	main factor	50 % RH
Humidity resistance	ISO 18946	25 °C	dark	<2 nl/l	main factor

The conditions in the top row (Thermal stability) are not a strictly pure single-factor test of heat; it actually includes the combined stress contributions from both humidity content and temperature. The variation ranges of moisture content of the humidity test conditions listed in the bottom row (Humidity resistance) is a sub-set (within the variation range) of moisture content in the thermal test, but without the involvement of temperature variation.

Some caveats need to be considered, when prints are tested together with some means of protection. For example, testing light stability of framed specimen print with glazing may result in elevated specimen temperature. In addition, material that may outgas during the test could become trapped in the vicinity of the test specimen, and induce additional image degradation. Similarly, test specimens that are laminated may also be subject to interactions that may confound the test results. The user is cautioned to keep such phenomena in mind if unexpected results occur.

This document advises the use of standard test parameter settings with fixed exposure or test load conditions to collect test data for reporting. It is recognized that other test parameter settings may be more representative for particular instances of the use profile or other applications. These other conditions may then be reported in addition and to the standard test parameters settings mentioned before.

The user of this document is advised that the actual image degradation that is observed by the end user or consumer will be a combination of all the degradation modes discussed above. However, complex interactions may exist between these different failure modes, which are not covered by the single stress factor of test approach. For example, the reported photochemical instability of the yellow stain developed during thermal aging[15] makes simple linear combinations inappropriate.

4.4 Accelerated tests and the concept of reciprocity

An important element of accelerated testing is the level of reliability obtained for the predicted results.

In thermal testing, for example, the underlying model for acceleration is based on a first order thermally activated process. The validity of that assumption is verified by a linear dependence of data in the well-known" Arrhenius-plot" described in ISO 18924.

The accelerated testing of degradation under both, light and ozone, is based on the concept of reciprocity. In the case of light, the principle of reciprocity states that increasing the incident light intensity without changing the spectral distribution of the illumination, while maintaining the same temperature and relative humidity will produce a proportional increase in the rate of photochemical reactions that cause colorant fading and stain formation[3]. But, different results may be obtained when colour prints are irradiated with high or lower-intensity light, even though the total exposure or test load (intensity × time) is kept constant[4][5]. This is called reciprocity failure and is often related to limitation of effective reaction rates by e.g. slower transport processes or competitive side reactions. Reciprocity failure in a light stability test means, that e.g. the effect of exposure to light of 1 000 lx intensity for 2 h is not the same as the exposure to light of 100 lx for 20 h.

Also in case of ozone testing, a combined transport and reaction process is present, and the rate of degradation may not linearly increase with ozone concentration. Reciprocity failure on ozone stability test means, that e.g. the effect of exposure to ozone gas of 10 µl/l[1)] intensity for 20 h is not the same as the exposure to ozone gas of 1 µl/l for 200 h. For their information, the interested user may refer to the references listed below[6]to[13]. Because reciprocity law failure can cause serious mis-predictions due to erroneous tests results, the user is strongly encouraged to determine if the system under test obeys the law of reciprocity or if it exhibits reciprocity law failure.

4.5 Concepts and limitations of data reporting

For actual testing of printed images, specific test targets with well-defined patches are prepared. Construction of the test targets depends on the failure modes, for which the changes need to be measured. ISO 18944 provides examples of test targets used for measurement of colour fading. The test target construction (frequency and distribution of test colours in colour space) as well as the approach for statistical data analysis together define the numerical values of the changes observed. Test target design and the actual difference metrics for measurement the change in colour are therefore indispensable elements in the definition of end of test and need to be selected to provide good correlation with visual judgements in view of the use profile.

Raw data collected from the image permanence tests are typically the changes in colour as function of exposure time at a specific stress level, which are then conveniently expressed as cumulative exposure, for example Mlx·h for light tests and µl/l·h for ozone tests. These raw data are sometimes translated in some rating, classification or expected print life supposing the actual usage of the prints.

TC 42/WG 5 initially had made it a goal to translate the test results to print life in “years”. However, it has been suspended due to the following reasons.

a) The “prediction” of print life is inherently difficult because of the reciprocity failure problem, differences of the test conditions from the actual environment, the synergetic effects or other stress factors (e.g. combination of light, thermal and humidity), and others.

b) The actual environmental conditions within the use profile “consumer home” vary widely. For example, the light level of consumer homes can vary from less than 10 lx to over 1 000 lx, and the ozone level of consumer homes can vary from almost zero or less than 1 nl/l to over 30 nl/l.

c) Given this, the years generated from the test predictions will likely be much different from the actual performance the consumer may see. Because of all the variables in the consumer environment, the actual performance the consumer will see may be much worse or much better than predicted.

1) 1 nl/l = 1 ppb (1×10^{-9}) and 1 µl/l = 1 ppm (1×10^{-6}). Although the notation “ppb” (parts per billion) and “ppm” (parts per million) are widely used in the measurement and reporting of trace amounts of pollutants in the atmosphere, they are language-dependent and therefore not used in the document.

It became apparent during discussion that it was decided to divide data reporting into three levels and discuss them as follows. The following three levels have been agreed upon for evaluation of image permanence of photographic colour prints in consumer home applications.

Level 1 is Test methods, test conditions and Basic Reporting rule.

Level 2 is End of test criteria.

Level 3 is Environmental conditions of consumer homes and Advanced Reporting.

In Level 1, two Basic Reporting methods were proposed and discussed. One is reporting the changes in graphs and the other is reporting the fade values at a fixed load. Fundamental test results will be reported by using these reporting methods. While Basic Reporting (graphical reporting or a fixed load approach) does not translate directly to a time based response like years, it may still be possible to provide information for customers on whether or not the product meets customer expectations. If a "reference" can be agreed upon, any product that shows less of a change (Delta E or Delta density) in a fixed load response or shows, a curve with a lower slope (rate of change with increasing stress value less than check) can be shown to meet or exceed customer expectations. However, the challenge here is agreeing on an appropriate "reference curve" for graphical reporting or a "spec limit" for fixed load reporting. The committee has discussed this on numerous occasions but has not yet been able to reach a consensus. In Level 2, Total exposures to the end of test will be described. In Level 3, Total exposures will be translated to an "*X* years", bins (star-rating, etc.)

In this document, the issues related to level 1 are explained in Clause 6. The details of level 2 are described in Clause 7, and Level 3 is explained in Clause 8.

The purpose of Level 2 and 3 is to provide reporting procedures in order to make it possible to translate the test results obtained from the above-mentioned test methods, which use accelerated exposures to heat, humidity, light, or ozone, to information, which is related to life expectancies of photographic images.

5 Preparation of test targets and analysis

5.1 General

The test targets contain a specific selection of colour patches that sample the colour gamut of the printing system in a representative way. The test colour selection given by a specific test target, together with the colour distance metrics (densitometric, colorimetric) employed, and the figures of merit derived from statistical data analysis (average, percentiles) determine the (range of) values measured as colour change after testing. The meaning for that range of values is then correlated to visual perception by psycho visual testing in order to define end of test. In addition, handling of the specimen is described in this document. The following factors influence the test results for print-life-estimations of photographic colour print images. The outlines are described here.

5.2 Factors influencing the test results

5.2.1 Test design

The test results may be varied depending on the test target, especially the densities and chromaticity of the patches to be measured before and after the image permanence test. The size of the patches is decided based on the geometric restriction of density or chromaticity measurements.

5.2.2 Test conditions

Accelerated tests are carried out under the stress condition for a specific factor, such as light or gas, etc. The other factors than the stress factors influence the test results. In general, temperature and humidity are essential factors. Airflow can also influence the test results.

5.2.3 Measurements

Densities or chromaticities are measured. The geometry of the optical measuring equipment is essential for the accurate and precise measurements. The light source, especially the inclusion or exclusion of the UV components are influential to the test results.

5.3 Test target

5.3.1 General

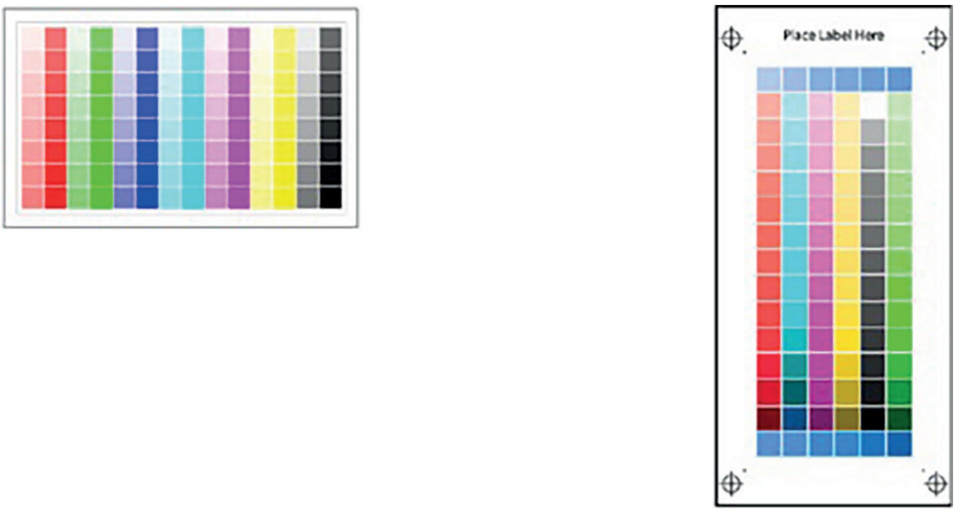
Test prints can be prepared according to the requirements given in the appropriate test method standards for the four environmental factors of heat, light, ozone and humidity. Test target, measurement, sample handling and preconditioning can be found in ISO 18944 for colour stability testing and ISO 18946 for humidity fastness testing.

ISO 18944 stipulates the details of sample preparation, including dry-down procedures for thermal, light and ozone stability testing, because most printing systems directed to the consumer use case start from sRGB encoded image information, a set of sRGB values has been defined that represents primary (CMYK) and secondary (RGB) colours with systematic variation of CIE L^* along the surface of the colour gamut that can be achieved by the system under test. From these sets, the neighbouring patches encompassing the starting densities of 0,5, 1,0 and 1,5 are identified. The neighbouring patches are used for interpolation as described in detail in ISO 18944.

There are two test targets available in ISO 18944: Test target designs are shown in Figure 1. One is the sRGB linear target shown in Figure 1 a) originally designed, and the other is the CIELAB constant hue target shown in Figure 1 b) uniquely designed. Users can choose either one of two depending on the objective of evaluation. Even though originally designed for densitometric analysis, the colour changes based on these sRGB test targets can also be evaluated using colorimetric analysis.

Image permanence performance of measures can be based on the degradation resulting for each of these initial optical densities. In general, the rate of image fading varies with the initial optical density.

Minimum density patches (D_{min}, usually paper white) also are included for evaluation of stain.

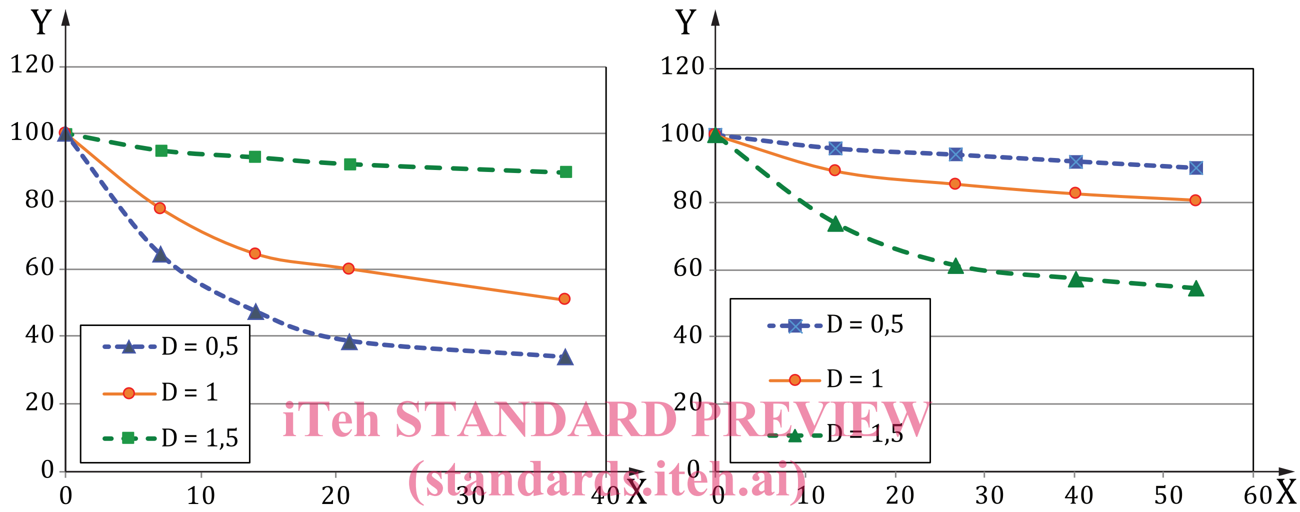


a) The sRGB linear target **b) The CIELAB constant target**

Figure 1 — Test target designs

In ISO 18944, the patch used for the evaluation of print life can be as follows. The initial density is D_{min}, 0,5 ± 0,05, 1,0 ± 0,10, and 1,5 ± 0,15 measured in Status A or T. If the maximum optical density for any colour is less than the target value, then the highest value possible for that printer system can be used. The colour includes Neutral, Y, M, C, R, G, and B.

Reasons for including the density of 0,5 and 1,5 patches are as follows. In ordinary cases, fading behaviours differ depending on the density range. In many cases the fade rate is faster at lower- density than the higher-density. Examples of fading curves of dependence on the initial density are shown by Sample A in Figure 2. Figure 2 a) shows an example of the density loss as a result of light expressing the stability of colorant itself. On the other hand, in some cases the fade rate is faster at higher-density than lower-density by Sample B. Figure 2 b) shows an example of the density loss because of light fading, observed on the R patches for initial densities of 0,5, 1,0, and 1,5 for an inkjet print. In this case, different colorants are used for the higher-density and lower-density ranges.



a) Sample A   b) Sample B

Key

X duration (Mlx·h)

Y residual R density (%)

Figure 2 — Examples of fading curves — Dependence on the initial density

Reasons for including the RGB patches are as follows. In some cases, the fading behaviours of R, G, and B patches differ from those of Y, M, C, or neutral patches. Examples of fading curves of dependence of the colour of the measured patch are shown in Figure 3. An example of the different fading behaviour of primary (cyan), secondary (green and blue), and neutral patches, observed in the density change of a thermal dye transfer process print during a light stability test is shown by Sample C in Figure 3 a). In the case the fading behaviours of R, G, and B patches about same with those of Y, M, C, or neutral patches, it can be evaluated of image permanence by using only Y, M, C, and neutral patches. An example of the same fading behaviour of primary (yellow and magenta), secondary (red), observed in the density change of an inkjet print during a light stability test is shown by Sample D in Figure 3 b).