TECHNICAL REPORT

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# Imaging materials — Pictorial colour reflection prints — Comparison of image degradation observed between ISO 18930 accelerated weathering test method and outdoor exposure

*Matériaux pour l'image — Réflexion des impressions photographiques en couleurs — Comparaison de la dégradation de l'image observée entre la méthode d'essai de vieillissement accéléré de l'ISO 18930 et l'exposition extérieure*



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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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For an explanation on 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 the following URL: 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

Printed digital images are used in many applications in which they are exposed to outdoor weathering. ISO 18930 provides standardized test procedures to evaluate image stability both in real-time outdoor weathering tests and in accelerated laboratory simulations of the weathering process. Accelerated laboratory weathering tests have been developed as a result of the desire to obtain test results faster than would be obtained by actual outdoor exposure. However, accelerated weathering tests only have value if they can be correlated with actual outdoor performance.

# Imaging materials — Pictorial colour reflection prints — Comparison of image degradation observed between ISO 18930 accelerated weathering test method and outdoor exposure

## 1 Scope

This document describes the experimental framework, results, and conclusions from a round robin test that was performed in order to establish correlations between accelerated weathering according to the ISO 18930 test method and outdoor weathering at nine outdoor sites.

The types of digital printing technology that were used in this round robin test are aqueous inkjet, solvent inkjet, UV curable inkjet, digitally-exposed silver halide, and thermal mass transfer. The image print stability data and correlations of this document are to be considered illustrative of the performance of these classes of materials. Extension of these correlations to other classes of materials, such as dye sublimation, is verified by appropriate experimentation.



## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions 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**
**digital printing media**
recording elements used by digital printers to receive inks or pre-formed colourants

EXAMPLE The substrate may be paper, plastic, canvas, fabric, metal, or other ink-receptive material; the substrate may, or may not, be coated with an ink-receptive layer. The category of digital printers includes inkjet, electrophotographic, and thermal transfer.

**3.2**
**laminate**
**overlaminate**
layer of material that goes over the top or bottom of a specimen

Note 1 to entry: Usually to provide water-resistance, physical, and/or ultraviolet (UV) light protection of the specimen during a weathering test. A layer of protective film is applied with a pressure-sensitive or heat-activated adhesive.

**3.3**
**accelerated laboratory weathering**
simulated weathering where instruments (weathering devices) are used to obtain very controlled conditions that simulate, to some degree, and generally accelerate, the outdoor weathering results

Note 1 to entry: The use of such instruments is described in ISO 4892-1[2] and ASTM G151[16].

**3.4**
**outdoor weathering**
actual placement of specimens outdoors in specific locations

Note 1 to entry: This is differentiated from simulated weathering where instruments (weathering devices) are used to obtain very controlled conditions that simulate, to some degree, and generally accelerate the outdoor weathering results. Use of such instruments is described in ISO 4892-1[2] and ASTM G151[16].

**3.5**
**reciprocity failure**
non-equivalence in weathering results between a long exposure/low-intensity experiment and its short exposure/high-intensity counterpart with an equivalent intensity-time product

**3.6**
**daylight filter**
optical filter or combination of filters that modifies the spectral power distribution of a light source to better represent some defined daylight spectrum

Note 1 to entry: These filters are not related to the blue filters used in the photographic industry for the change of correlated colour temperature of light sources.

Note 2 to entry: Adapted from ISO 18913[5].

**3.7**
**coefficient of variation**
standard deviation of a variable divided by the arithmetic mean of the variable

**3.8**
**Pearson correlation coefficient**
statistical measure of the degree of linear correlation between two variables, with value between −1,0 and +1,0 inclusive, where a value of +1,0 represents perfect positive correlation, a value of 0,0 signifies no correlation, and a value of −1,0 represents perfect negative correlation

**3.9**
**acceleration factor**
ratio of the time required to reach an endpoint in an outdoor weathering test to the time required to reach the same endpoint in a laboratory accelerated weathering test

**3.10**
**colour fade acceleration factor**
acceleration factor for which the bases of comparison are the ratios of reflected optical density during the test to the initial reflected optical density prior to the start of the test



## 4 General considerations for accelerated weathering tests

The ability to accurately predict the long-term outdoor performance of materials and printed images is essential to many industries. Since many of the relevant products are designed to last years or decades, accelerated weathering test methods have been developed to more rapidly assess outdoor performance and to investigate failure mechanisms associated with outdoor exposure. Unfortunately, this is an extremely complex task.

The three key components of accelerated weathering tests are heat, light, and water. The primary determinant of the degree of correlation for between outdoor weathering and an accelerated test method is the degree to which the spectral power distribution (SPD) of the light source in the test chamber matches the SPD of sunlight[7]. This is so critical because material photodegradation mechanisms are very specific to certain wavelengths of light[8]. The UV spectrum between 295 nm and 400 nm is responsible for most of the damage to polymers and colourants. The current state-of-the-art light source is filtered xenon arc lamps. In a comprehensive study of the accelerated weathering of polyester gel coats, Crump[9] found that xenon arc weathering gave higher correlation coefficients than methods employing carbon arc or fluorescent light sources. Previous investigations by Klemann[10][11] also indicated high correlation coefficients for xenon arc light sources.

Water exposure is also essential because many materials exhibit hydrolytic degradation pathways. Heat, in terms of elevated chamber temperatures, is used to accelerate all of the reactions that contribute to material and image degradation. Other factors such as ozone, pollutants, freeze-thaw cycles, and abrasion due to airborne particles may also affect material longevity, but are not included in most accelerated test cycles.

Two metrics are used to gauge the efficacy of accelerated weathering test methods: the acceleration factor and the Pearson correlation coefficient. An acceleration factor is a scale factor that relates the rate of degradation in an accelerated test to the rate of degradation in real-time outdoor exposure. For example, if a colour patch fades by 40 % over one year on an outdoor rack in South Florida and also fades 40 % after 1 month of an accelerated weathering test, then the acceleration factor would be 12, as one month of accelerated testing is equivalent to 12 months of outdoor testing. The correlation coefficient is the degree to which, and the consistency of, the agreement between accelerated and outdoor testing.

The user of any accelerated weathering method should be cautioned that the acceleration factors are specific to both the outdoor location and to the material, or combination of materials, that are tested. It should be obvious that acceleration factors depend upon the climate of the outdoor site. Average radiant exposure, rainfall, relative humidity, and temperatures of an outdoor location all affect the acceleration factor. Indeed, even year to year climatic variations will change the acceleration factor to some degree. What may be less obvious is that there are also some differences in acceleration factor for different materials. This is due to the different photodegradation mechanisms and their wavelength specificity, to the rates of water absorption and the saturation moisture levels, and to any changes in degradation mechanisms as a function of temperature (for example, outdoor conditions are below a polymer glass transition temperature and the temperature of an accelerated weathering test is above it). An investigation of fade of colour patches on signs and labels showed that that the average acceleration factor for a set location may vary as much as ±50 % by material construction[10].

NOTE If use of an acceleration factor is desired in spite of the warnings given in this document, such acceleration factors for a particular material are only valid if they are based on data from a sufficient number of separate exterior or indoor environmental tests and accelerated laboratory exposures so that results used to relate times to failure in each exposure can be analysed using statistical methods, see ISO 4892-1.

No standard accelerated weathering test method results in a perfect correlation with outdoor performance. ASTM G155[17], Cycle 1, and its predecessor ASTM G26, uses one or more xenon lamps with borosilicate type S inner and outer filters, which gives an excellent approximation for the SPD of sunlight, and has a periodic water spray, but is an isothermal test. SAE J2527[12] test cycle and its predecessor SAE J1960 both include segments with high temperatures and a segment with lower temperature, water spray, and no light, to simulate night. For some materials that are sensitive to expansion and contraction, or to the stresses of drying while heating, this type of day-night cycle may give more realistic results. However, the quartz inner/borosilicate outer filter combination of these SAE tests exposes samples to light in the 280 nm to 295 nm range that would be screened out by the earth's ozone layer outdoors.

To improve upon previous accelerated weathering standards, the ISO 18930 test method was developed. It was confirmed in 2011. The light source SPD (see Annex A) is specified in terms of spectral output by 10 nm or 20 nm bands of wavelengths so as to provide a best match to the SPD of sunlight in CIE 85:1989[18], Table 4. Four cycle segments are incorporated: three at high black panel and chamber temperatures with light exposure, and one at lower temperature in the dark. Water spray is included for one of the high-temperature segments and for the cool, dark cycle segment (Table 1). The International Standard requires that testing be conducted at a 45° angle of inclination, although other angles of inclination may be added, as this maximizes the solar irradiance received by the samples[13].

**Table 1 — ISO 18930 xenon arc exposure test cycle**

| Cycle Segment | Time (min) | Irradiance – Narrowband (340 nm) W/m² | Irradiance – Broadband (300 to 400 nm) W/m² | Black Panel Temperature °C | Chamber Temperature °C | Relative Humidity % | Water Spray |
|---|---|---|---|---|---|---|---|
| 1 | 40 | 0,55 ± 0,02 | 60 ± 2 | 63 ± 2 | 40 ± 2 | 50 ± 6 | None |
| 2 | 20 | 0,55 ± 0,02 | 60 ± 2 | — | 40 ± 2 | — | Front |
| 3 | 60 | 0,55 ± 0,02 | 60 ± 2 | 63 ± 2 | 40 ± 2 | 50 ± 6 | None |
| 4 | 60 | 0,00 | 0 | — | 38 ± 2 | — | Front |

This paper describes the details and results of a round-robin study with nine outdoor global locations and six laboratories running ISO 18930 in order to validate the new test method.

## 5 Materials

This investigation encompassed 32 material/ink combinations and digital printing technologies. Technologies represented included aqueous inkjet, solvent inkjet, UV inkjet, digital silver halide, thermal transfer, and for comparison, flexography. Some were overlaminated, others remained directly exposed to the elements. For all materials, two replicates of the target below were printed. The target has six patches each varying in lightness for cyan, magenta, yellow, true black, red, green, blue, and process black (CMY) see Figure 1. Two small white patches were included for measurements of material yellowing, and large black and white patches were added below for gloss measurements.

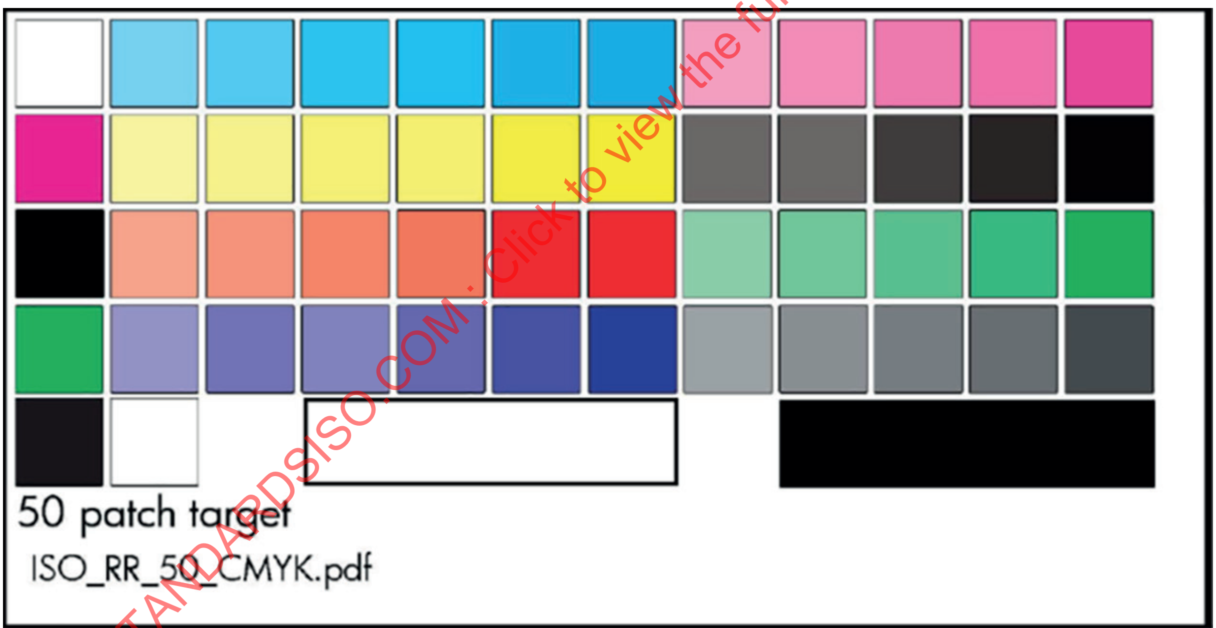



**Figure 1 — ISO 18930 Round Robin Test Target**

Two replicates each of the test targets were printed for nine outdoor sites and six accelerated test instruments running ISO 18930 (see Table 1). After printing, the samples were maintained at 23 °C and 50 % relative humidity until the start of the tests.

# 6 Test methods

## 6.1 Outdoor exposure tests

Both accredited and non-accredited outdoor sites were included in this investigation (see Table 2). Printed test targets were mounted on aluminum panels. These outdoor panels were placed on racks at a 45° angle of inclination, south facing. For a comparison of exposures at angles of inclination of 45° and 90°, see Annex E. Measurements of the colour patches were taken at 0 year, 1 years and 2 years for the outdoor sites.

**Table 2 — Outdoor test site climate data**

| Site | Latitude | Radiant Exposure | Precipitation | Average Temperature | Accredited Lab |
|---|---|---|---|---|---|
| | | MJ/m2/y | mm | °C | |
| South Florida, USA | 25,87° N | 6 588 | 1 655 | 23 | YES |
| San Diego, CA USA | 33,03° N | 6 602 | 262 | 18 | NO |
| DSET, Arizona, USA | 33,90° N | 8 004 | 255 | 22 | YES |
| Tokyo, Japan | 35,71° N | 4 959 | 1 682 | 14 | YES |
| Chicago, IL USA | 41,78° N | 5 100 | 856 | 10 | YES |
| Sanary, France | 43,13° N | 5 500 | 700 | 13 | YES |
| Milwaukee, WI USA | 43,14° N | 5 103 | 884 | 9 | NO |
| Marly, Switzerland | 46,78° N | 4 590 | 1 075 | 9 | NO |
| Mortsel, Belgium | 51,17° N | 3 708 | 825 | 10 | NO |

## 6.2 Laboratory accelerated weathering tests

All accelerated weathering instruments were set for Borosilicate Type S inner/Borosilicate Type S outer, Daylight Q, Daylight B/B, Quartz/#295, or other combinations appropriate to match the SPD requirements associated with ISO 18930. Colour measurements were taken after 0 h, 24 h, 200 h, 400 h, 800 h, 1 200 h, 1 600 h and 2 000 h of exposure to the ISO 18930 test cycle (see Table 1) for all accelerated testing chambers. For some of the chambers, the testing time was increased to as long as 5 200 h of exposure. For all colour measurements 45°/0° geometry, a 10° observer, and D65 illuminant were specified. Spectrophotometer data was converted to reflected optical densities according to the ANSI Status A Standard for densitometer filters.

## 6.3 Data analysis and work-up

The procedure for data analysis employed optical density ratios – the ratio of optical density to initial optical density. For primary colours only a single density ratio was tracked. For secondary colours two density ratios were tracked, and for the process black patches all four densities (C, M, Y, and K or $D_{VIS}$) were tracked. For the secondary and process patches, the difference in density ratios for the relevant densities were also tracked as a measure of colour shifts. For the two white patches, ΔE76 was measured to evaluate substrate yellowing.

For each outdoor site after one year of exposure the test targets were measured with the spectrophotometer. Density ratios were calculated and used on a patch by patch basis. To find the acceleration factor for a single patch in an accelerated weathering chamber, the number of hours needed to obtain the same density as that of the outdoor site were determined via linear interpolation of the accelerated colour data. The acceleration factor is then calculated as 8 766 h (one year) divided by the number of hours in ISO 18930 that gives the same density ratio. The 48 patch acceleration factors on a target could then be used for statistical comparisons by material, accelerated testing laboratory, outdoor site, print technology, etc. Only density ratios between 0,95 and 0,30 were used for analysis, as it was thought that less than a 5 % density loss did not give a large enough signal to noise ratio, and that degradation would slow down or even reach an asymptote at density ratios less than 0,30.

# 7 Results and discussion

## 7.1 Colour Fade Acceleration Factors

Acceleration factors were calculated for colour fade, colour shifts, and for background yellowing. For reasons that will be specified later, colour fade acceleration factors were found to be the most useful output of the study.

Initially, the accelerated ISO 18930 tests were scheduled to run only 2 000 h. However, it was soon determined that this test duration was insufficient, especially when correlating to the more aggressive climates of South Florida, Arizona, and San Diego. This was found to be critical in the determination of correct acceleration factors. Not all 48 patches on a test target yield useful data points, and these data points are first available when the patch on the accelerated test target reaches the same density ratio as the outdoor test patch. There are two possibilities for missing data points:

a) The outdoor test patch has a density ratio above 0,95 or below 0,30 and is excluded from analysis;

b) The outdoor test patch is in the correct density ratio range, but the accelerated test has not been run long enough to reach that density ratios.

In Case 1, the data points will never be available. For Case 2, however, more data points come in as the length of the accelerated test is extended. This causes the apparent acceleration factor to decrease over time until all of the Case 2 points come in and the apparent acceleration factor converges to the true acceleration factor. An example of this is shown in Table 3 for South Florida, one of the most aggressive climates.

**Table 3 — Change in apparent acceleration factor as more accelerated test data is collected**

| Colour Patch Fade Data for South Florida Test Site | | | |
|---|---|---|---|
| **Hours of Accelerated Testing ISO 18930** | **Percentage of Maximum Data Points Available** | **Apparent Acceleration Factor for 1 Year Outdoors** | **Hours of Accelerated Testing ISO 18930** |
| 2 000 | 9 | 7,77 | 2 000 |
| 4 200 | 51 | 4,34 | 4 200 |
| 5 200 | 56 | 4,13 | 5 200 |

After accelerated testing was extended to 5 200 h to ensure that all of the obtainable data points were collected, true acceleration factors could be determined for all nine outdoor sites. The average acceleration factors for the 32 materials are shown in Table 4. As would be expected, the most aggressive climates show smaller acceleration factors than the sites farther north; the trends intuitively seem to make sense. The differences between the highest and lowest acceleration factors also scale with results of previous studies that indicated approximately a factor of two ratio between South Florida and sites with latitude of 42 N to 55°N[10][14].

**Table 4 — Colour fade acceleration factors (AF) by site for 1 y outdoor exposure**

| | **Arizona** | **Chicago** | **Sanary, FRA** | **South Florida** | **Milwaukee** | **San Diego** | **Tokyo, JP** | **Mortsel, BEL** | **Marly, CH** |
|---|---|---|---|---|---|---|---|---|---|
| **AF Colour Fade – 1 year** | **4,84** | **7,38** | **6,13** | **4,13** | **7,47** | **5,61** | **8,28** | **8,22** | **8,49** |
| Material Stdev – 1 year | 1,91 | 3,17 | 2,19 | 2,53 | 2,96 | 2,00 | 3,38 | 4,06 | 3,85 |
| % Data Points Available | 50 | 54 | 62 | 56 | 59 | 57 | 49 | 63 | 58 |



## 7.2 Replicability of data

Consistency of the data is evaluated on a lab-lab basis in Table 5, for which the standard deviations compare the acceleration factors for data points at a given lab to the average acceleration factor for that material and outdoor location for labs 3 to 5. Note that only Labs 3, 4, and 5 were included, because the other labs had different accelerated test durations. Replicability is evaluated in Table 6, for which the standard deviations for the two replicates per lab are compared. In both Tables the standard deviations were normalized to the coefficient of variation (standard deviation/average) for comparison. The average coefficients of variation were 13,5 % and 14,6 % for lab-lab and replicate comparisons, respectively. Since the lab-lab variation is barely higher that the variation of replicates in the same instrument, in may be inferred that the standard test method is barely affected by changes of the test instrument, as long as it is capable of meeting the specifications stipulated in the test method standard. It is also seen that the variations are a bit lower for the more aggressive climates than for the higher latitudes. This will be discussed later with the correlation coefficients.

**Table 5 — Lab-lab coefficient of variation for colour fade failure hours**

| Outdoor Site | Lab 3 | Lab 4 | Lab 5 | Average |
|---|---|---|---|---|
| DSET Arizona | 0,084 | 0,108 | 0,112 | 0,106 |
| Chicago | 0,131 | 0,125 | 0,172 | 0,146 |
| Sanary, France | 0,119 | 0,121 | 0,142 | 0,130 |
| South Florida | | 0,064 | 0,087 | 0,063 |
| Milwaukee, Wis. | 0,171 | 0,219 | 0,170 | 0,191 |
| San Diego | 0,124 | 0,133 | 0,175 | 0,149 |
| Tokyo, Japan | 0,175 | 0,144 | 0,194 | 0,170 |
| Mortsel, Belgium | 0,175 | 0,156 | 0,215 | 0,184 |
| Marly, Switzerland | 0,114 | 0,157 | 0,165 | 0,153 |
| **Overall Average** | **0,137** | **0,136** | **0,159** | **0,146** |

**Table 6 — Replicate coefficient of variation for colour fade failure hours**

| Outdoor Site | Lab 1 | Lab 2 | Lab 3 | Lab 4 | Lab 5 | Lab 6 | All Labs |
|---|---|---|---|---|---|---|---|
| DSET Arizona | 0,117 | 0,174 | 0,061 | 0,123 | 0,105 | 0,136 | 0,139 |
| Chicago | 0,130 | 0,141 | 0,076 | 0,114 | 0,128 | 0,180 | 0,137 |
| Sanary, France | 0,114 | 0,106 | 0,073 | 0,102 | 0,109 | 0,152 | 0,114 |
| South Florida | 0,103 | 0,164 | 0,061 | 0,104 | 0,102 | 0,152 | 0,127 |
| Milwaukee, Wis. | 0,139 | 0,137 | 0,071 | 0,292 | 0,141 | 0,179 | 0,163 |
| San Diego | 0,156 | 0,142 | 0,066 | 0,093 | 0,135 | 0,169 | 0,136 |
| Tokyo, Japan | 0,125 | 0,127 | 0,085 | 0,102 | 0,135 | 0,168 | 0,128 |
| Mortsel, Belgium | 0,154 | 0,122 | 0,076 | 0,116 | 0,086 | 0,156 | 0,132 |
| Marly, Switzerland | 0,164 | 0,160 | 0,078 | 0,148 | 0,141 | 0,189 | 0,156 |
| **Overall Avg.** | **0,130** | **0,140** | **0,074** | **0,126** | **0,125** | **0,164** | **0,135** |

## 7.3 Applicability to multiple digital printing technologies

The scope of ISO 18930 covers all digital printing. Since standards are generally developed to have universal applicability across large classes of materials and technologies, materials and inks from five digital printing technologies plus analog flexography were included in the round robin test. Table 7 shows a comparison of the acceleration factors for the different groups and confidence intervals of ±2σ around the averages. It is observed that the confidence intervals for the print/ink technologies are larger than the differences between the averages of the technologies. So, with this small data set, it is not possible to say that any of the print technologies show statistically significant differences. Indeed, the only one for which that looks possible is digitally-exposed silver halide.

**Table 7 — Colour fade acceleration factors by printing technology**

| Print Technology | Average AF | Stdev AF | Lower Confidence Interval | Upper Confidence Interval | Materials |
|---|---|---|---|---|---|
| Aqueous Inkjet | 5,32 | 2,22 | 0,88 | 9,76 | 11 |
| UV Inkjet | 4,91 | 1,46 | 1,99 | 7,83 | 8 |
| Solvent Inkjet | 5,83 | 2,24 | 1,35 | 10,31 | 6 |
| Digital Silver Halide | 8,80 | 1,94 | 4,92 | 12,68 | 3 |
| Thermal Mass Transfer | 5,21 | 0,99 | 3,23 | 7,19 | 2 |
| Flexography | 5,96 | — | — | — | 2 |

**Table 8 — Classification of test materials by print technology**

| Print Technology | Number of Materials Tested | Materials without Protective Layers | Materials with Pressure-Sensitive Overlaminates | Materials with Liquid Clear Coats | Inkjet Materials | |
|---|---|---|---|---|---|---|
| | | | | | Piezoelectric Printheads | Thermal Printheads |
| Aqueous Inkjet | 11 | 8 | 3 | 0 | 7 | 4 |
| UV Inkjet | 8 | 7 | 0 | 1 | 8 | 0 |
| Solvent Inkjet | 6 | 3 | 3 | 3 | 6 | 0 |
| Digital Silver Halide | 3 | 0 | 3 | 0 | — | — |
| Thermal Mass Transfer | 2 | 1 | 1 | 0 | — | — |
| Flexography | 2 | 1 | 1 | 0 | — | — |



### 7.4 Effects of colour and patch darkness

The use of six patches for each colour of ascending colour density on the test target makes it simple to break down the results by colour and patch darkness. The surprise here is that the average correlation coefficient did vary to some extent with those two factors. While the rest of the colours are within 10 % of the overall average, yellow patches faded 22 % faster than the average for all colours. There is also a slight increase in acceleration factor as the patches in a series get lighter (from 6 to 1 in the target). However, no satisfactory explanation for this behaviour has been proposed. Indeed, it is not known whether these results are due to a few materials in a small data set, or whether they signify a real phenomenon. See G.5 for an example of several materials for which the Tokyo data showed very high acceleration factors, but the South Florida data was very close to the overall average acceleration factor.

**Table 9 — Average colour fade AF by colour**

| Colour | Average AF | AF as % of Overall Average |
|---|---|---|
| Cyan | 5,25 | 80,8 |
| Magenta | 6,19 | 95,4 |
| Yellow | 7,97 | 122,7 |
| Black (K) | 5,96 | 91,7 |
| Red | 6,95 | 107,0 |
| Green | 6,67 | 102,8 |
| Blue | 6,11 | 94,2 |
| Process Black (CMY) | 6,57 | 101,2 |
| Overall Average | 6,49 | 100,0 |

**Table 10 — Average colour fade AF by patch darkness**

| Patch | Average AF | AF as % of Overall Average |
|---|---|---|
| 1 | 6,85 | 105,5 |
| 2 | 6,75 | 103,9 |
| 3 | 6,61 | 101,8 |
| 4 | 6,55 | 100,9 |
| 5 | 6,11 | 94,1 |
| 6 | 6,03 | 92,8 |
| Overall Average | 6,49 | |



### 7.5 Analysis of colour shifts

Attempts to generate correlation coefficients for colour shifts were less successful than the efforts for colour fade. A minimum shift in colour balance of 5 % was used as a threshold for inclusion in this data set. However, ink sets are often formulated with a mind to minimize any colour shifts, so several of the ink sets tested were so well balanced that none of the patches on their targets showed a 5 % colour shift. For example, for Mortsel, Belgium, the least aggressive climate in this study, only 8,1 % of the possible data points were available. A greater concern is the life cycle of a colour shift during a weathering test. The colour balance shift is zero both initially and when the colourants have all faded to white after severe degradation. At some point in between, the colour balance shift reaches a maximum. For the accelerated data, which is taken frequently, it is easy to see which side of the maximum the data is at. For one year outdoor data, on the other hand, it is very hard to determine whether a data point is before or after the maximum colour shift. If it is before the maximum, then a correct data point will be obtained. If it is after the maximum, then a false data point will be obtained with an acceleration factor that is higher than the correct data point. This effect skews the data unless one has the ability to monitor each patch on the outdoor samples and to determine when the maximum colour shift occurs. It also explains the large standard deviations for the colour shift acceleration factors. Note that the data in Table 11 has excluded all data points with acceleration factors of 20 or greater, as it is assumed that those are all false data points on the wrong side of the colour shift maxima. For examples of the colour shifting behaviour of the materials in this study, see G.4.

**Table 11 — Colour shift acceleration factors for 1 y**

| | DSET Arizona | Chicago | Sanary France | South Florida | Milwaukee | San Diego | Tokyo Japan | Mortsel Belgium | Marly Switz. |
|---|---|---|---|---|---|---|---|---|---|
| Average Colour Shift AF | 7,62 | 8,81 | 8,53 | 6,46 | 9,05 | 7,92 | 9,54 | 11,06 | 11,61 |
| Stdev AF | 3,85 | 3,96 | 3,98 | 3,44 | 4,21 | 3,68 | 4,54 | 4,08 | 3,02 |
| % of Data Points Available | 18,1 | 14,4 | 18,2 | 27,4 | 18,0 | 17,8 | 13,6 | 8,1 | 14,8 |

There was very little data available for $D_{min}$ yellowing. Only three of the materials had white patches that reached a Δ$E$ of 10 in the accelerated test. The apparent acceleration factors for the yellowing were in the expected range, but it was not a large enough data set be considered representative of the entire set of 32 materials.

## 7.6 Two-year data analysis

Another aspect of the round robin test for which sufficient data was lacking was the correlation of two year outdoor exposure with colour fade. As is implied in Table 3, it is necessary to get 45 – 60 % of the possible data points before the colour fade acceleration factors converge to their true values. Table 12 shows both 1 y and 2 y data. Especially for the more aggressive climates, not enough data points are in to consider the 2 y colour fade acceleration factors to be valid. Because of this, the reciprocity performance of ISO 18930 cannot be determined from this test. The data for the less aggressive climates implies that any reciprocity failure between 1 y and 2 y of outdoor exposure would be small. It is recommended that a future test be run with the outdoor exposure extended to 5 y to 10 y in order to evaluate performance in regard to reciprocity.

**Table 12 — Colour fade acceleration factors (AF) by site – 1 y and 2 y**

| | Arizona | Chicago | Sanary, FRA | South Florida | Milwaukee | San Diego | Tokyo, JP | Mortsel, BEL | Marly, CH |
|---|---|---|---|---|---|---|---|---|---|
| AF Colour Fade – 1 y | 4,84 | 7,38 | 6,13 | 4,13 | 7,47 | 5,61 | 8,28 | 8,22 | 8,49 |
| Material Stdev – 1 y | 1,91 | 3,17 | 2,19 | 2,53 | 2,96 | 2,00 | 3,38 | 4,06 | 3,85 |
| % Data Points Available – 1 y | 50 | 54 | 62 | 56 | 59 | 57 | 49 | 63 | 58 |
| AF Colour Fade – 2 y | 7,18 | 8,42 | 7,43 | 6,10 | 8,77 | 6,59 | 9,12 | 10,35 | 9,84 |
| Material Stdev – 2 y | 2,10 | 2,95 | 2,57 | 2,24 | 3,16 | 1,91 | 2,76 | 4,07 | 3,48 |
| % Data Points Available – 2 y | 38 | 50 | 48 | 28 | 52 | 27 | 49 | 48 | 56 |

## 7.7 Correlation coefficients and predictive correlations

The Pearson correlation coefficients for colour fade acceleration factors are shown in Table 13. The data sets compared are

a) hours of outdoor exposure, and

b) hours of accelerated test to reach the same fade ratio.

Each colour patch of each sample panel used for ISO 18930 accelerated testing is represented by a data point. The overall average correlation coefficient of 0,677 compares well with xenon arc weathering results from Crump[9], Klemann[10], and Bauer[14][15]. It is also observed that the correlation coefficients are highest for the sites at the lowest latitudes. Again, these sites also showed lower coefficients of variation for their acceleration factors.

**Table 13 — R-squared Pearson correlation coefficients**

| Outdoor site | $R^2$ correlation coefficient |
|---|---|
| DSET Arizona | 0,736 |
| Chicago | 0,636 |
| Sanary, France | 0,708 |
| South Florida | 0,772 |
| Milwaukee, Wis. | 0,637 |
| San Diego | 0,723 |
| Tokyo, Japan | 0,606 |
| Mortsel, Belgium | 0,631 |
| Marly, Switzerland | 0,635 |
| Overall Avg. | 0,677 |

In order to predict acceleration factors for local climates, the relationships between annual climatic parameters and accelerations factors was explored. Ideally, one would like to select annual climatic parameters that represent the effects of the three key factors that drive degradation: light, water, and heat. If these parameters correlate strongly enough with the 18930 accelerated test, it would then be possible simply to look at the relevant climatic data for a site to predict an acceleration factor before running any tests on printed materials. In order to select the appropriate parameters, a series of variables for the nine outdoor sites were plotted against both acceleration factor and its reciprocal, the number of hours in ISO 18930 per year outdoors (see Table 14). Average annual temperature has the highest correlation coefficient, so it is selected as representative of thermal effects. Annual solar radiant exposure also correlates well with acceleration factor, so it may be selected as the proxy for light exposure. The surprise here is how poorly the variables representative of moisture correlate; annual precipitation has almost no relationship at all with the acceleration factor. The best climatic parameter related to moisture is average annual dew point, which still has $R^2$ below 0,5.

When the selected parameters are plotted versus the acceleration factor to establish appropriate exponents, and then combined together into an equation, the results are excellent. The predictive equation for hours in ISO 18930 testing per year outdoors shows an $R^2$ value of 0,89. This exercise also uncovers a reason why the correlation coefficients are larger for the low-latitude, aggressive climates. The aggressive climates are characterized primarily by radiant exposure and temperature. They can be very humid, like South Florida, or very dry, like Arizona. ISO 18930, and most other accelerated weathering test cycles, increases the dosage of light and heat more than that of water. So, low-latitude test sites are more similar to ISO 18930 test conditions and correlate more strongly with it than high-latitude sites.

**Table 14 — Variable Selection for Predictive Correlations**

| Dependent variable | Independent variable or equation | $R^2$ correlation coefficient |
|---|---|---|
| h in ISO 18930/y Outdoors | Annual solar radiant exposure (GHI) | 0,70 |
| Acceleration Factor | Annual solar radiant exposure (GHI) | 0,76 |
| h in ISO 18930/y Outdoors | Average annual temperature | 0,85 |
| Acceleration Factor | Average annual temperature | 0,80 |
| h in ISO 18930/y Outdoors | Annual precipitation | 0,01 |
| Acceleration Factor | Annual precipitation | 0,05 |
| h in ISO 18930/y Outdoors | Average relative humidity (RH) | 0,17 |
| Acceleration Factor | Average relative humidity (RH) | 0,25 |
| h in ISO 18930/y Outdoors | Average annual dew point (TDP) | 0,40 |
| Acceleration Factor | Average annual dew point (TDP) | 0,32 |
| h in ISO 18930/y Outdoors | Latitude | 0,67 |
| Acceleration Factor | Latitude | 0,62 |
| h in ISO 18930/y Outdoors | $(GHI)^{0,973}(AT)^{0,618}(TDP)^{0,210}$ | 0,89 |

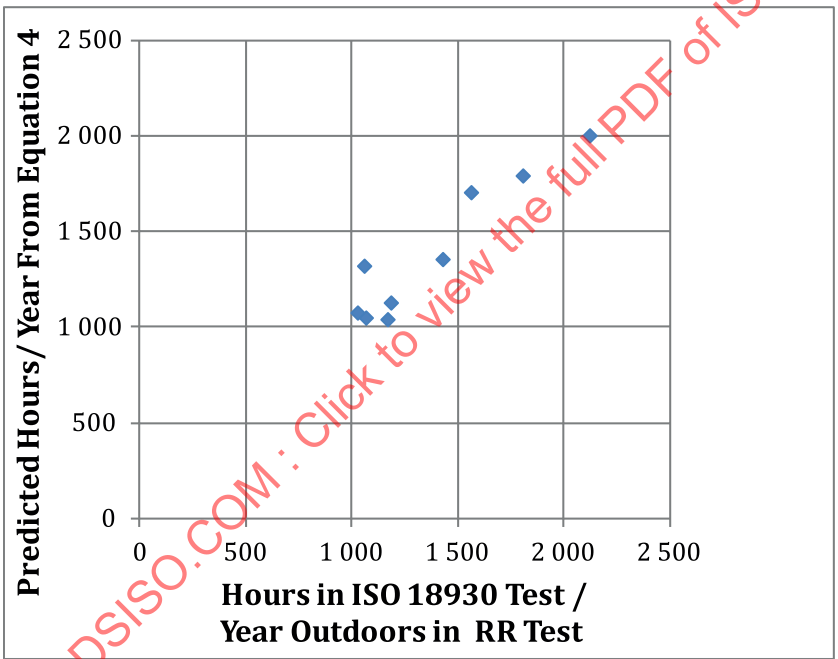



**Figure 2 — Results with predictive equation based upon climatic data**



## 7.8 Example — Degradation of Material H4

Material H4 has been selected as an illustrative example of the degradation during the ISO 18930 accelerated weathering test. The material has been chosen here since its degradation rate is fast enough to illustrate general trends, but slow enough that sample fade was still taking place at the end of the 5 200 h test. Each laboratory tested two replicates which are numbered sequentially (samples 31 and 32 are from the same laboratory, samples 33 and 34 were provided by a different laboratory…). The fade curves show geometric similarity and very similar density ratios until some divergence is observed near the end of the test when degradation has become severe. The pattern of geometric similarity for fade curves from different test instruments was not specific to material H4, but was a general feature of the data for all of the materials in the round robin test. To convey the levels of degradation characteristic of material H4, photographs of the outdoor wreathing panels have been included in Annex B. Annex D illustrates the many types of degradation that were observed for the range of print materials tested

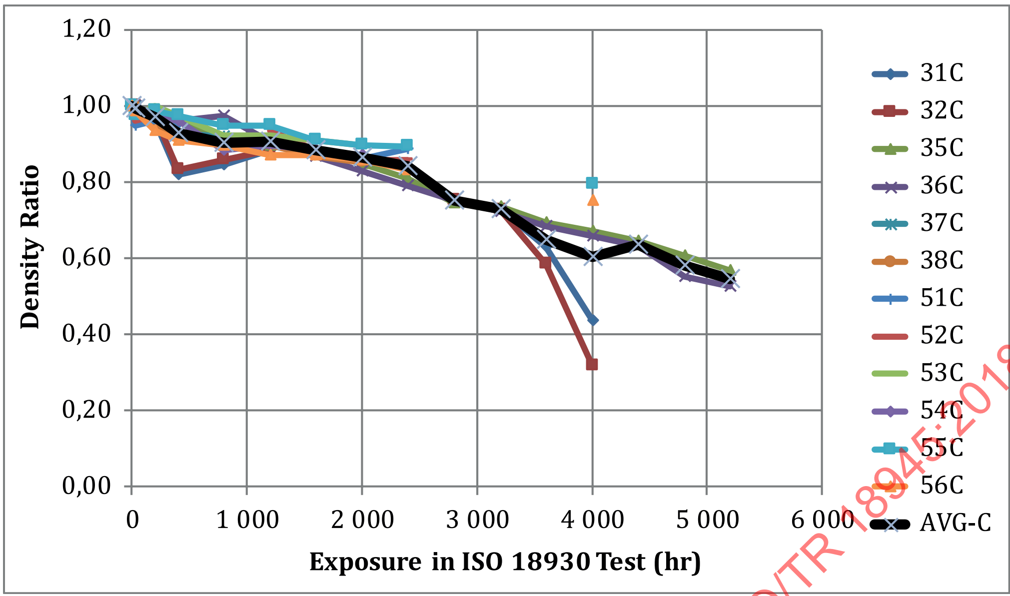



**Figure 3 — Degradation in ISO 18930 for darkest cyan patch for material H4**

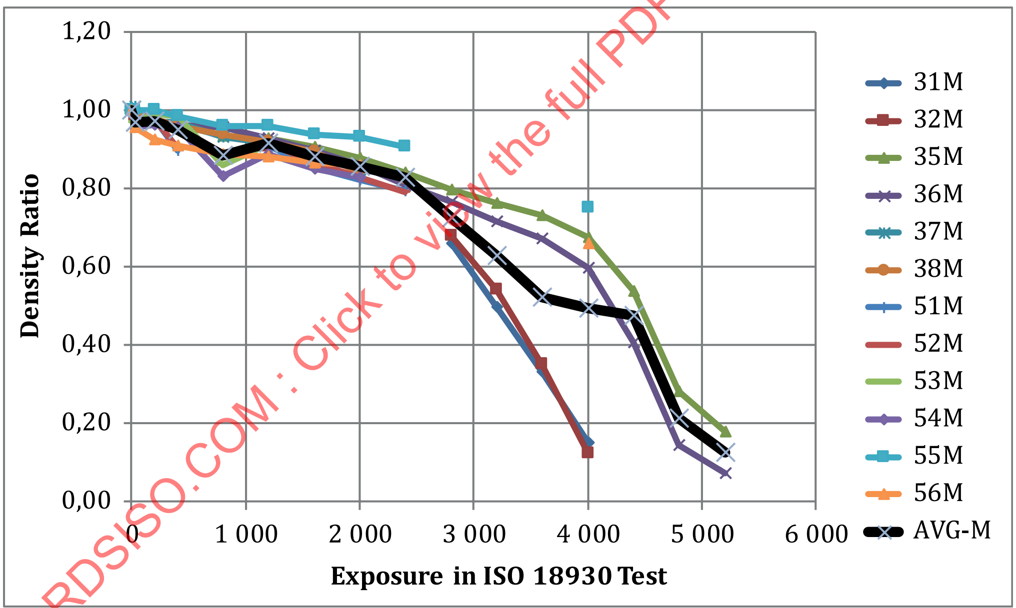



**Figure 4 — Degradation in ISO 18930 of darkest magenta patch for material H4**

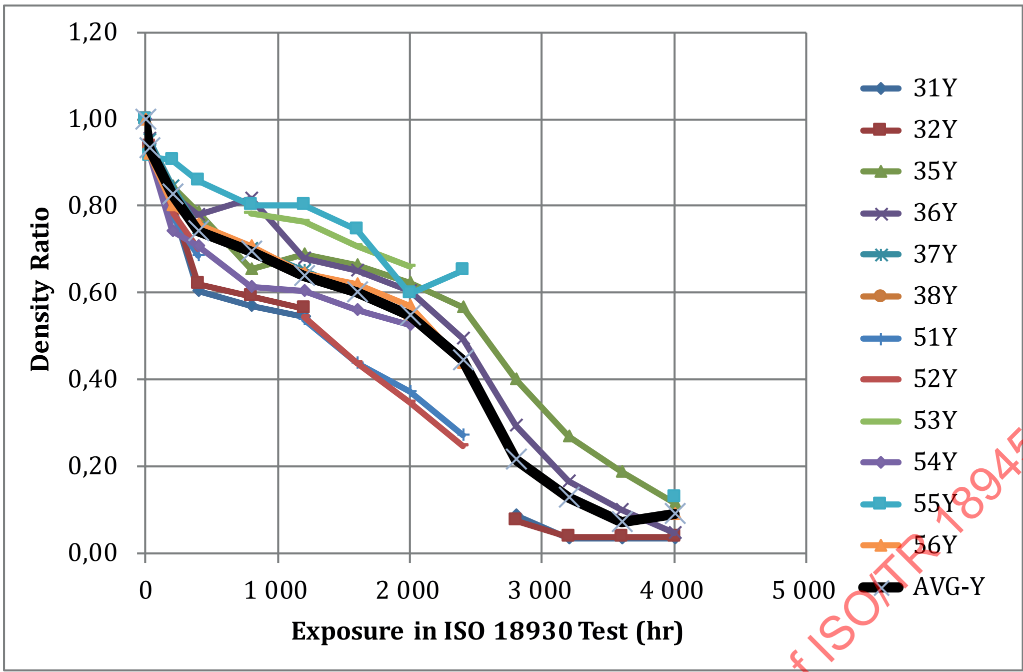



**Figure 5 — Degradation in ISO 18930 of darkest yellow patch for material H4**



## 7.9 Comparison of material degradation during outdoor and ISO 18930 accelerated laboratory weathering tests (see Annex G)

### 7.9.1 General

In 7.9, some of the results and discussion described in the previous clauses are illustrated using colour fade and colour shift graphs that compare degradation of colour patches during accelerated and outdoor weathering tests.

### 7.9.2 Colour fade graphs

The residual density ratios of the CMYK patches with density of 1,0 for each material are shown in G.1. The vertical axes are the ratio of the residual density to the initial density, and the horizontal axes are the exposure time for accelerated or outdoor tests.

The graphs on the left side of the page are the test results for the ISO 18930 xenon arc accelerated weathering tests at each laboratory, and the graphs on the right side of the page are the test results for each of the outdoor sites.

From these graphs, several points may be noted:

a) The consistency between the laboratories is generally good, although some inconsistencies are observed in certain materials. Specifically, more rapid fading is observed in the results from Laboratory A compared to those from Laboratories B through F. The levels of those differences vary from material to material.

b) As expected, the results are quite different from the nine outdoor test sites, as their climatic conditions are not the same. Again, there are also variations from material to material at these sites.

c) The average fading rates of all of the materials are compared by outdoor site in G.2. This treatment is too rough to discuss scientifically, because such a broad range of digital imaging materials were tested. However, the figures in G.2 will help one to understand roughly the overall nature of each outdoor site.

### 7.9.3 Comparison of ISO 18930 accelerated tests to nine outdoor exposure sites

The ratios of the fading rates from the outdoor exposures to those from the laboratory accelerated tests are plotted in G.3. It may be more appropriate to calculate the total exposures to an endpoint, however, only the fading rates at a fixed point (one year outdoors, and the equivalent number of hours of the accelerated test compared to each outdoor site) are adopted here. Annexes C and F show additional data from Tokyo and comparisons of Tokyo with Okinawa and Arizona.

From all of these annexes, the primary conclusion that can be drawn is that the relationships between outdoor exposure and laboratory accelerated tests vary from material to material. The relations can also differ from colour to colour for the same material. Therefore, simple and accurate prediction of outdoor performance from the accelerated weathering test may not be possible. An accurate prediction should be based upon the knowledge of the relation of outdoor weathering performance to the accelerated tests for each individual material.

### 7.9.4 Colour shift graphs

As discussed in 7.5, when materials exhibit significant colour shifts, the typical pattern is for the colour balance shifts to reach a maximum and then to decay to zero as the colour target eventually fades to white. Depending upon the magnitude of the colour shifts and the time in the accelerated test required to reach the maximum colour shift, material behaviour for the graphs of G.4 can be categorized into three groups:

— Group A: The colour balance shifts monotonically and increases with testing time. It is understood that the colour balance would eventually reach a maximum and then decrease if the accelerated test were extended. Materials A1 and A2 are examples of this type of response.

— Group B: The colour balance shift reaches a maximum and then decreases, for the reasons stated above. Materials A4, B1, C2, F2, H5, and J1 are good examples of this behaviour.

— Group C: Some of the ink-substrate combinations have a colour set that is well-balanced, and the primary colour fade at essentially the same rate. In this case, the colour shifts are very small, and any signal tends to get buried in the noise. Materials C5, H1, and H2 all showed very small colour shifts.

## 8 Conclusions and recommendations

It is concluded that ISO 18930 is a valid and versatile accelerated weathering test method that is applicable to a large range of materials and digital printing technologies. Due to the dark cycle segment with water spray followed by a light cycle segment at elevated temperature, it is believed that this cycle will perform better than ASTM G155, Cycle 1 for materials that are brittle, porous, or hygroscopic. The similarity of the variance in acceleration factors for both replicates in the same lab and lab-to-lab comparisons indicates that any laboratories that run the appropriate test conditions should obtain similar results. The correlation coefficients for colour fade acceleration factors compare well with other, previously published, studies of xenon-arc-based accelerated weathering tests.

It is recommended that the user of the ISO 18930 test method use the one year colour fade acceleration factors published here as starting points for the prediction of printed image longevity in the nine locations that were part of this round robin test. The colour shift acceleration factors from this round robin test are not considered to be reliable, but the authors believe that this type of acceleration factor could easily be derived from a similar test in which more frequent outdoor sample colour measurements were taken so as to accurately determine the exposure at which the maximum colour shift occurred.

For future work, it is recommended that more printing technologies, and more representative materials and inks for each technology be tested. In addition to colour fade and colour shifts, an extensive investigation of the changes in gloss is suggested, especially for products without pressure-sensitive overlaminates; this would be particularly beneficial for comparisons with published investigations of weathering in coatings, paints, and plastics that have employed gloss changes as the metric. A longer-term correlation study, on order of 5 y to 10 y, is advised to determine whether or not any reciprocity failures occur with this test, and to estimate their magnitude.

# Annex A
(informative)

# Spectral power distribution for accelerated laboratory weathering tests

**Table A.1 — Target irradiance and operating limits for accelerated testing with irradiance control at 340 nm**

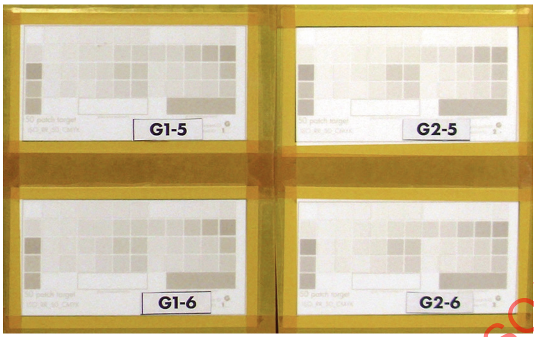
| Wavelength band<br>nm | Target irradiance normalized to 0,55 W/m²/340 nm<br>W/m² | Irradiance lower bound<br>W/m² | Irradiance upper bound<br>W/m² |
|---|---|---|---|
| 280 to 290 | 0,00 | 0,00 | 0,05 |
| 290 to 300 | 0,00 | 0,00 | 0,30 |
| 300 to 310 | 0,72 | 0,51 | 0,94 |
| 310 to 320 | 2,55 | 1,78 | 3,31 |
| 280 to 320 | 3,28 | 2,30 | 4,27 |
| 320 to 360 | 23,04 | 16,13 | 29,95 |
| 360 to 400 | 34,05 | 23,84 | 44,27 |
| 400 to 450 | 63,06 | 44,14 | 81,98 |
| 450 to 500 | 74,19 | 51,93 | 96,44 |
| 500 to 550 | 77,83 | 54,48 | 101,18 |
| 550 to 600 | 64,76 | 45,33 | 84,19 |
| 600 to 650 | 62,51 | 43,76 | 81,26 |
| NOTE Target irradiance taken from CIE 85:1989[18], Table 4. | | | |

**Table A.2 — Target irradiance and operating limits for accelerated testing with irradiance control at 300 - 400 nm**

| Wavelength band<br>nm | Target irradiance normalized to 0,55 W/m²/340 nm<br>W/m² | Irradiance lower bound<br>W/m² | Irradiance upper bound<br>W/m² |
|---|---|---|---|
| 300 to 400 | 60,00 | 58,00 | 62,00 |

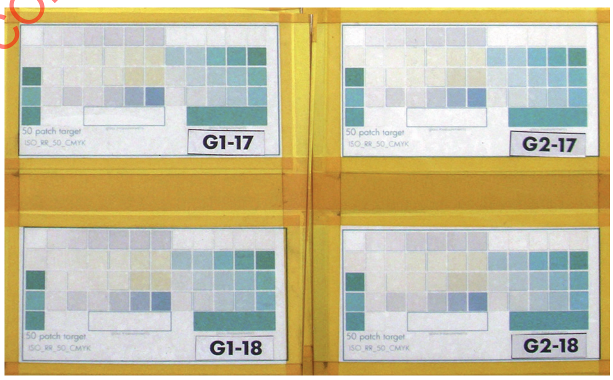
# Annex B
(informative)

## Photographs of weathered test target degradation



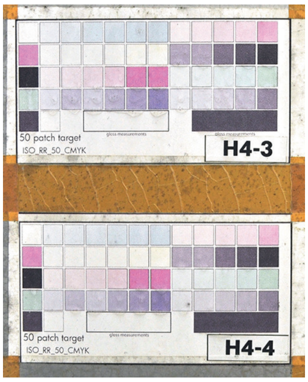

a) DSET Arizona


b) Sanary, France




c) Tokyo, Japan

**Figure B.1 — Photographs for one-year outdoor exposures of fast-fading materials in three climates.**




South Florida 2 y


Tokyo 1 y Tokyo 2 y


DSET Arizona 1 y DSET Arizona 2 y


Milwaukee 1 y Milwaukee 2 y




Sanary, France 1 y                Sanary, France 2 y


Chicago 1 y                Chicago 2 y

**Figure B.2 — Photographs of 1 year and 2 year outdoor weathering panels for Material H4 (for comparison with accelerated weathering data in 7.8)**


a) Accelerated weathering, 2 000 h exposure b) Accelerated weathering, 4 000 h exposure


c) Outdoor weathering, 1 y Chicago d) Outdoor weathering, 2 y Chicago

**Figure B.3 — Comparison of accelerated and real-time weathering for a moderately-stable material**


**Figure B.4 — Photographs of two replicates in an accelerated weathering test; images from left to right are a time series with 800 h, 1 600 h, 2 400 h, and 3 200 h of exposure**

# Annex C
(informative)

# Comparison of accelerated weathering test methods and outdoor results

## C.1 Comparison of test conditions and spectral power distributions

**Table C.1 — Equipment and accelerated test conditions**

| Test instrument | Test method | Light filters | Irradiance | Notes |
|---|---|---|---|---|
| Xenon SX75 | ISO 18930 | Daylight filter | 60 W/m2 (300 to 400 nm) | Water spray 80 min/180 min; irradiance 120 min/180 min |
| Sunshine Carbon Arc S300 | ISO 4892-2 | A | | BPT = 63 °C; 50 % RH; Water spray 18 min/120 min |
| Super Xenon SX75 | ISO 4892-4 | Daylight filter | 180 W/m2 (300 to 400 nm) | High intensity irradiance |
| Metaling Weather Meter MV300 | | Daylight filter | 530 W/m2 (300 to 400 nm) | BPT = 63 °C; 50 % RH; Water spray 18 min/120 min |



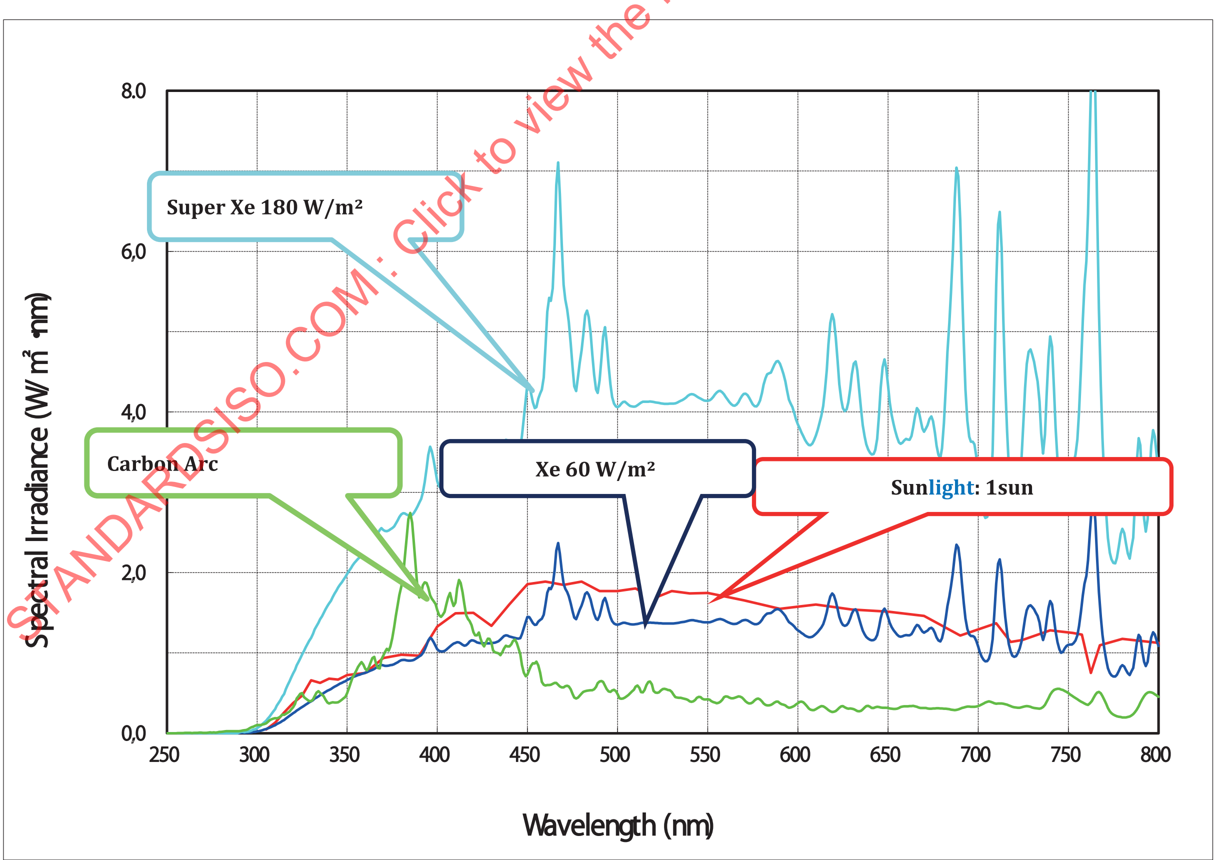



**Figure C.1 — Test equipment, test conditions, and spectral power distributions**

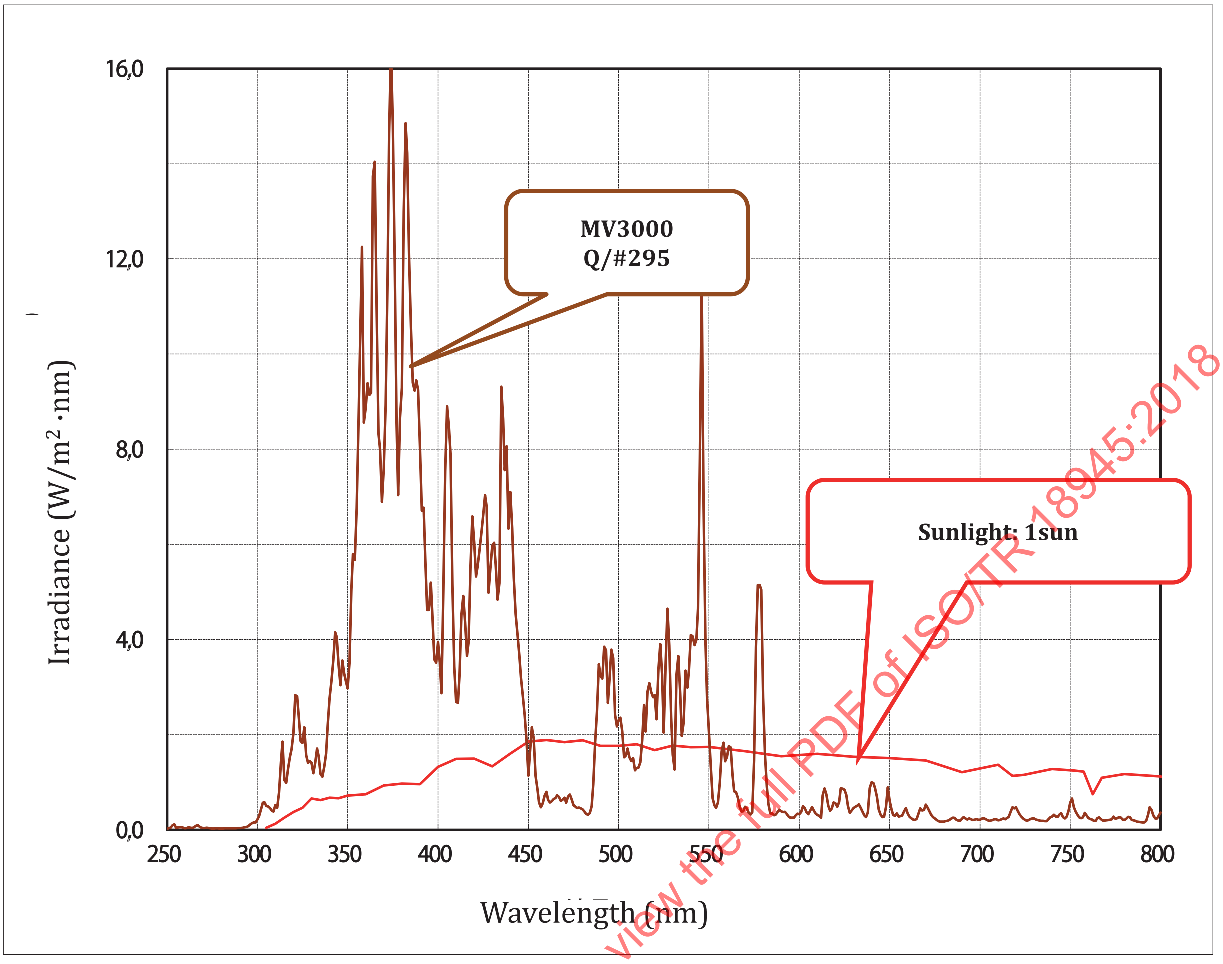



**Figure C.2 — Test equipment, test conditions, and spectral power distributions**

**Table C.2 — ISO 18930 test conditions**

| **Cycle segment** | **Time**<br>min | **Irradiance – Broadband (300 to 400 nm)**<br>W/m2 | **Black panel temperature**<br>°C | **Chamber temperature**<br>°C | **Relative humidity**<br>% | **Water spray** |
|---|---|---|---|---|---|---|
| 1 | 40 | 60 ± 2 | 63 ± 2 | 40 ± 2 | 50 ± 6 | None |
| 2 | 20 | 60 ± 2 | — | 40 ± 2 | — | Front |
| 3 | 60 | 60 ± 2 | 63 ± 2 | 40 ± 2 | 50 ± 6 | None |
| 4 | 60 | 0 | — | 38 ± 2 | — | Front |

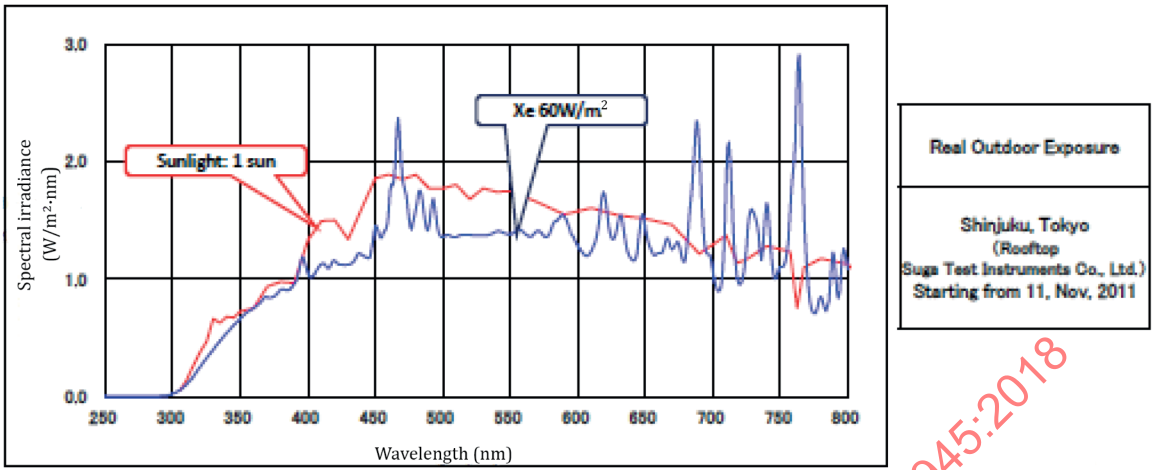



**Figure C.3 — ISO 18930 test conditions and spectral power distribution**

## C.2 Test sample and test conditions

Printing: common eco-solvent printer

Media: common self-adhesive vinyl media (PVC)

Laminates: none/common cold lamination

Patches: RR test patches

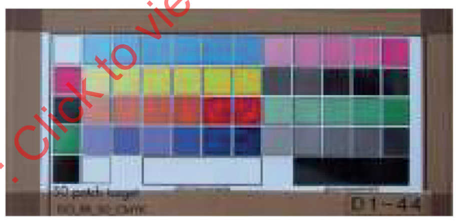


**Figure C.4 — Test sample**

## C.3 Comparison between accelerated test methods and real outdoor results

### C.3.1 Features of deterioration of unlaminated sample in the real outdoor test

— Until one year of testing is passed, colour fading is gradually seen for each of the colours.

— Rapid change has occurred from 15 months to 18 months.

— White background of the media is partially visible under the colourant.

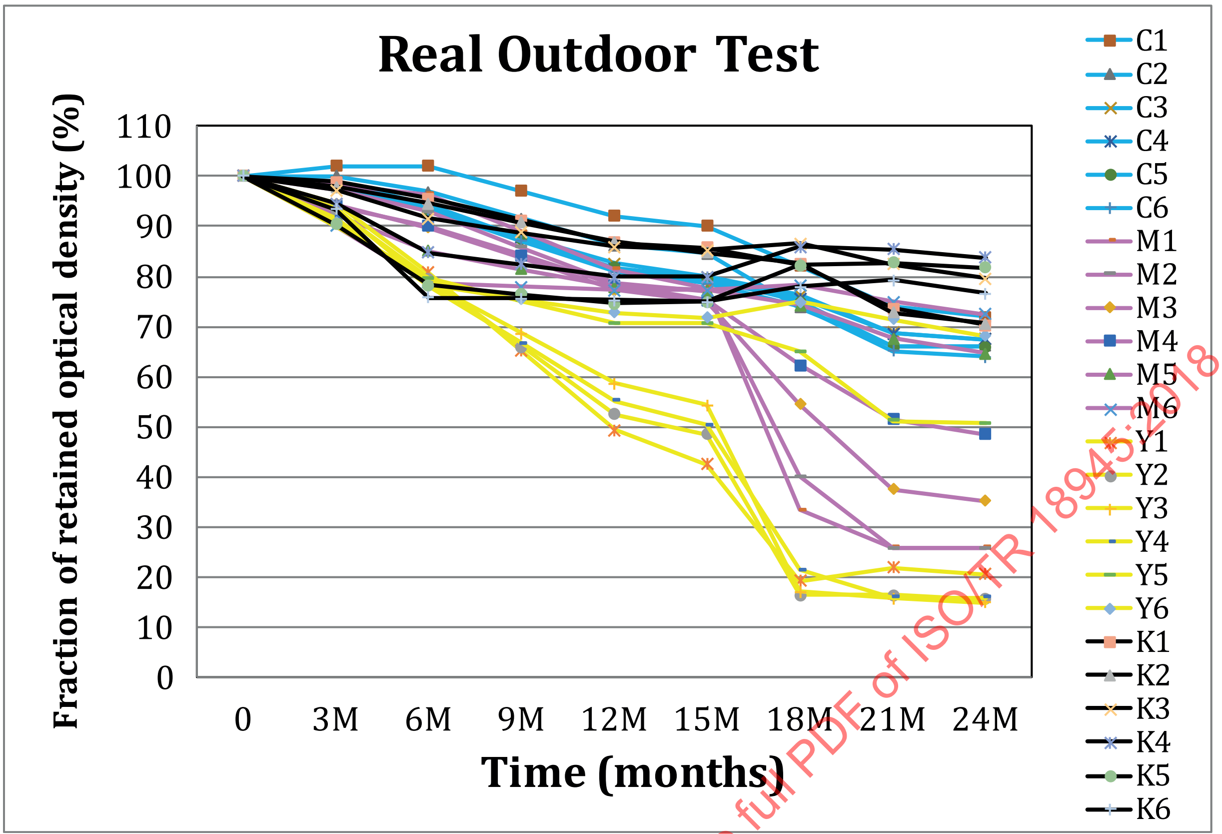



Figure C.5 — Results of real outdoor test

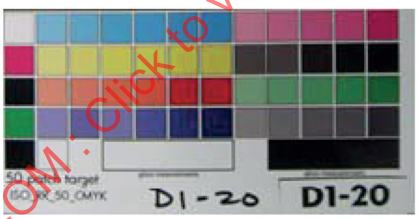



Figure C.6 — Sample at start of test

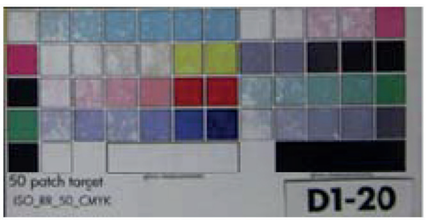
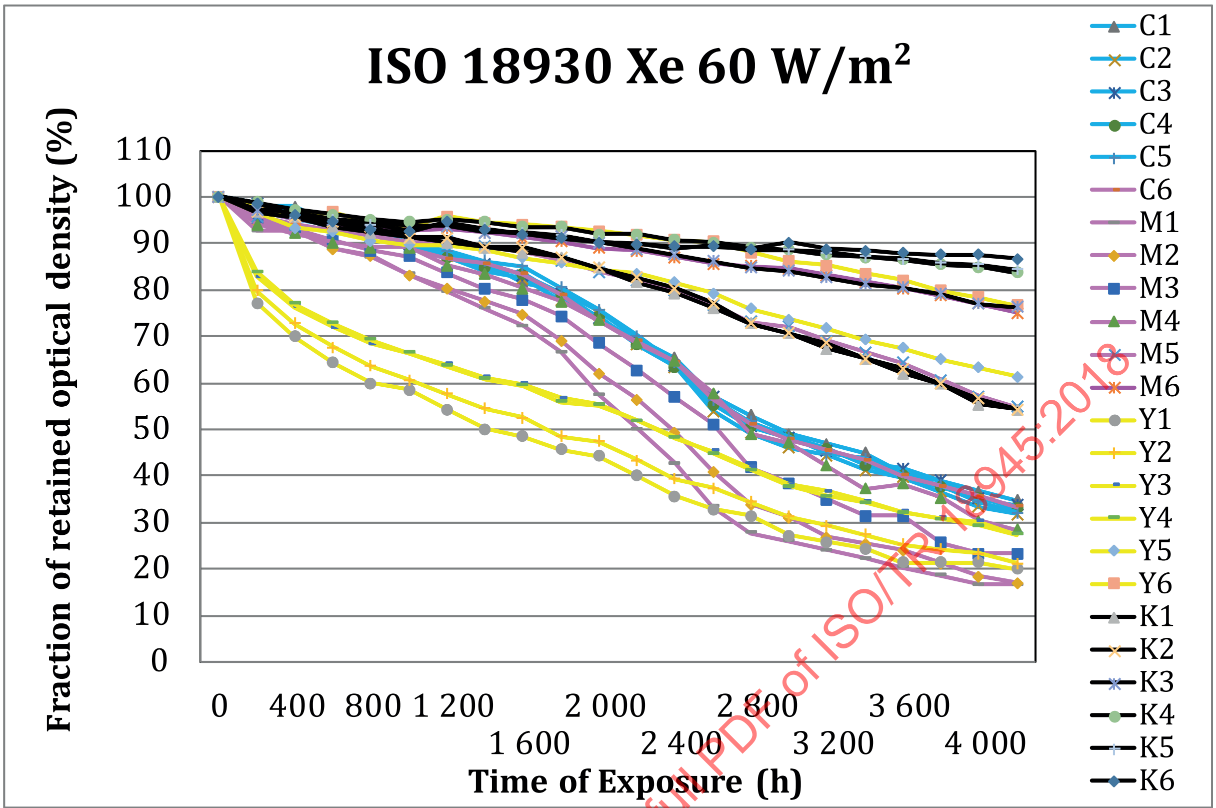


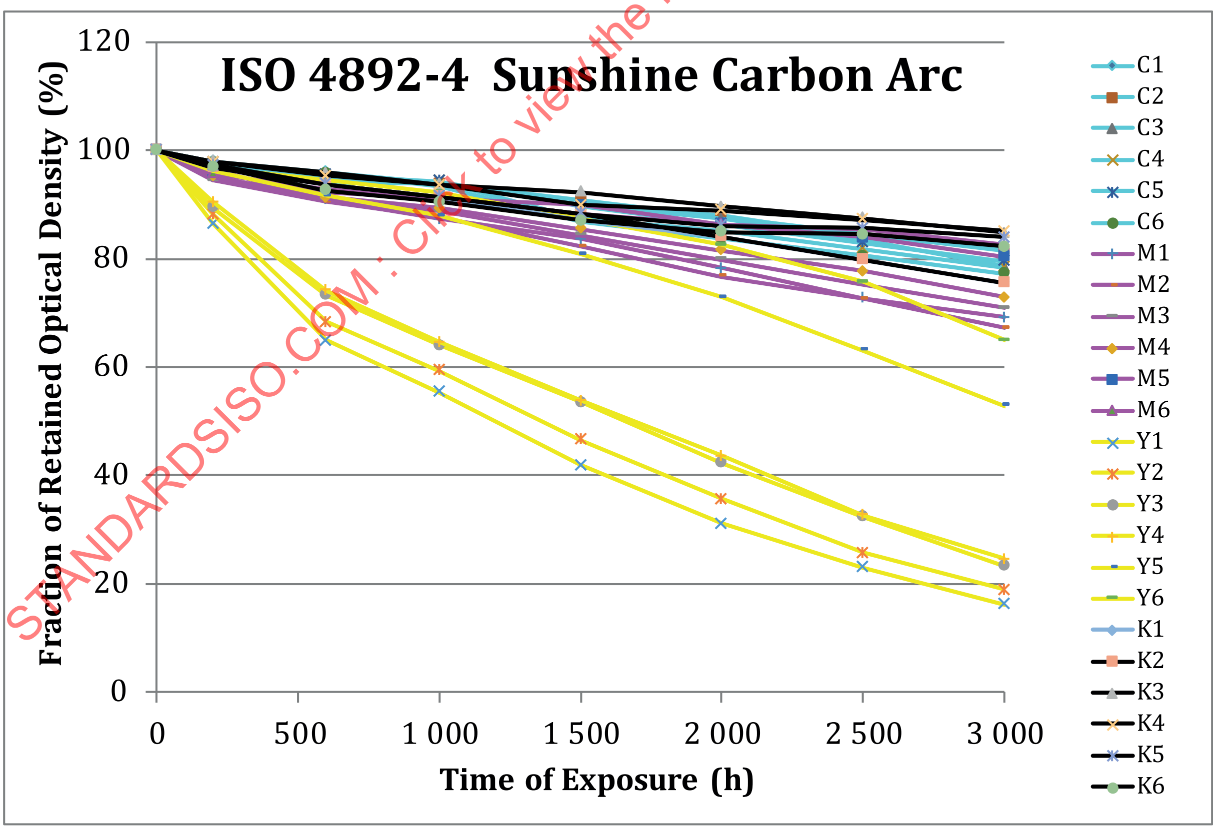

Figure C.7 — Sample after 2 years outdoors

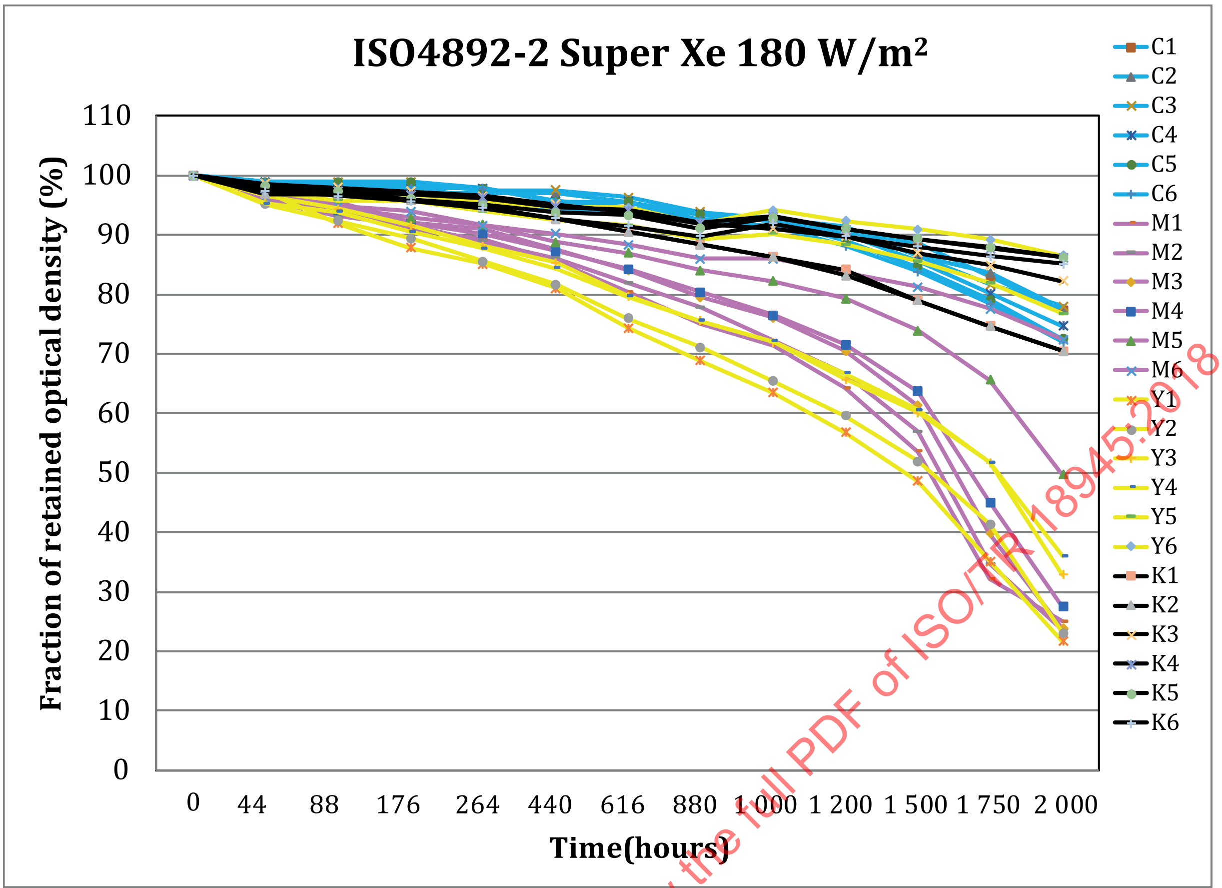
### C.3.2 Features of deterioration of unlaminated samples in accelerated test methods

— Colour fading is different for different accelerated test methods. ISO 18930 is very close to real outdoor condition results.

— By sunshine carbon arc test, only yellow fading is close to real outdoor conditions results.


ISO 18930 Xe 60 W/m²
Fraction of retained optical density (%)
110
100
90
80
70
60
50
40
30
20
10
0
0
400
800
1 200
1 600
2 000
2 400
2 800
3 200
3 600
4 000
Time of Exposure (h)
C1
C2
C3
C4
C5
C6
M1
M2
M3
M4
M5
M6
Y1
Y2
Y3
Y4
Y5
Y6
K1
K2
K3
K4
K5
K6


ISO 4892-4 Sunshine Carbon Arc
Fraction of Retained Optical Density (%)
120
100
80
60
40
20
0
0
500
1 000
1 500
2 000
2 500
3 000
Time of Exposure (h)
C1
C2
C3
C4
C5
C6
M1
M2
M3
M4
M5
M6
Y1
Y2
Y3
Y4
Y5
Y6
K1
K2
K3
K4
K5
K6



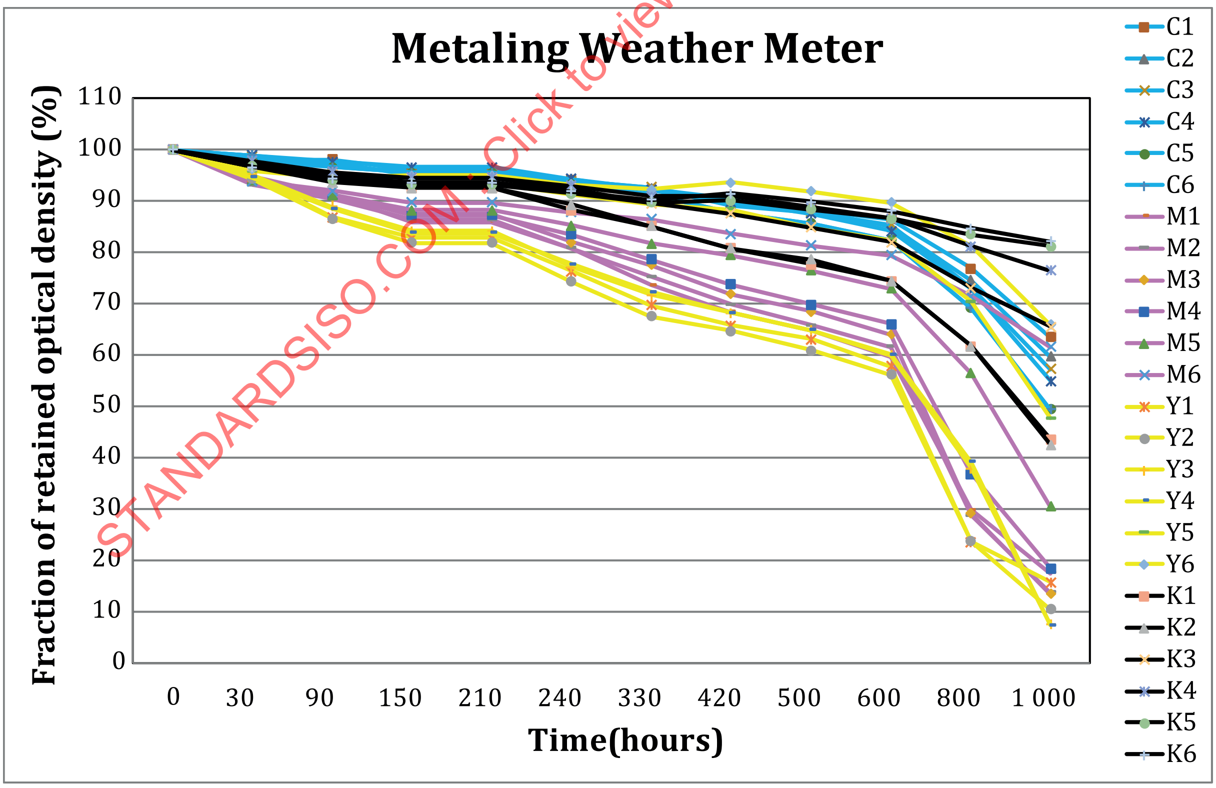






**Figure C.8 — Results of four accelerated test methods**

### C.3.3 Features of deterioration of laminated samples in accelerated test methods

— ISO 18930 is very close to real outdoor condition results.

— Yellowing of lamination occurred under sunshine carbon arc test.

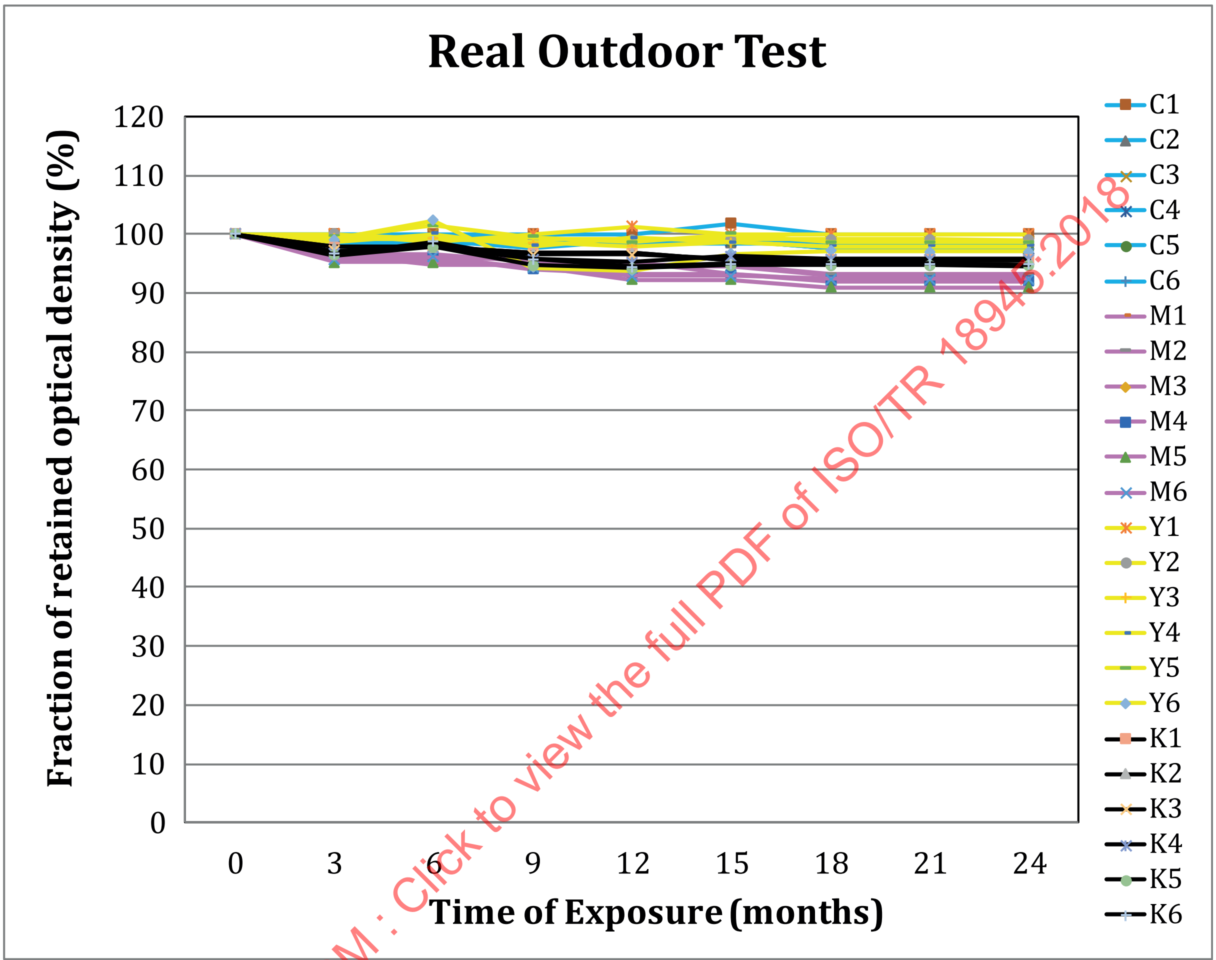



**Figure C.9 — Results of real outdoor test for laminated samples**

### C.3.4 Conclusions

ISO 18930 is a suitable accelerated test method for outdoor conditions. In other words, colour fading is similar to the real outdoor test. By the other test methods, colour fading does not match the real outdoor test and the yellowing of lamination caused.

To be able to get closer to the results for real outdoor conditions, the accelerated test should have:

— appropriate spectral power distribution of light source and filters;

— dark and light phases;

— water spray and dry phases, long water spray time.

# Annex D
(informative)

# The various types of deterioration observed in ISO 18930

Photographs of the examples of various types of deterioration:

— With outdoor testing, colour fading is not the only type of deterioration.

— Examples of other types of deterioration: colourants are stripped off, inks and colourants cracking, media cracking, media or laminates yellowing.

— A report of results could focus on colour fading phenomena only.

— If the colour fade level is small, print life should be judged based on further confirming all types of deterioration that are present.


**Figure D.1 — Degradation of samples at the end of the ISO 18930 accelerated test**


**Figure D.2 — Degradation of samples at the end of the ISO 18930 accelerated test**


**Figure D.3 — Degradation of a sample with ink cracking at an intermediate stage of the ISO 18930 accelerated weathering test**

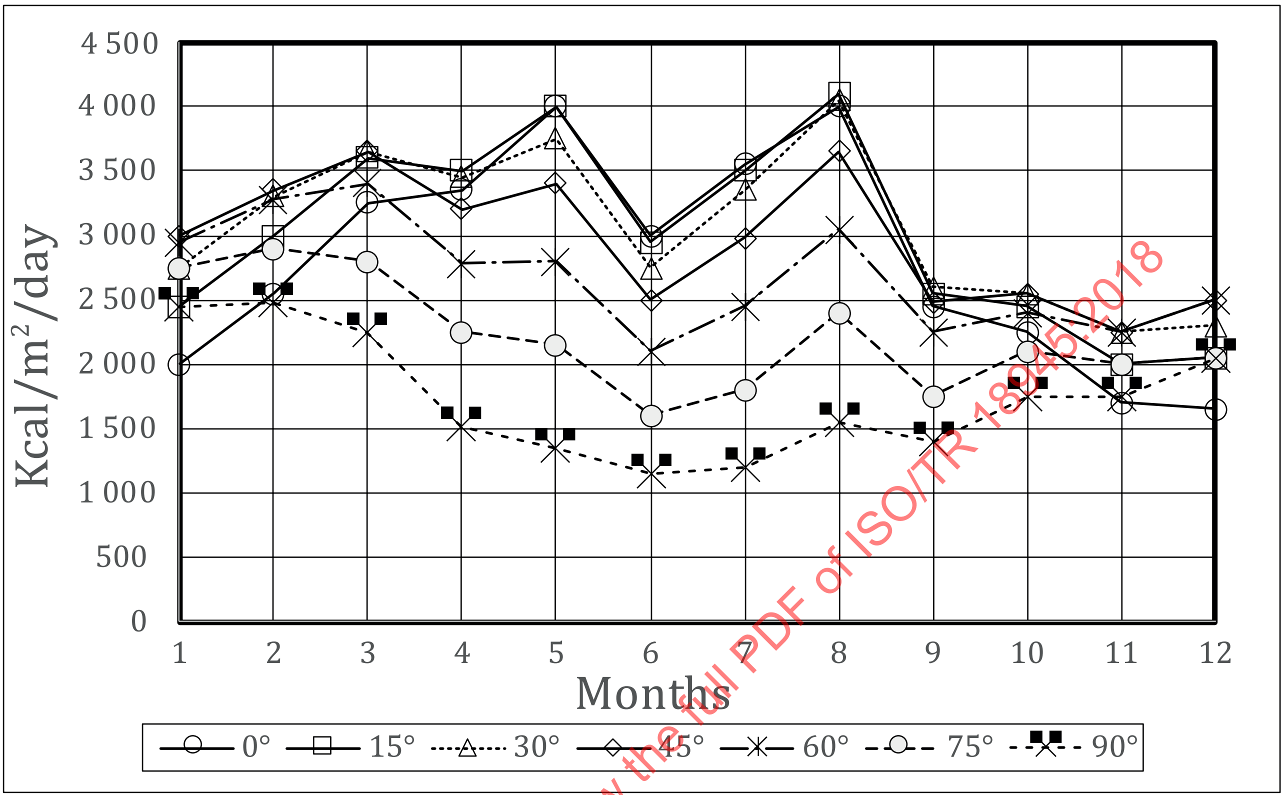
# Annex E
(informative)

# Effects of the angle of inclination in outdoor testing



### E.1 The ratio of the amount of solar radiation at several angles to the amount of solar radiation at 0 degrees tilt angle (horizontal orientation)



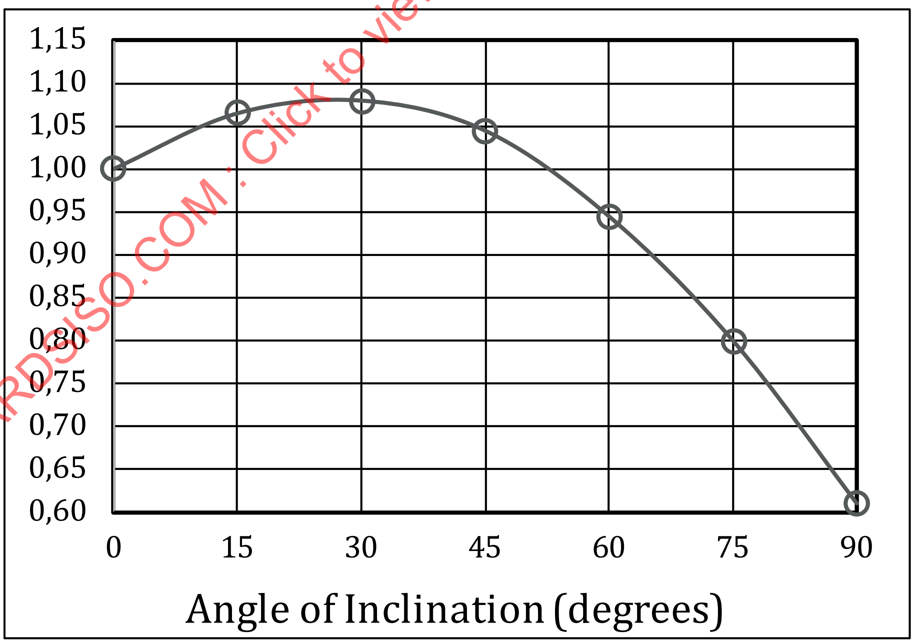






**Figure E.1 — Ratio of solar radiation 45°/90 = 1,04/0,61 = 1,7 in real outdoor test at Tokyo, Japan**

### E.2 Materials and methods

Test site: Shinjuku, Tokyo, Japan (Rooftop of Suga Test Instruments Co., Ltd.)

Test dates: July, 2012 to October, 2013

Angles of Inclination Tested: 45° and 90°

Test samples: Inkjet prints on PVC media with Eco-solvent, latex, and UV curable inks; 10 total types of samples


**Figure E.2 — Angle of Inclination = 45°**


**Figure E.3 — Angle of Inclination = 90°**

## E.3 Results

### E.3.1 Colour fade for the average of all patches

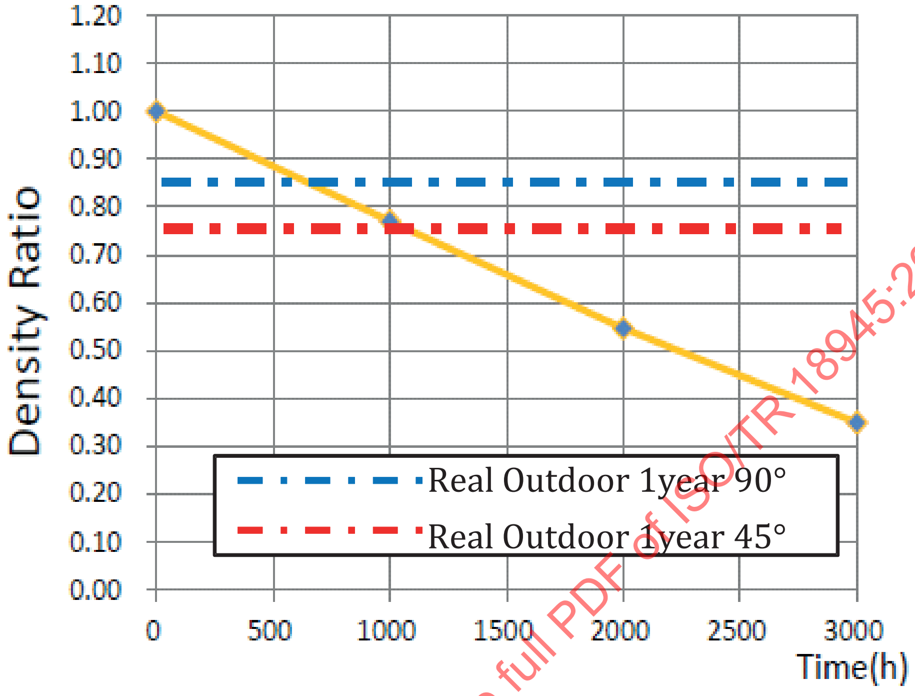



**Figure E.4 — Average fade of yellow patches**

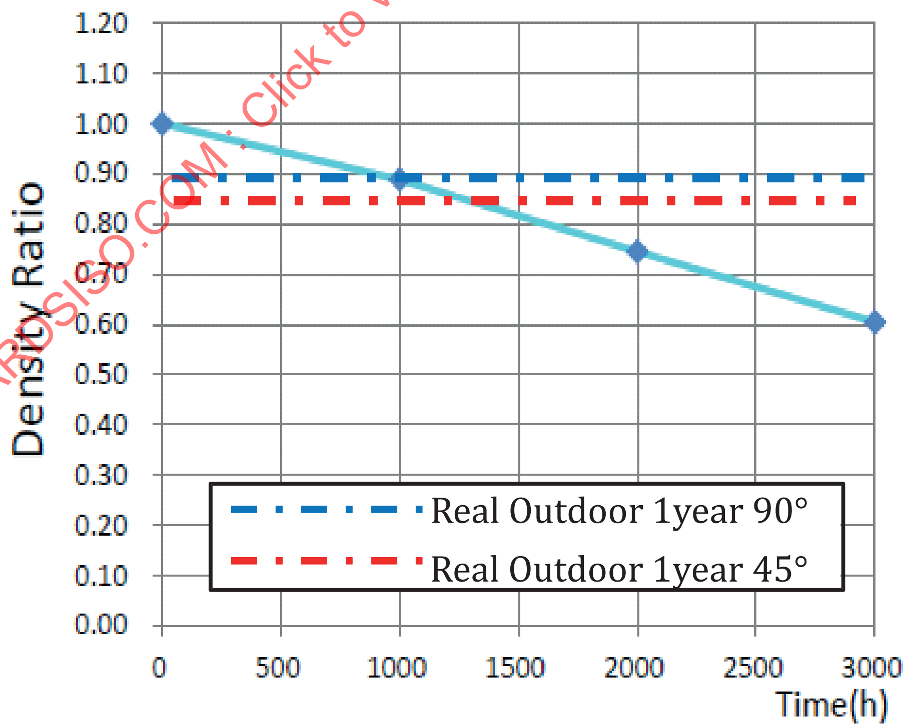



**Figure E.5 — Average fade of cyan patches**

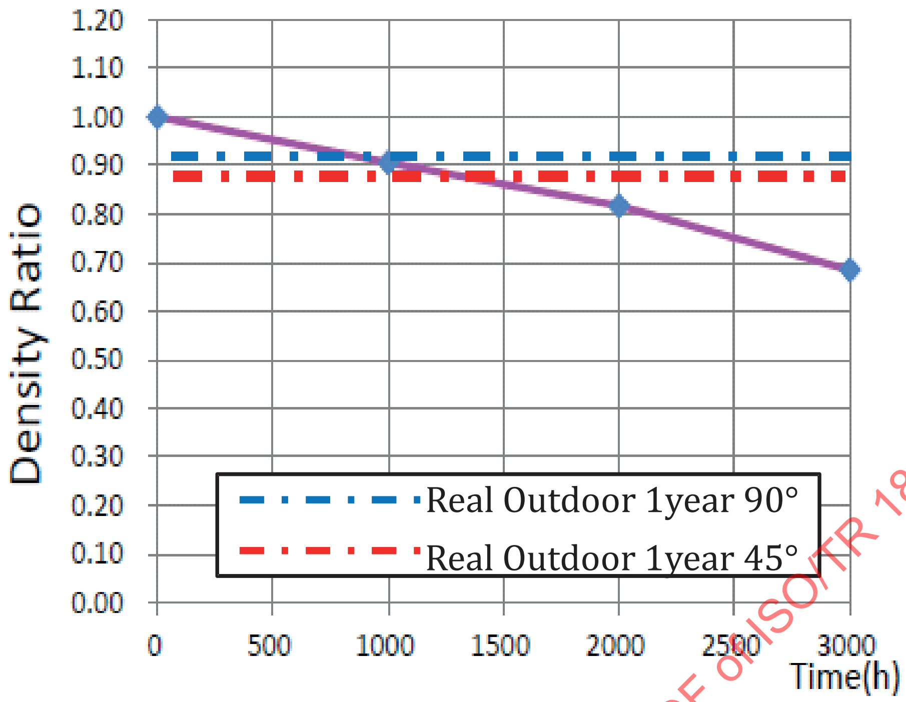



**Figure E.6 — Average fade of magenta patches**

**Table E.1 — Average acceleration factor (AF) by colour at 45° and 90° angles of inclination**

| Angle and Colour | Accelerated Test Time (h) | AF | AF 45°/AF 90° (Stdev) |
|---|---|---|---|
| Yellow 45° | 596 | 14,71 | 1,7 (Stdev 0,52) |
| Yellow 90° | 1 039 | 8,44 | |
| | | | |
| Cyan 45° | 1 045 | 8,39 | 1,1 (Stdev 0,32) |
| Cyan 90° | 1 118 | 7,84 | |
| | | | |
| Magenta 45° | 933 | 9,40 | 1,0 (Stdev 0,31) |
| Magenta 90° | 1 149 | 9,70 | |

NOTE The colour fade of yellow scales with the ratio of solar radiation between the inclination angles of 45° and 90°. In other words, the colour fade of yellow at 90° is 1,7 times slower than at 45°.

### E.3.2 Colour fade of the darkest patches

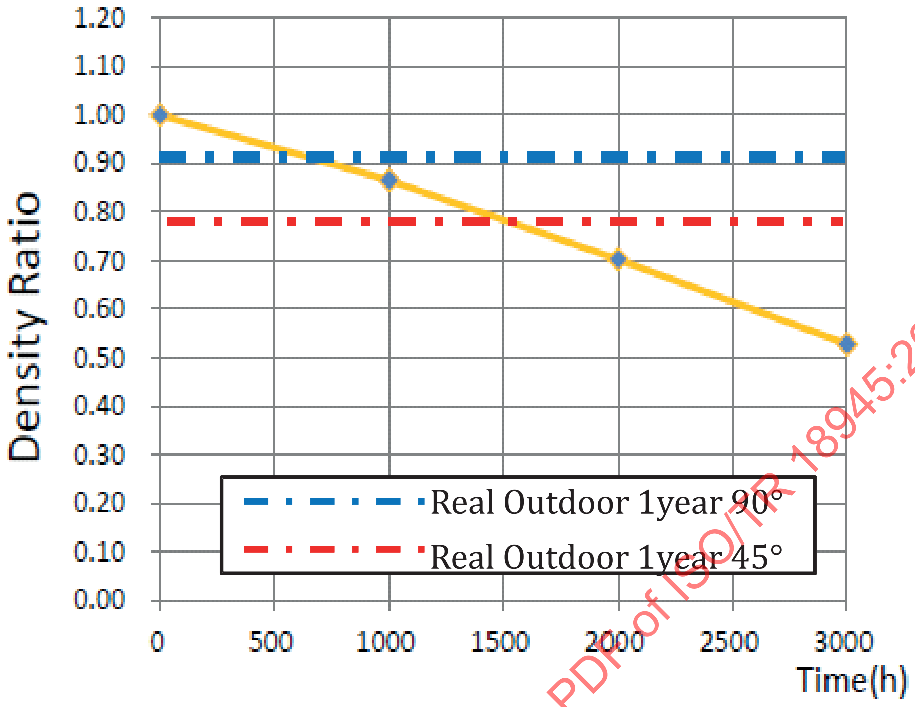



**Figure E.7 — Fade of the darkest yellow patches**

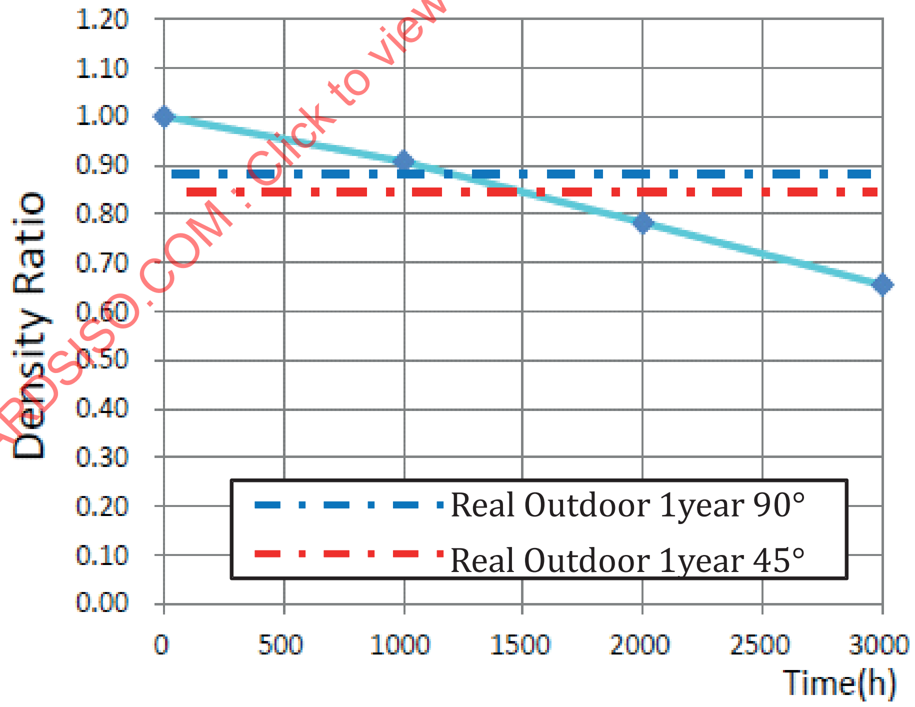



**Figure E.8 — Fade of darkest cyan patches**

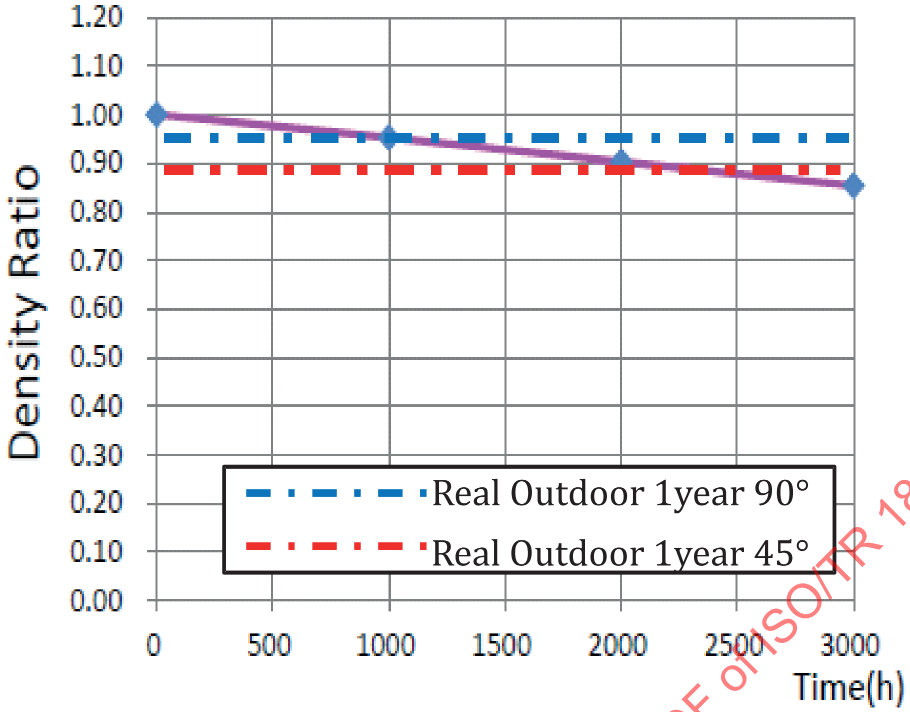



**Figure E.9 — Fade of darkest magenta patches**



**Table E.2 — Acceleration factors (AF) for the darkest colour patches at 45° and 90° angles of inclination**

| Angle and Colour | Accelerated Test Time (h) | AF | AF 45°/AF 90° (Stdev) |
|---|---|---|---|
| Yellow 45° | 769 | 11,40 | 2,2 (Stdev 1,04) |
| Yellow 90° | 1 687 | 5,20 | |
| | | | |
| Cyan 45° | 1 272 | 6,89 | 1,3 (Stdev 1,06) |
| Cyan 90° | 1 641 | 5,34 | |
| | | | |
| Magenta 45° | 1 064 | 8,24 | 1,8 (Stdev 0,69) |
| Magenta 90° | 1 957 | 4,48 | |

**Calculations and conclusions**

— When comparing the outdoor test results between inclination angles of 45 degrees and 90 degrees, for samples that show significant colour fading, results at 45 degrees are closer to the results obtained in ISO 18930 accelerated tests.

— The reasons for the observation above are:

— At 45 degrees, the samples are exposed to more direct sunlight.

— At 90 degrees (vertical), water cannot pool on top of the samples for long periods of time.

— Ratio of solar irradiance 45°/90° = 1,7.

— It is concluded that it is very important to consider the angle of inclination when conducting and outdoor weathering test.

— The results of ISO 18930 accelerated weathering tests can be used for outdoor print life estimation.

— When samples are tested outdoors at a 90° angle of inclination in Tokyo, it is to be expected that the print life will be approximately 1,7 times as long as for exposure at a 45° angle of inclination.



# Annex F
(informative)

# Environmental condition data under real outdoor conditions

## F.1 Differences among outdoor exposure sites

Exposure period: 2009-11 to 2011-10

**Table F.1 — Climatic comparison for outdoor exposure sites**

| Outdoor exposure site | | Okinawa | Arizona | Shinjuku |
|---|---|---|---|---|
| Radiant Exposure | UV | 685<br>Angle: 20°<br>315 - 400 nm | 660<br>Angle: 5°<br>300 - 385 nm | 602<br>Angle: 35°<br>300 - 400 nm |
| (MJ/m$^2$) | Total | 11113<br>Angle: 20°<br>315 - 400 nm | 15490<br>Angle: 5°<br>300 - 3 000 nm | 10161<br>Angle: 35°<br>300 - 3 000 nm |
| Maximum Temperature (°C) | | 24,6 | 47,0 | 37,7 |
| Max. monthly average humidity (% rh) | | 88 | 58 | 72 |
| Total amount of rainfall (mm) | | 4 276 | 178 | 3 221 |
| NOTE The weather factors different greatly among outdoor exposure sites. Temperature and humidity of Shinjuku, Tokyo are moderate, and the condition is urban. | | | | |

## F.2 Environmental condition data at Shinjuku, Tokyo

Exposure period: 2010-11 ~ 2013.3 (29 months)

**Table F.2 — Climate averages and extremes during test at Shinjuku, Tokyo site**

| Environmental condition | | Unit | Min./month | Max./month | Ave./29 months | Total of the 29 months |
|---|---|---|---|---|---|---|
| Solar energy exposed at 45° | 300 to 400 nm | MJ/m$^2$ | 16,3 | 32.,3 | 22,5 | 651,0 |
| | 300 to 3 000 nm | MJ/m$^2$ | 312,5 | 546,7 | 426,0 | 12 354,4 |
| BPT | | °C | −5,8 | 66,1 | 18,5 | — |
| WPT | | °C | −5,9 | 46,2 | 15,2 | — |
| Temperature | | °C | −2,1 | 37,7 | 14,3 | — |
| Humidity | | %RH | 8,0 | — | 57,3 | — |

**Table F.3 — Climate extremes during outdoor test at Shinjuku, Tokyo site**

| | | | | |
|---|---|---|---|---|
| BPT | °C | Min. temp. in winter −5,8 | Max. temp. of the lowest temp. day 39,6 | Temp. difference of the day 45,4 |
| | | Max. temp. in summer **66,1** | Min. temp. of the highest temp. day **24,0** | Temp. difference of the day **42,1** |
| WPT | °C | Min. Temp. in winter **−5,8** | Max. Temp. of the lowest temp. day **17,1** | Temp. difference of the day **23,0** |
| | | Max. Temp. in summer **46,2** | Min. Temp. of the highest temp. day **27,1** | Temp. difference of the day **19,1** |
| Temperature | °C | Min. Temp. in winter **−2,1** | Max. Temp. of the lowest temp. day **14,2** | Temp. difference of the day **16,3** |
| | | Max. Temp. in summer **37,7** | Min. Temp. of the highest temp. day **24,8** | Temp. difference of the day **12,9** |
| NOTE Above data is details of the environmental condition and BPT and WPT. | | | | |

## F.3 Maximum panel temperatures for white, gray and black panels at Shinjuku, Tokyo

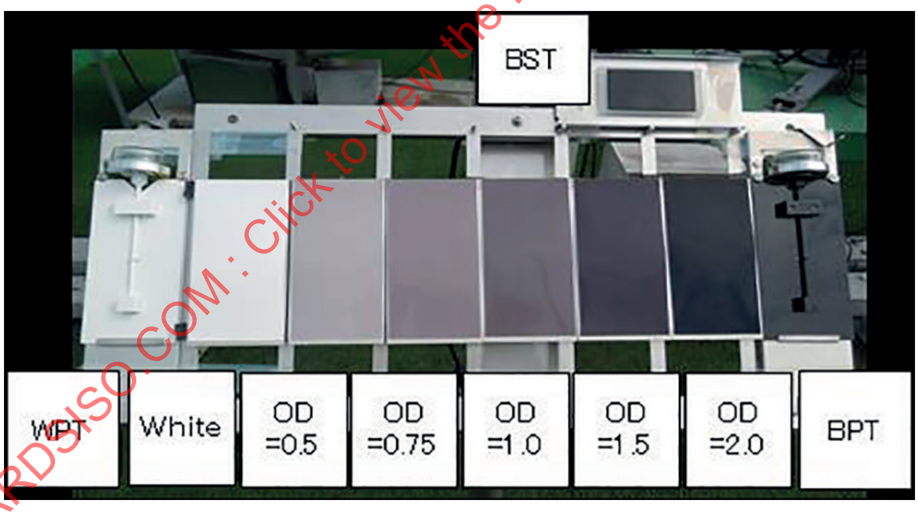



**Figure F.1 — White, gray, and black panels in outdoor test at Shinjuku, Tokyo**

**Table F.4 — Surface temperatures as a function of angle of inclination for white, gray, and black panels at Shinjuku, Tokyo**

| | **0° (Horizontally)** | **45°** | **90° (Vertically)** |
|---|---|---|---|
| WPT(°C) | 42,4 | 43,0 | 41,2 |
| White | 42,1 | 42,2 | 41,0 |
| OD=0,5 | 51,9 | 50,8 | 44,8 |
| OD=0,75 | 54,3 | 53,3 | 46,0 |
| OD=1,0 | 55,1 | 55,0 | 46,2 |
| OD=1,5 | 57,4 | 56,8 | 47,7 |
| OD=2,0 | 58,3 | 57,6 | 46,8 |

**Table F.4** *(continued)*

| | 0° (Horizontally) | 45° | 90° (Vertically) |
|---|---|---|---|
| BPT (°C) | 59,4 | 59,6 | 47,8 |
| BST (°C) | 59,8 | 59,1 | 52,6 |
| NOTE It is important that we know the surface temperature of the sample as well as the environmental conditions of each site. | | | |

- Three standard temperatures were measured:
  - WPT: white panel temperature;
  - BPT: black panel temperature;
  - BST: black standard temperature;
- Five samples were tested for each optical density.
- Measurement environment details:
  - The measurement time: 11:05
  - Weather: Sunny
  - Solar altitude: 73,8°
  - Solar orientation: −36,4°
  - Ambient air temperature: 36,3 °C
  - Humidity: 39,5 %
  - Wind Velocity: ≤1 m/s

## F.4 Surface temperatures during outdoor exposure

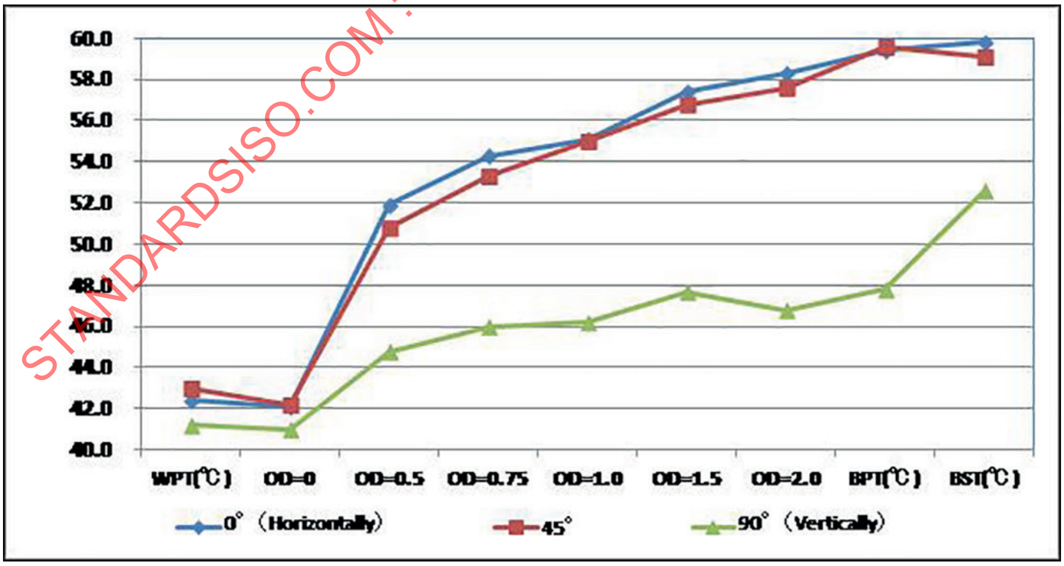



**Figure F.2 — Surface temperatures as a function of angle of inclination for white, gray, and black panels at Shinjuku, Tokyo**

NOTE The surface temperatures for 45° and 0° are very close for this data set. The solar altitude was 73,8° in this measurement. If the solar altitude decreases, the surface temperatures change, and surface temperature becomes higher at 45° than at 0°. The surface temperature is low at 90° in comparison with both 45° and 0°.

# Annex G
(informative)

# Comparison of material degradation during outdoor and ISO 18930 accelerated laboratory weathering tests

## G.1 Colour fade graphs

The vertical axes are the ratio of the residual density to the initial density, and the horizontal axes are the exposure time for accelerated or outdoor tests. The graphs on the left side of the page are the test results for the ISO 18930 xenon arc accelerated weathering tests at each laboratory, and the graphs on the right side of the page are the test results for each of the outdoor sites.

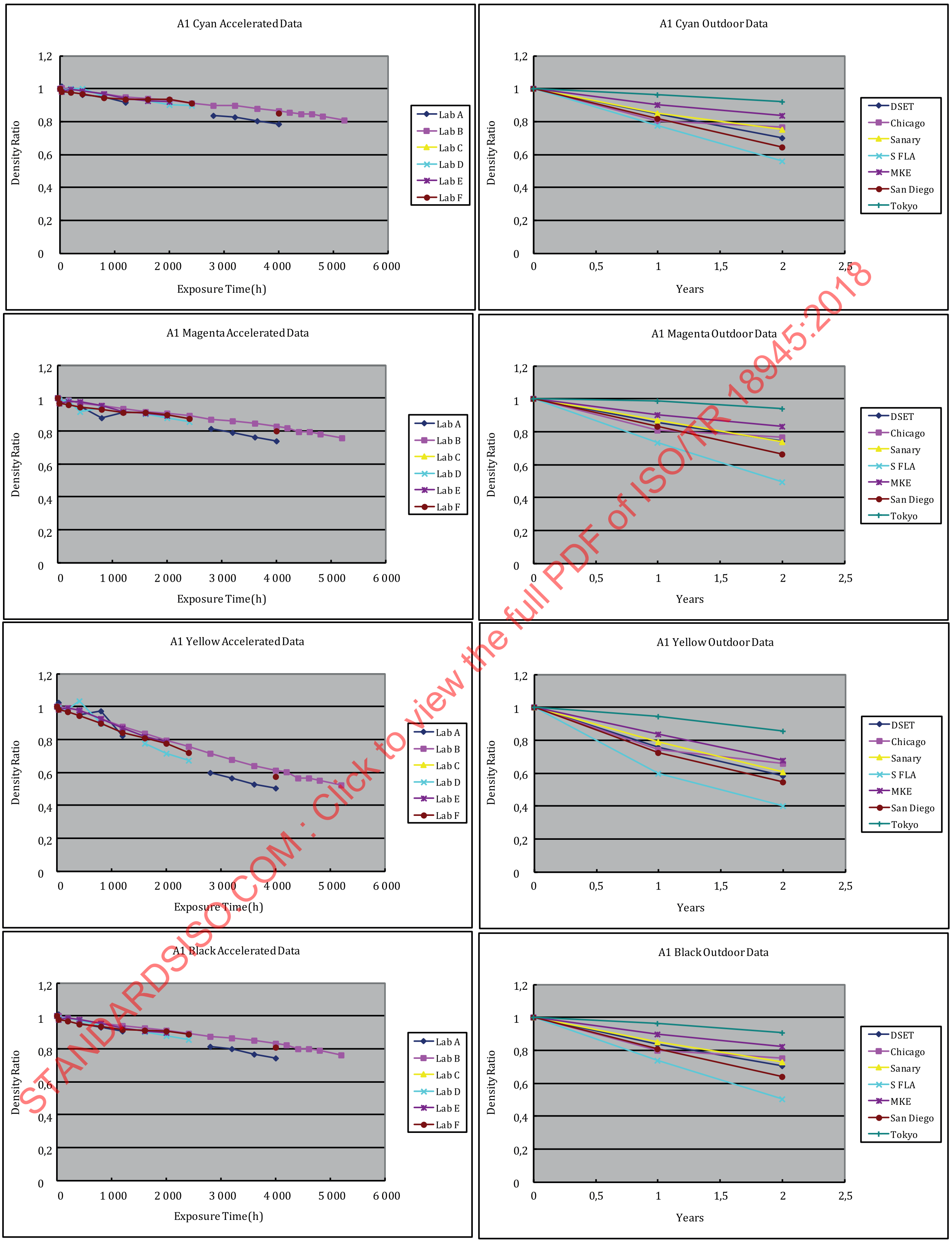



**Figure G.1 — Material A1 — Accelerated test results at 5 laboratories (left) and outdoor test results at 7 locations (right)**

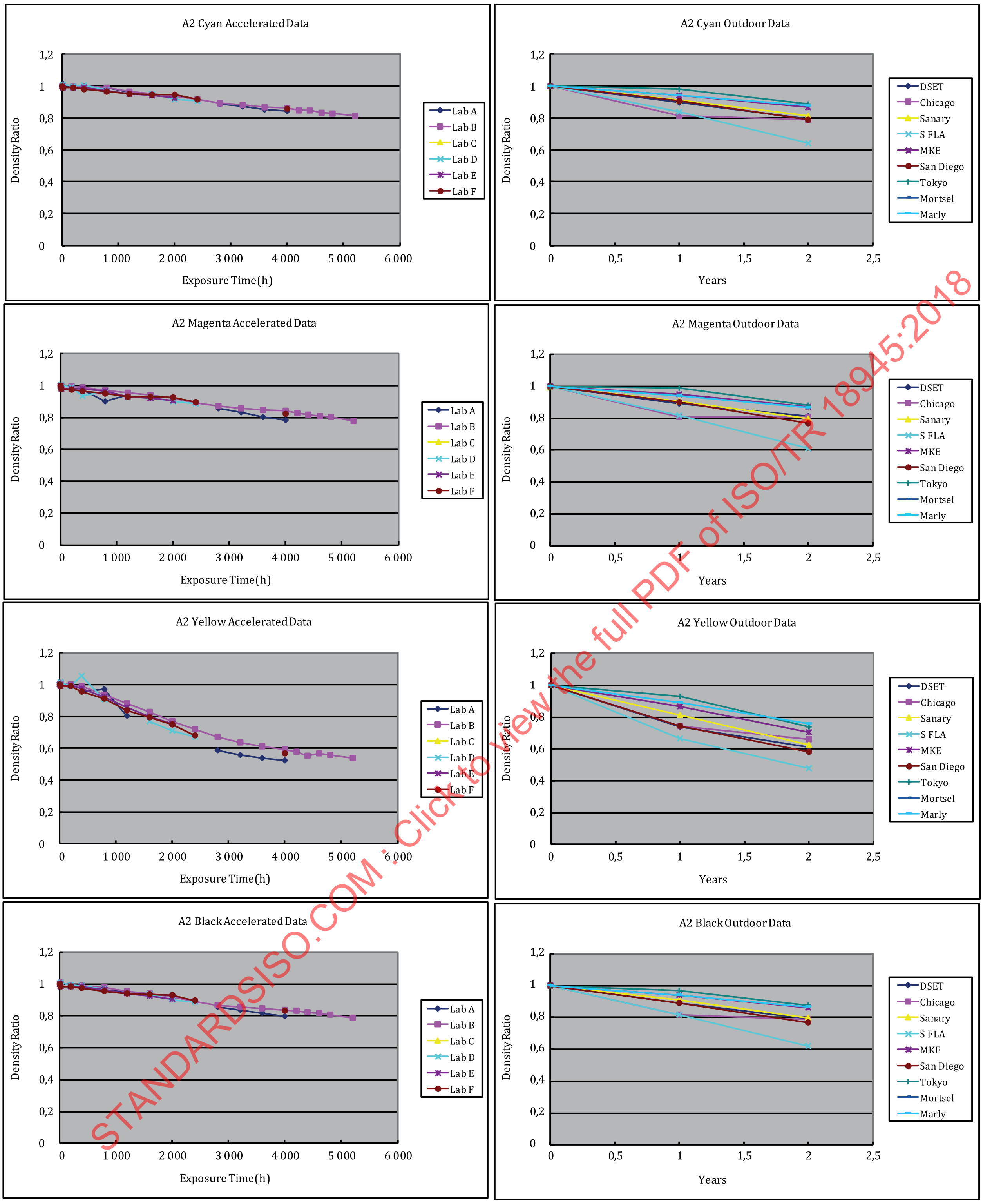



**Figure G.2 — Material A2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

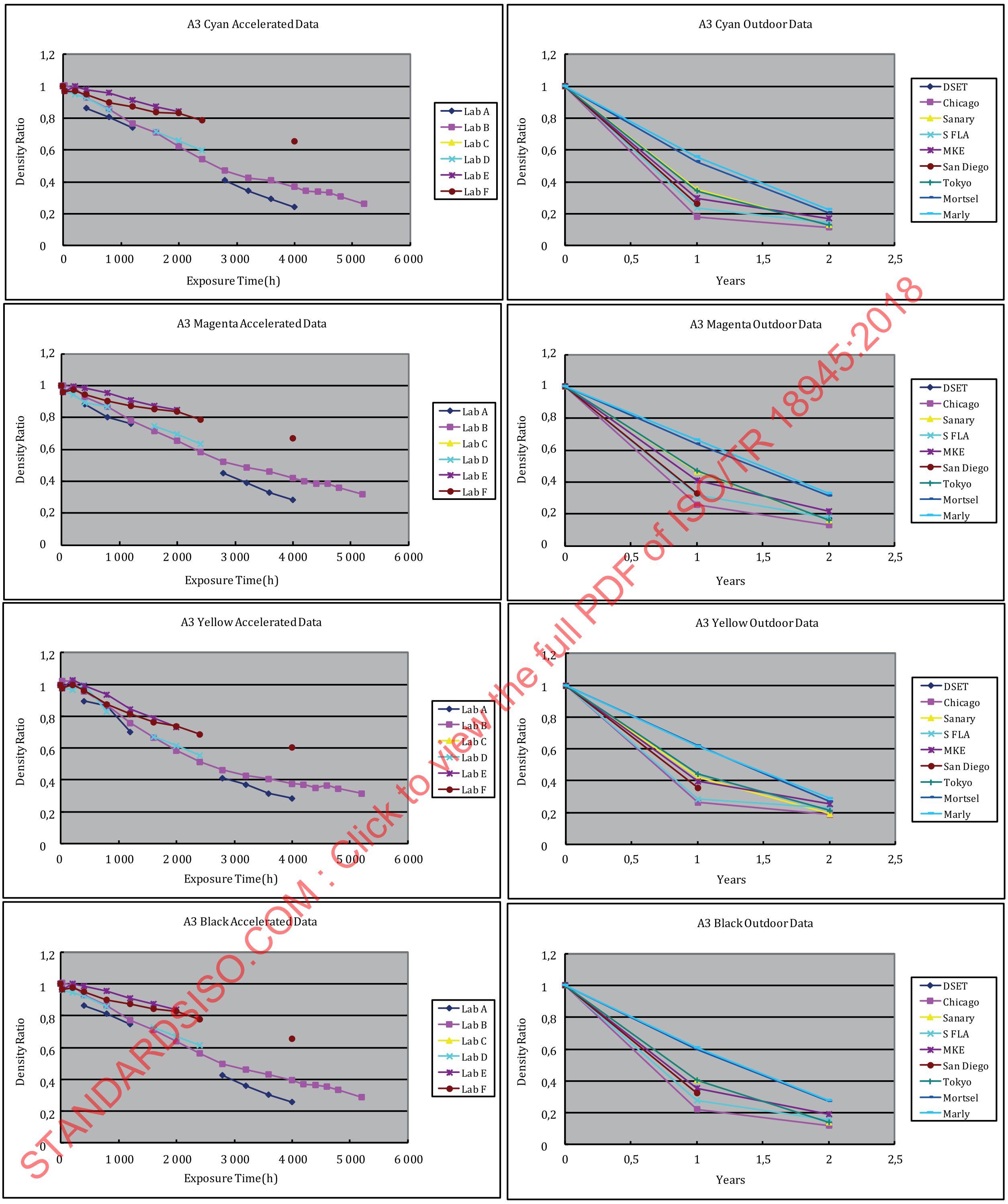



**Figure G.3 — Material A3 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

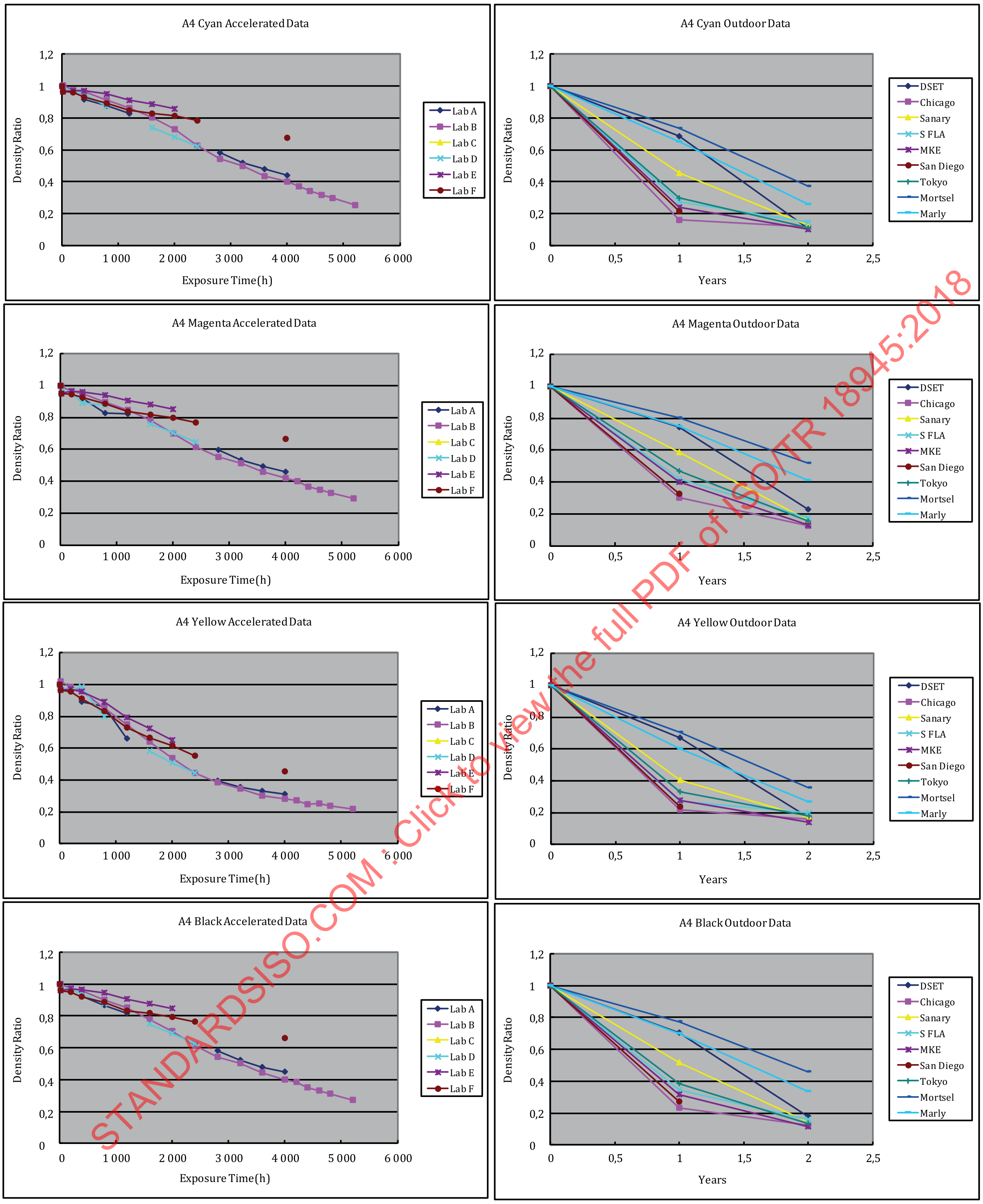



**Figure G.4 — Material A4 — Accelerated test results at 5 laboratories (left) and outdoor test results at 9 locations (right)**

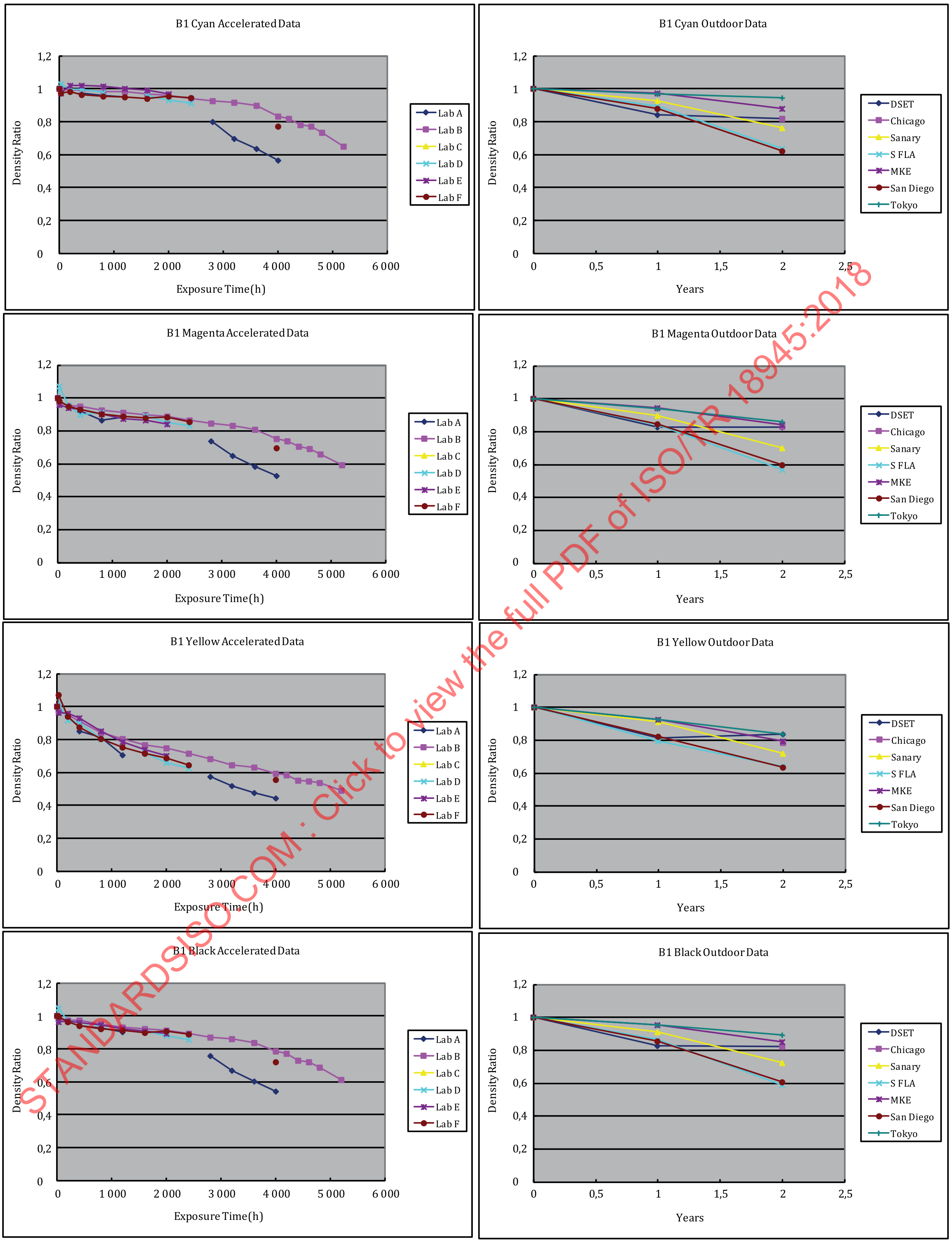





**Figure G.5 — Material B1 — Accelerated test results at 5 laboratories (left) and outdoor test results at 6 locations (right)**

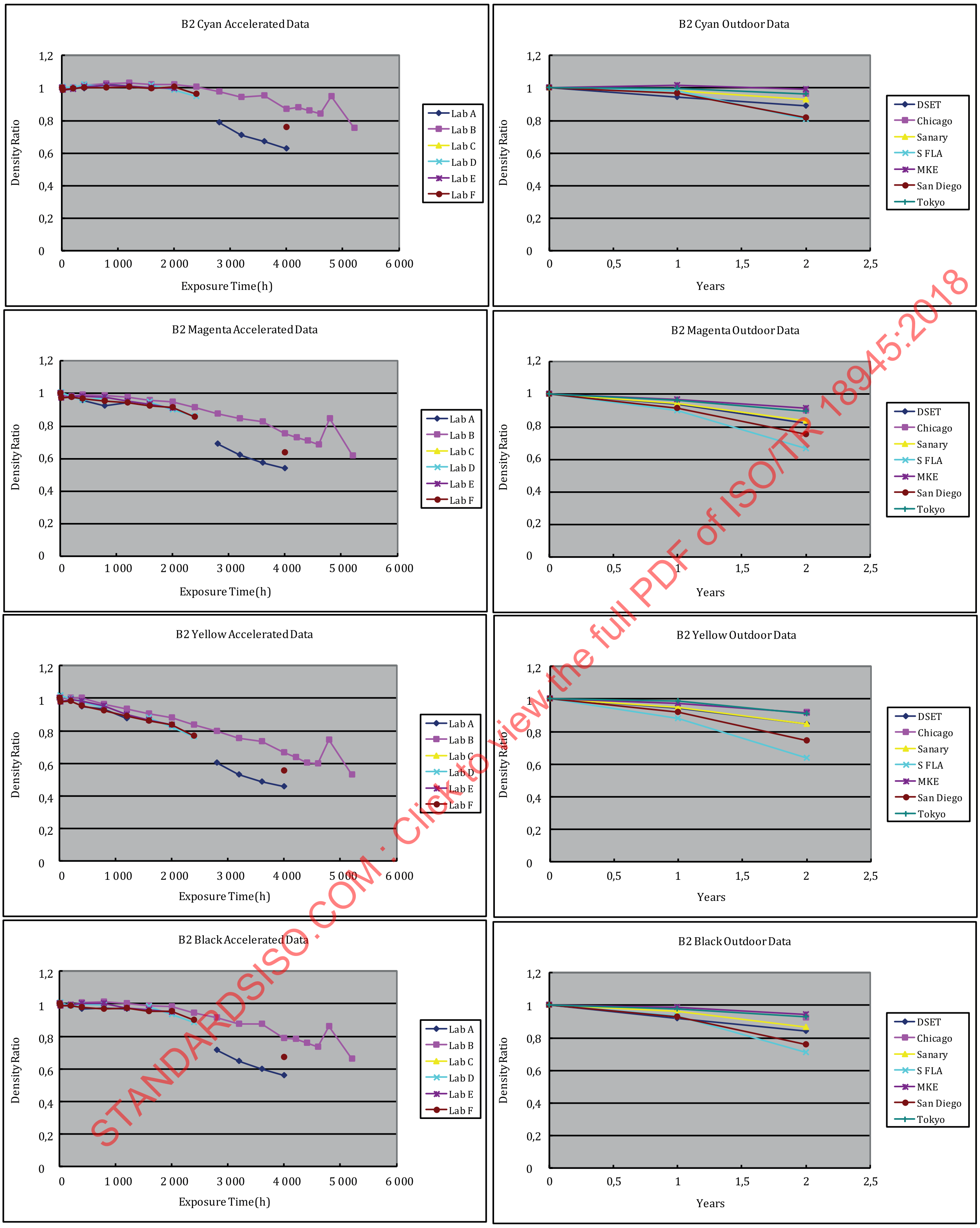



**Figure G.6 — Material B2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 6 locations (right)**

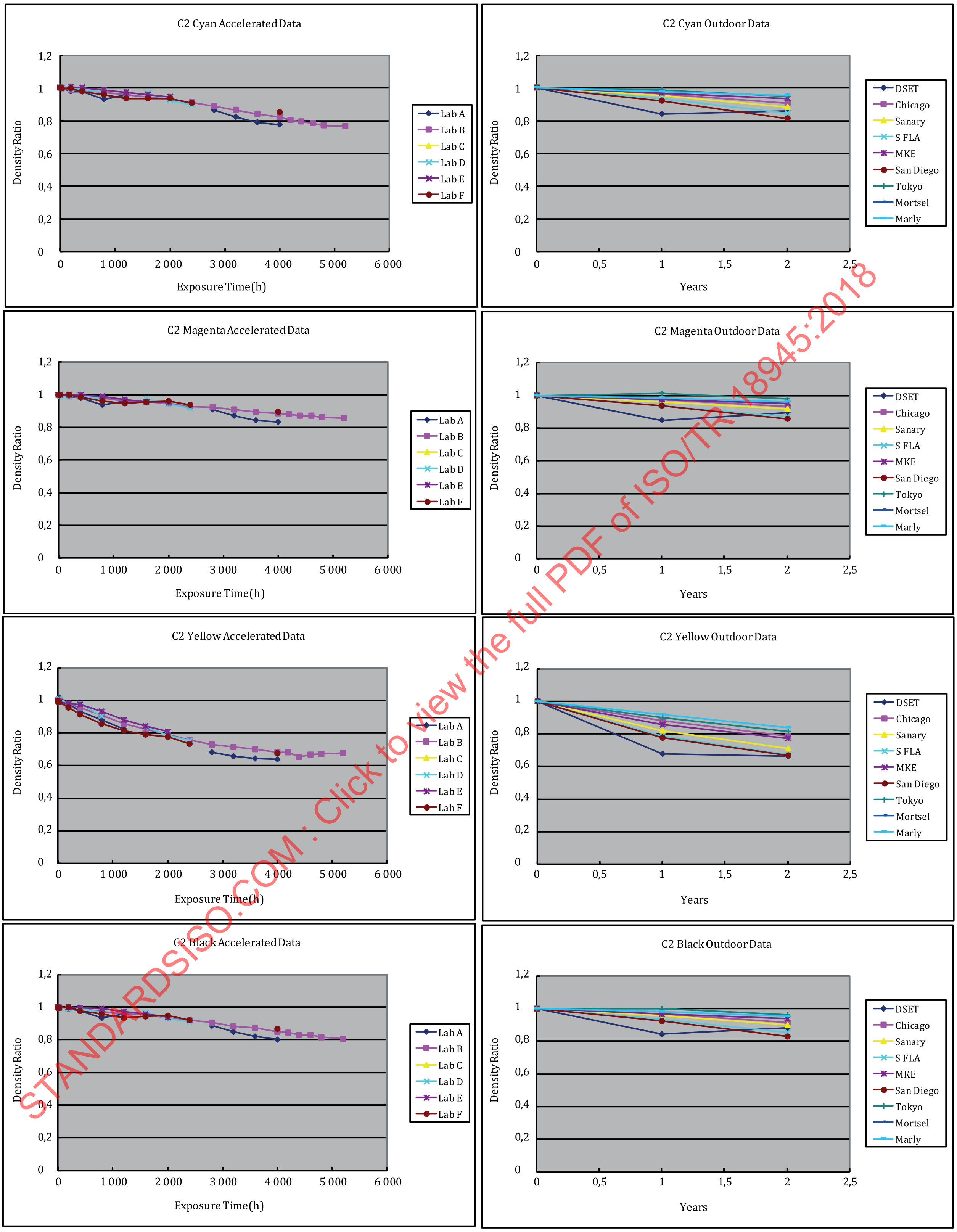



**Figure G.7 — Material C2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

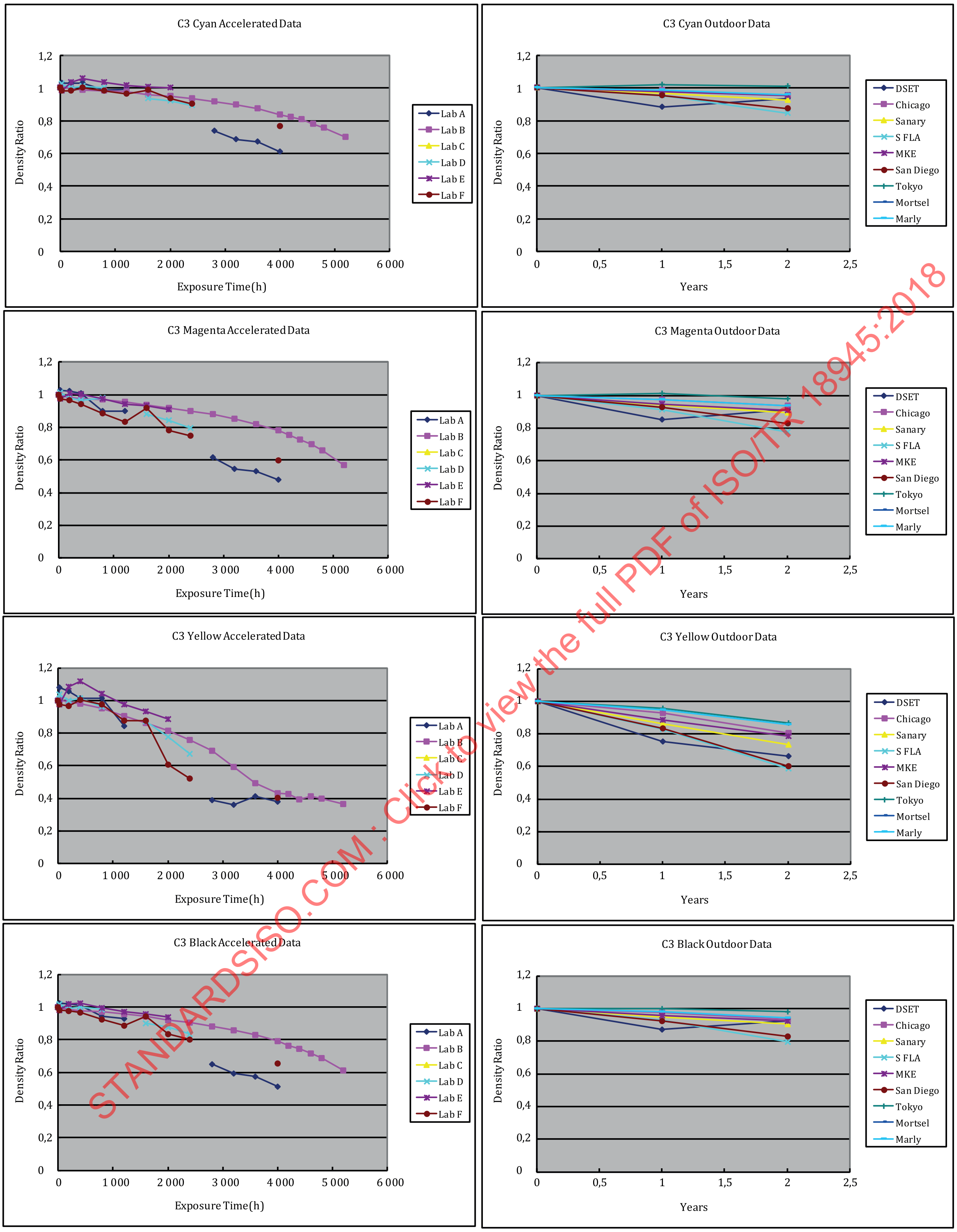



**Figure G.8 — Material C3 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

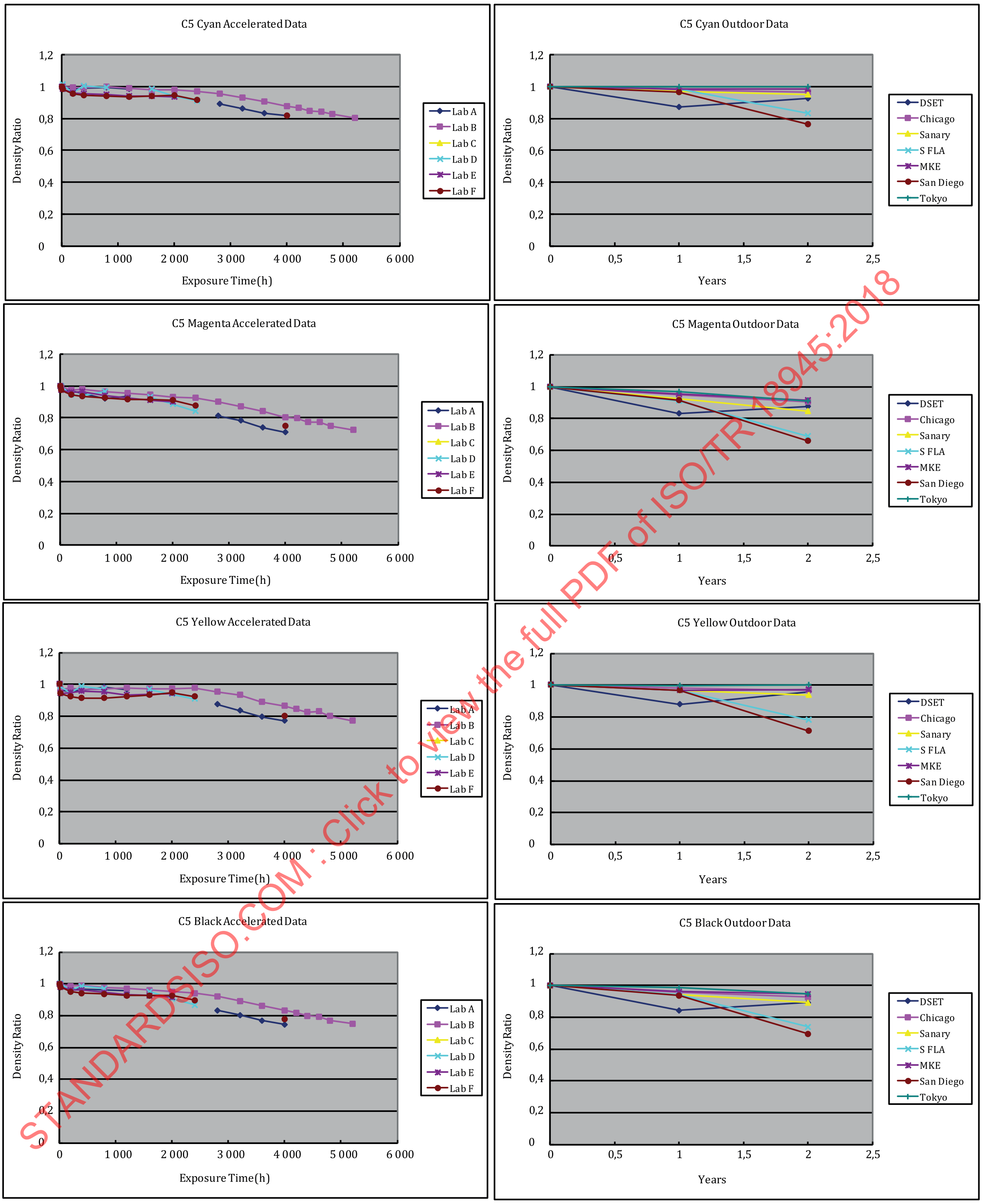





**Figure G.9 — Material C5 — Accelerated test results at 5 laboratories (left) and outdoor test results at 7 locations (right)**

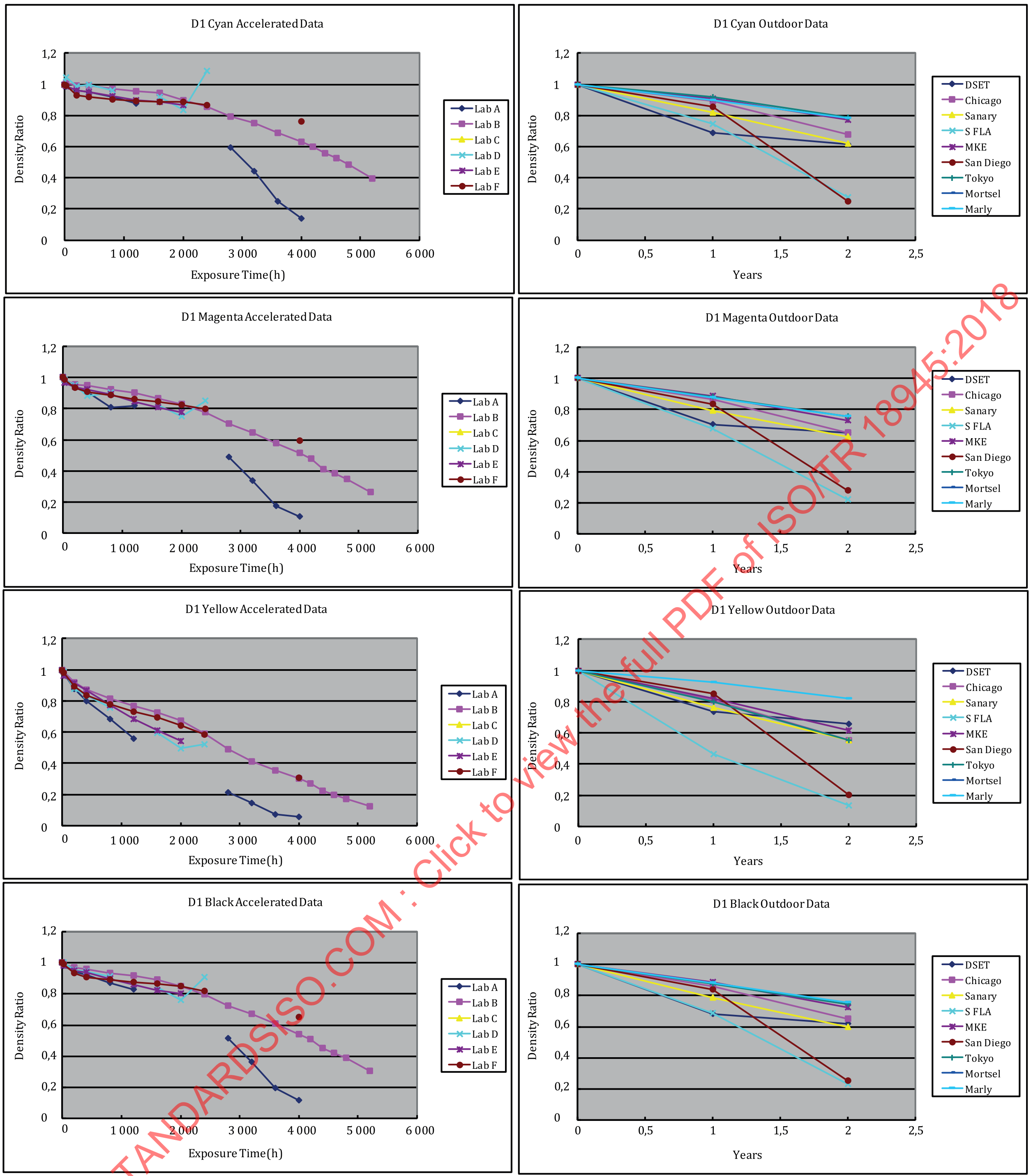



**Figure G.10 — Material D1 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**



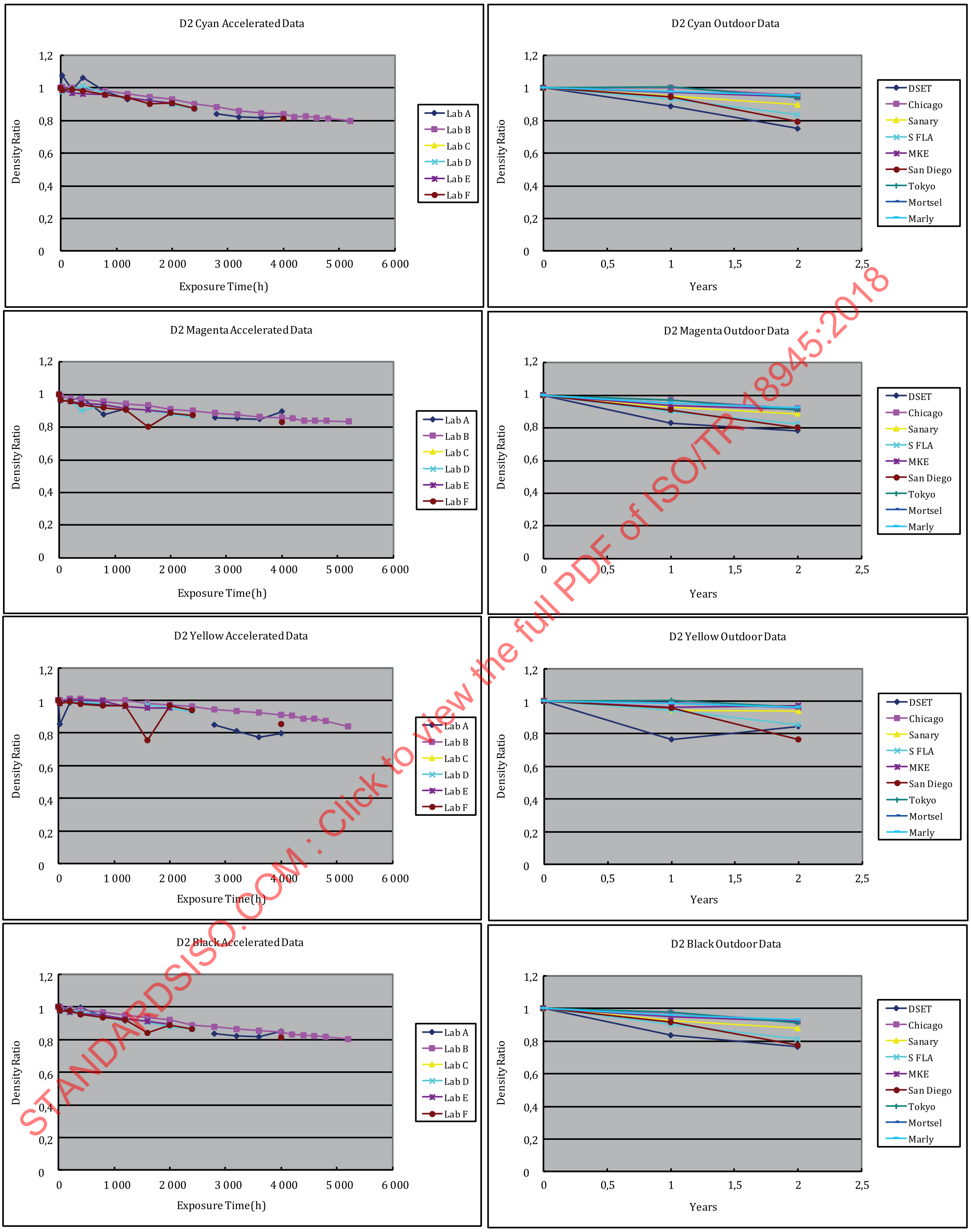



**Figure G.11 — Material D2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

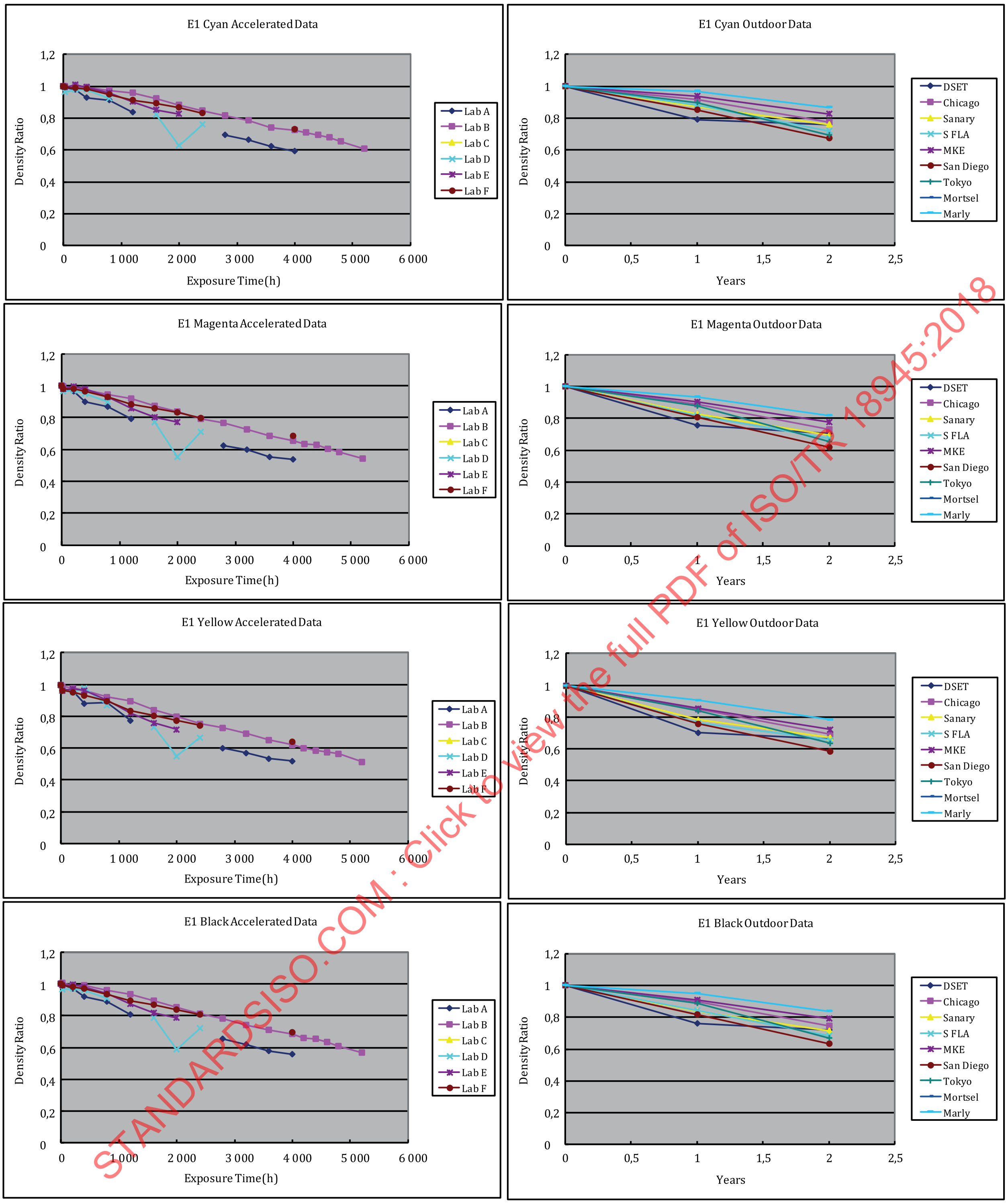



**Figure G.12 — Material E1 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**



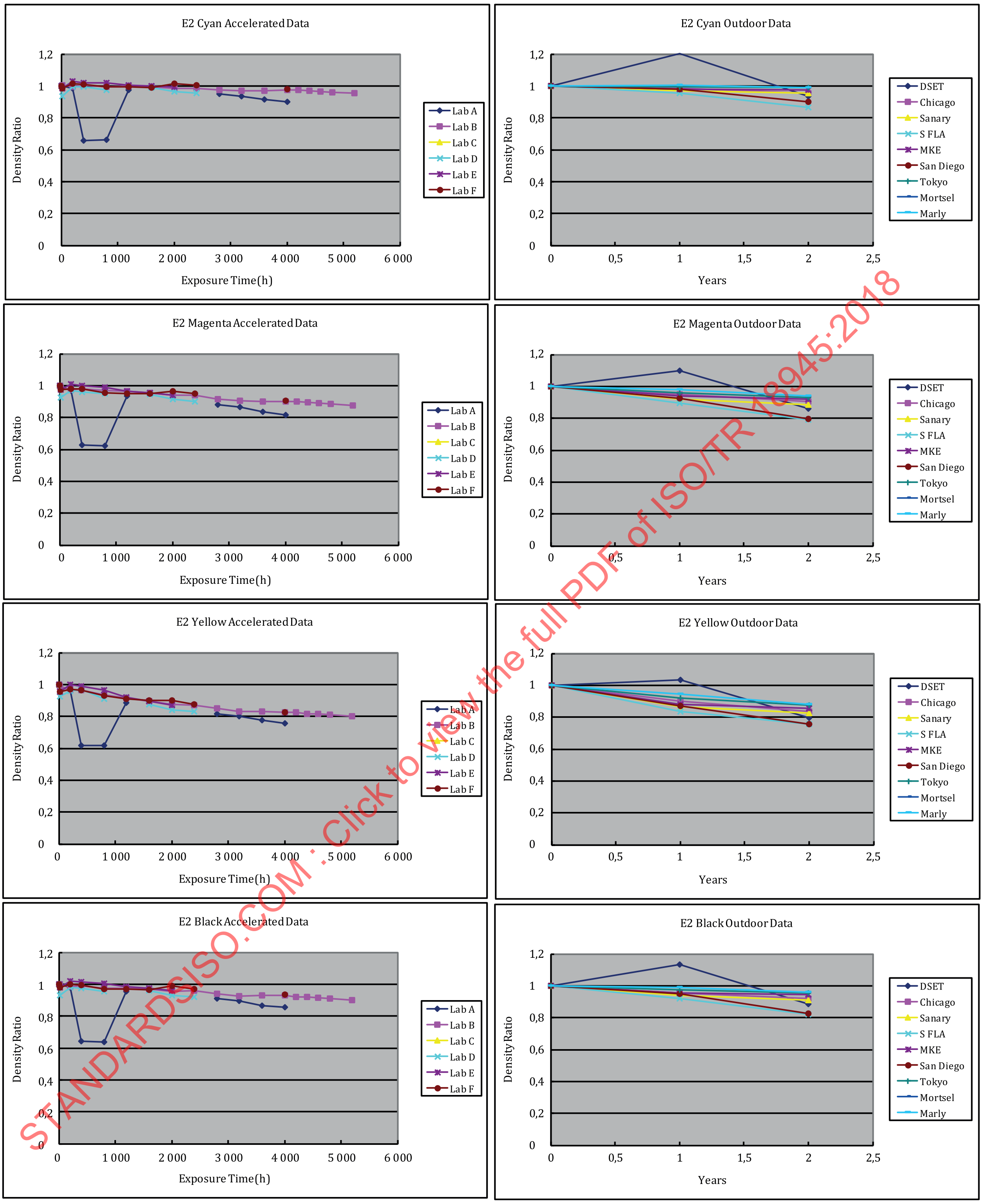



**Figure G.13 — Material E2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 8 locations (right)**

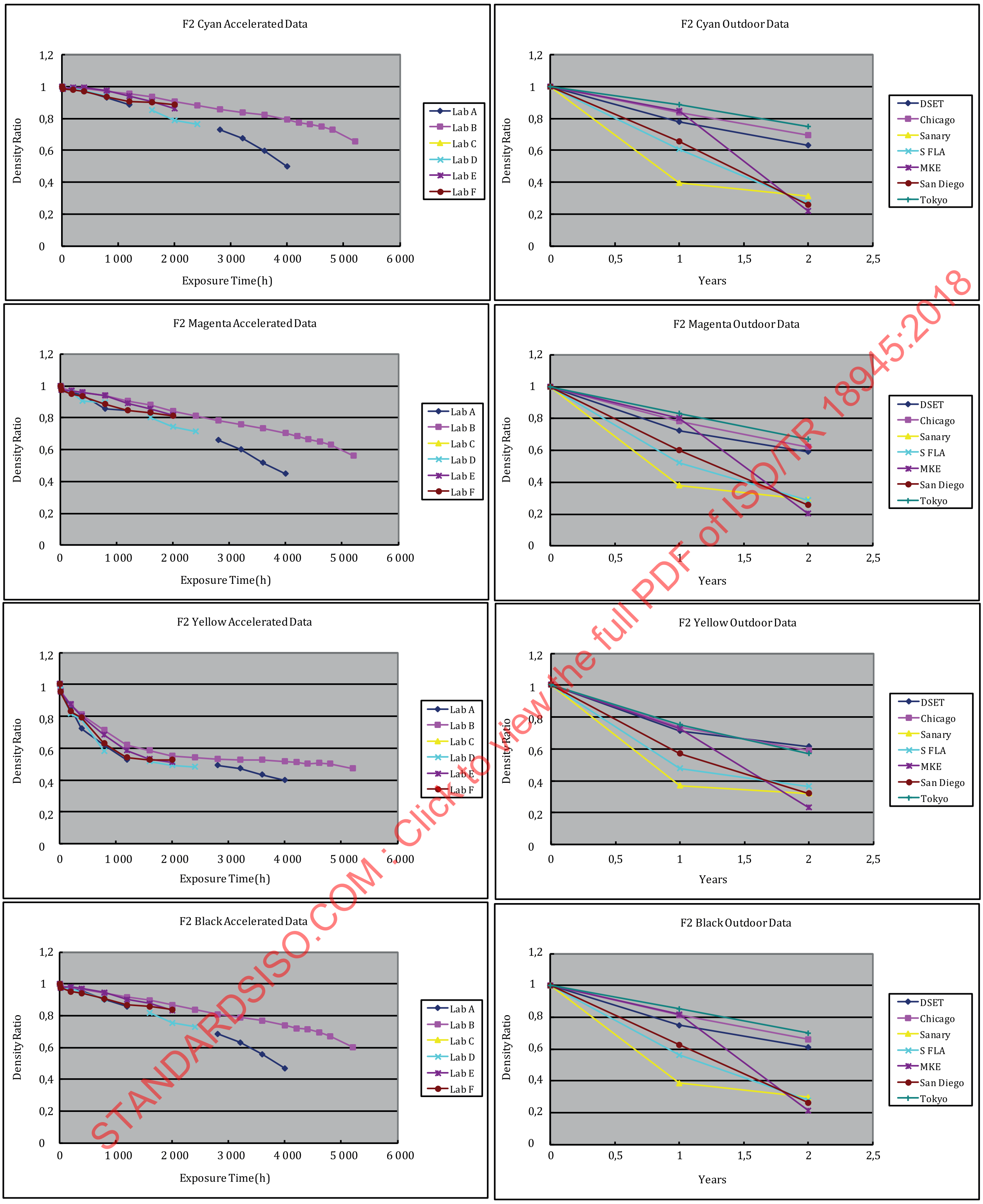



**Figure G.14 — Material F2 — Accelerated test results at 5 laboratories (left) and outdoor test results at 7 locations (right)**

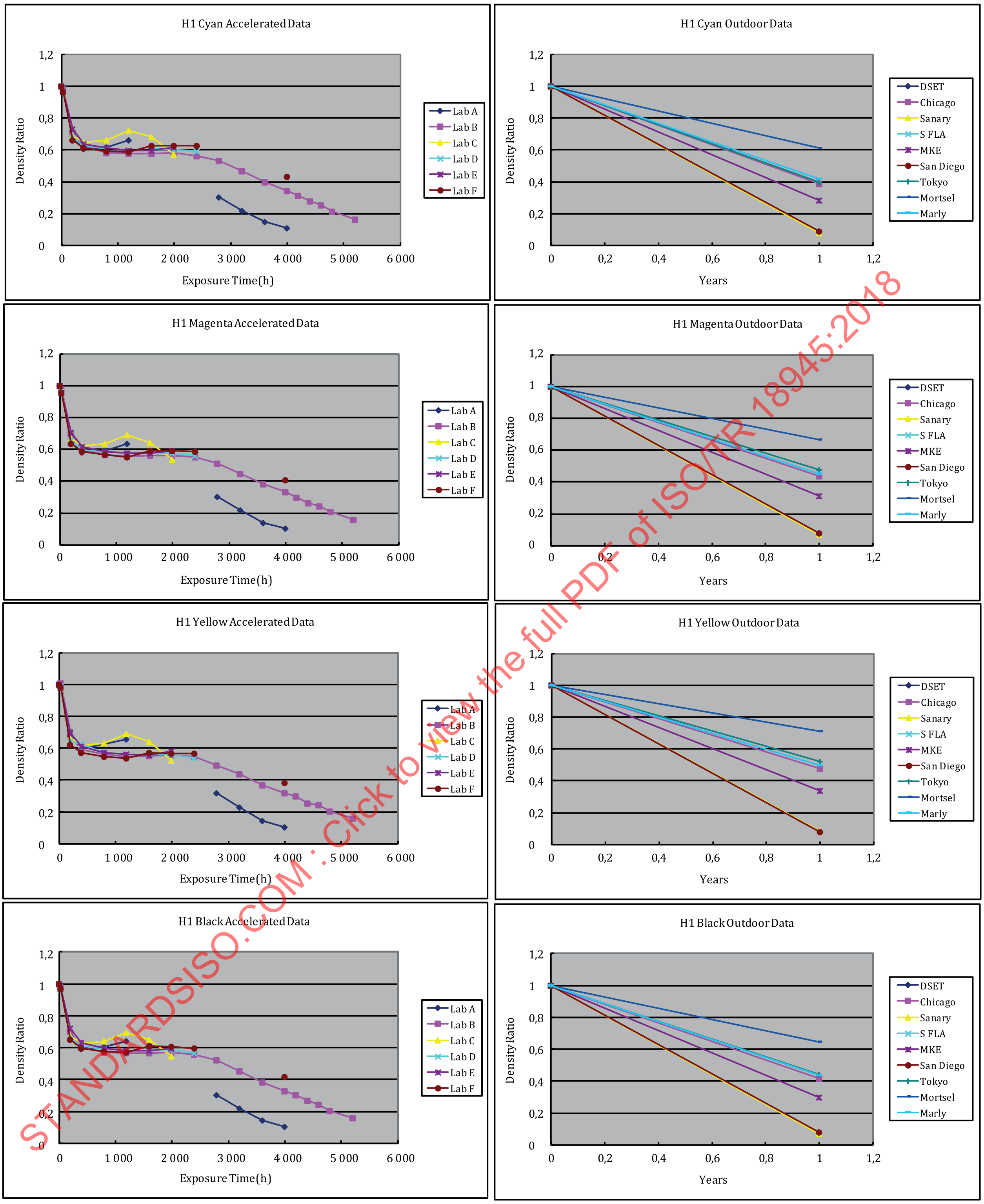



**Figure G.15 — Material H1 — Accelerated test results at 6 laboratories (left) and outdoor test results at 7 locations (right)**

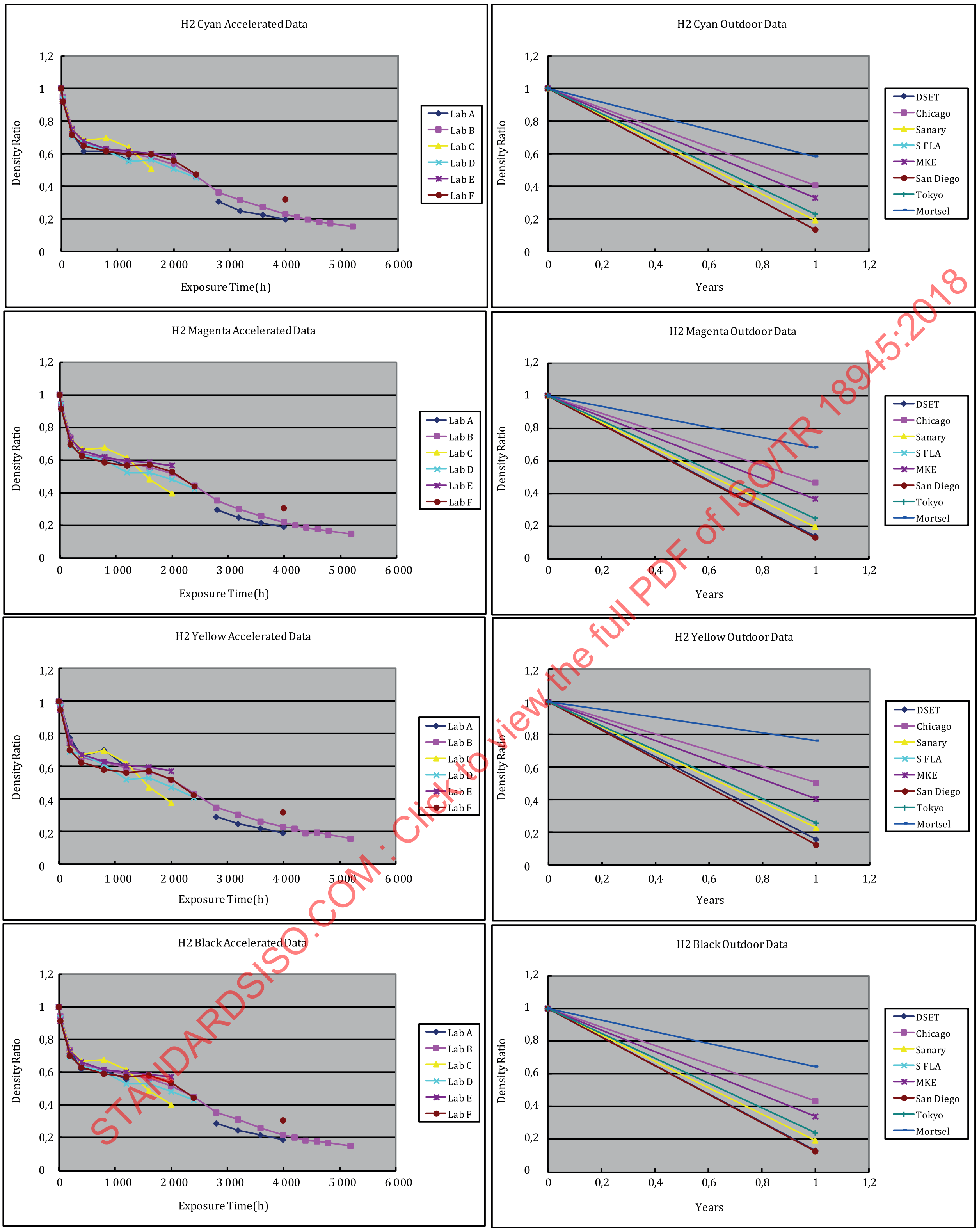



**Figure G.16 — Material H2 — Accelerated test results at 6 laboratories (left) and outdoor test results at 7 locations (right)**

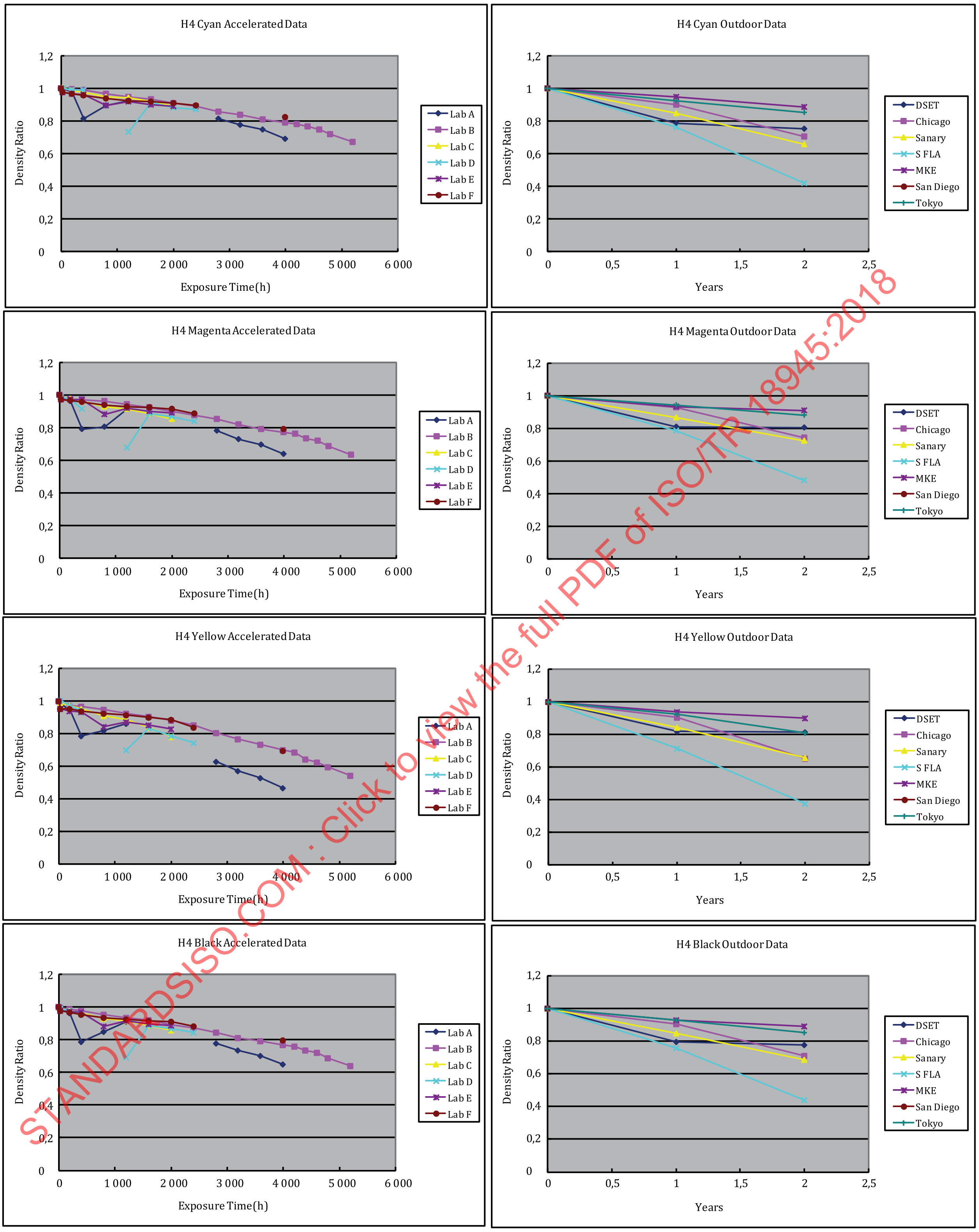





**Figure G.17 — Material H4 — Accelerated test results at 6 laboratories (left) and outdoor test results at 6 locations (right)**

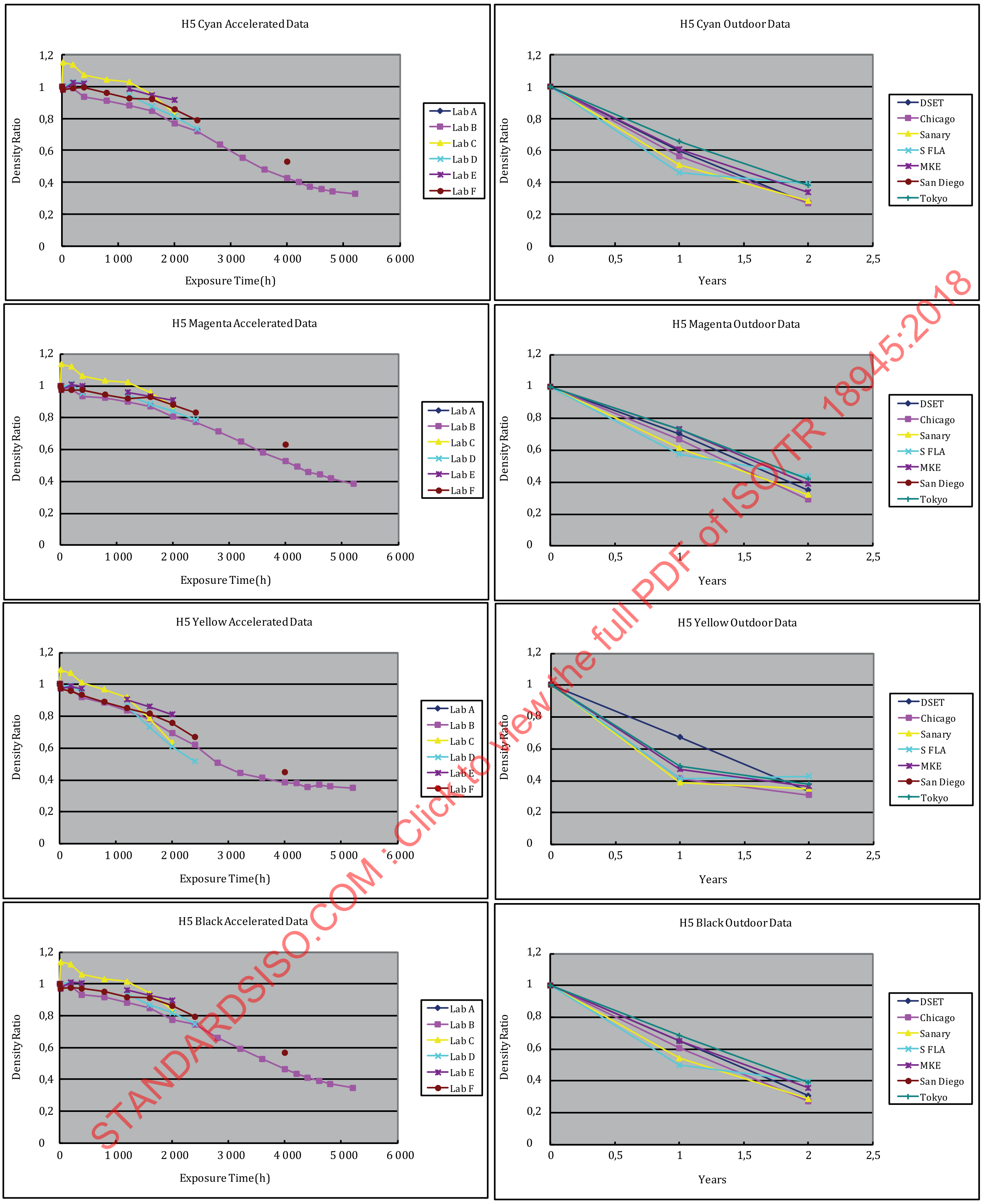



**Figure G.18 — Material H5 — Accelerated test results at 5 laboratories (left) and outdoor test results at 6 locations (right)**

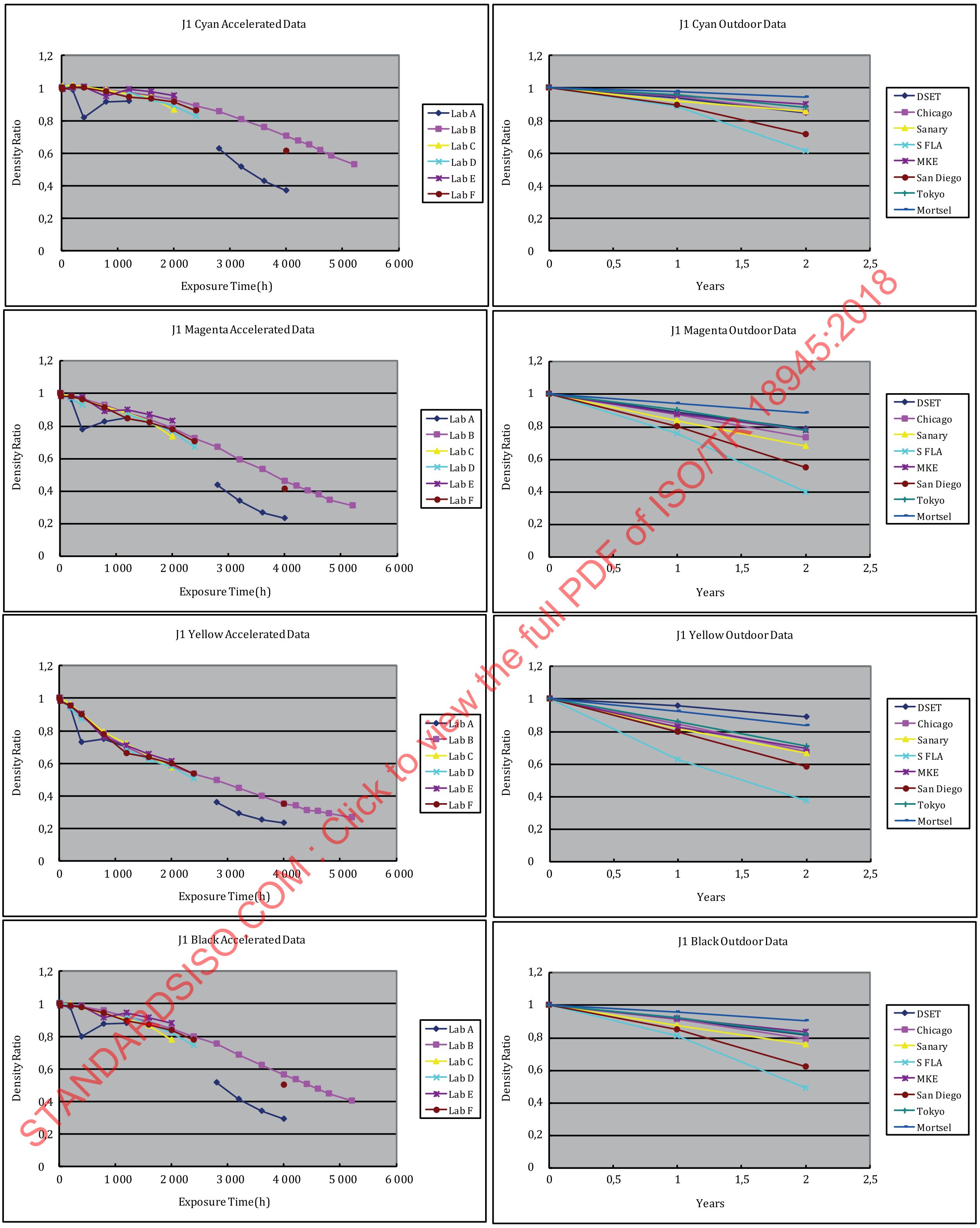



**Figure G.19 — Material J1 — Accelerated test results at 6 laboratories (left) and outdoor test results at 8 locations (right)**

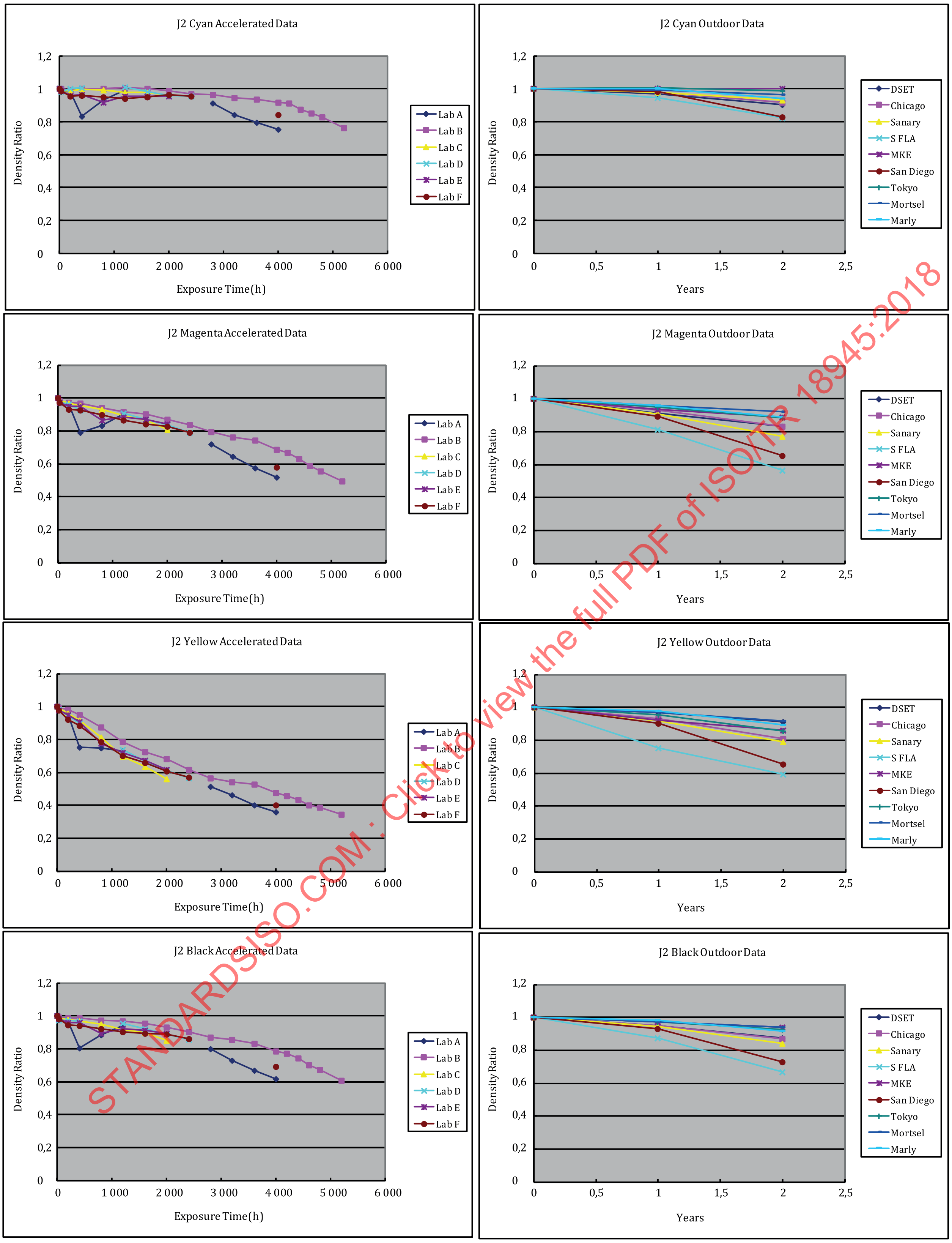



**Figure G.20 — Material J2 — Accelerated test results at 6 laboratories (left) and outdoor test results at 9 locations (right)**

## G.2 Comparison of outdoor test sites

The average fading rates of all of the materials are compared by outdoor site in this subclause. These figures should help one to understand roughly the overall nature of each outdoor site.

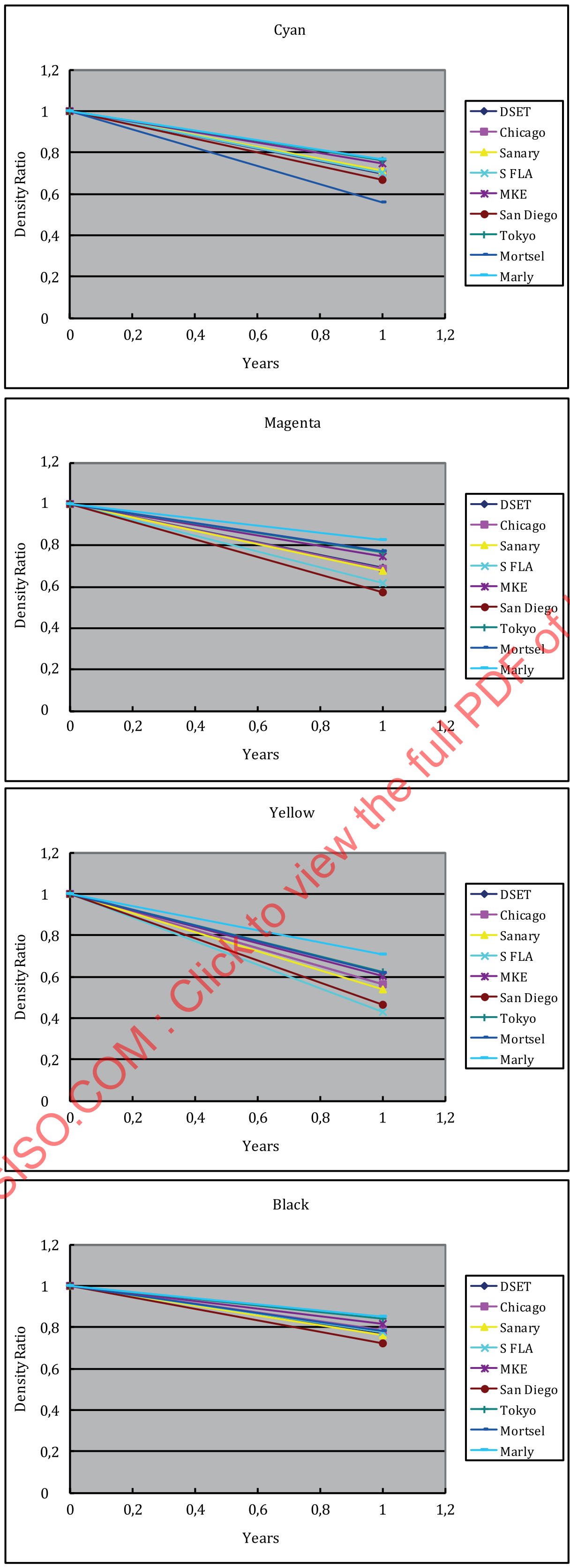



**Figure G.21 — Average fading rate of the materials**

## G.3 Comparison of outdoor exposures to laboratory accelerated tests

The ratios of the fading rates from the outdoor exposures to those from the laboratory accelerated tests are plotted in G.3. Fading rates at a fixed point (one year outdoors, and the average equivalent number of hours of the accelerated test for all 32 materials compared to each outdoor site) are adopted here. These fading rates are analogous to, but not the same as, the colour fade acceleration factors used in this document.

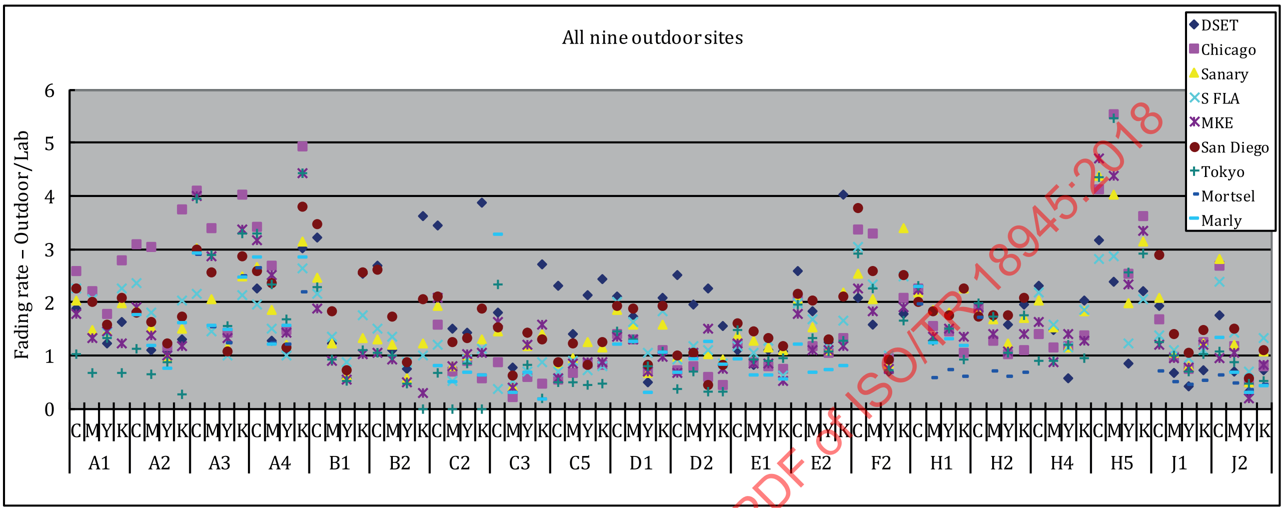



**Figure G.22 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material at all outdoor sites**

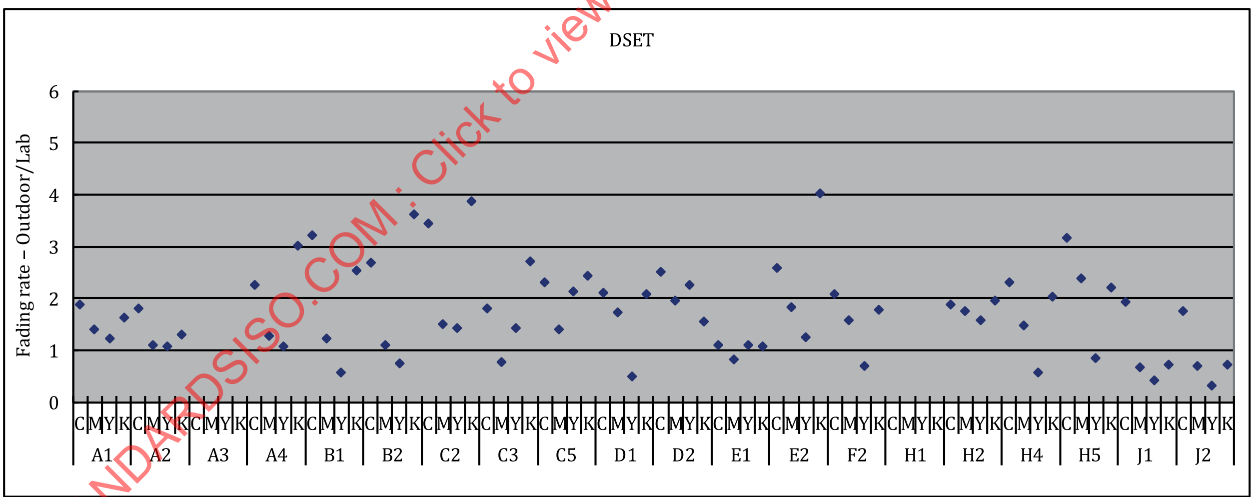



**Figure G.23 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in DSET**

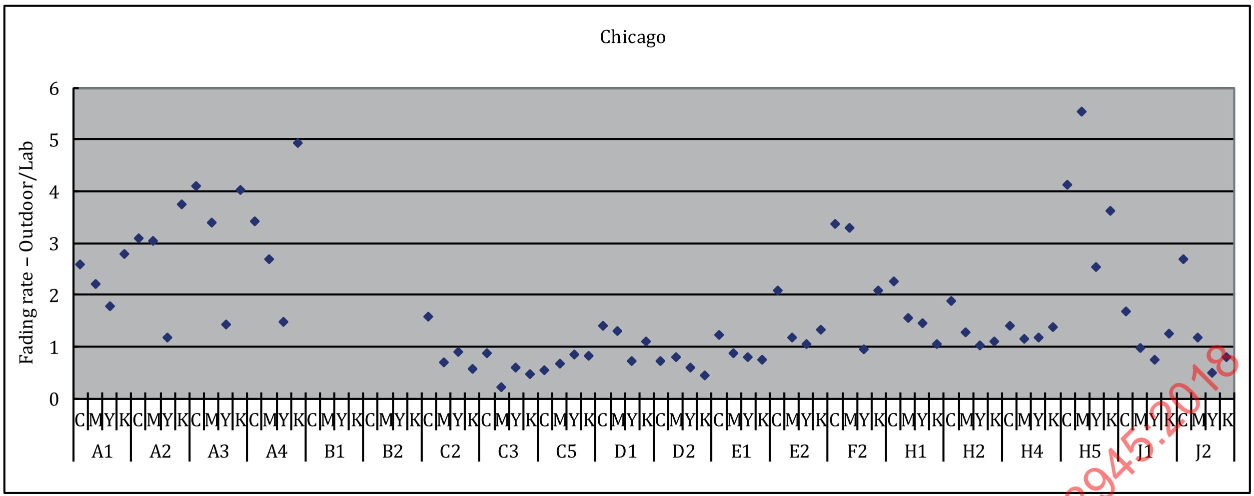



**Figure G.24 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Chicago**

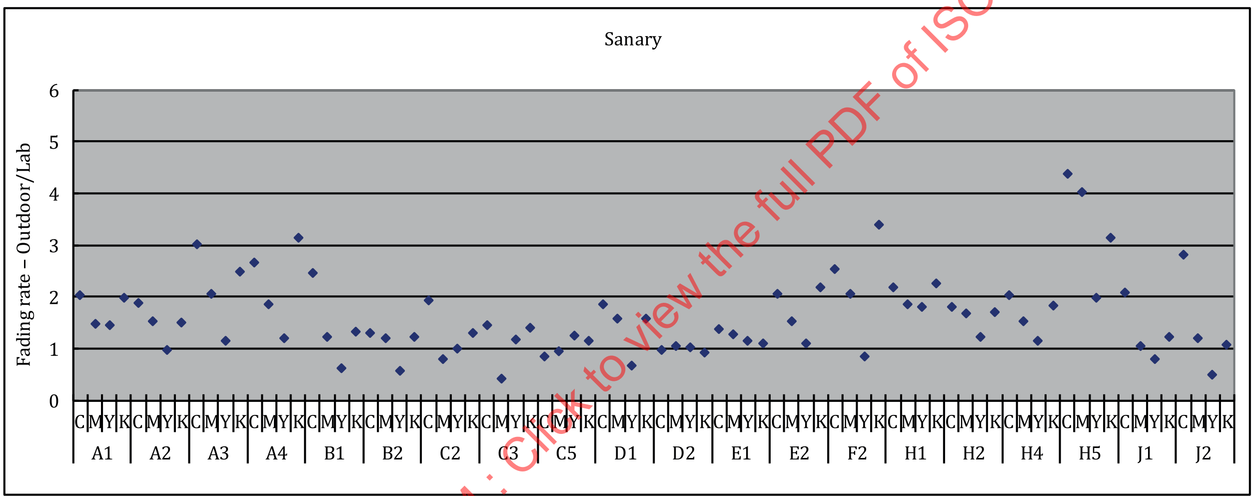



**Figure G.25 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Sanary**

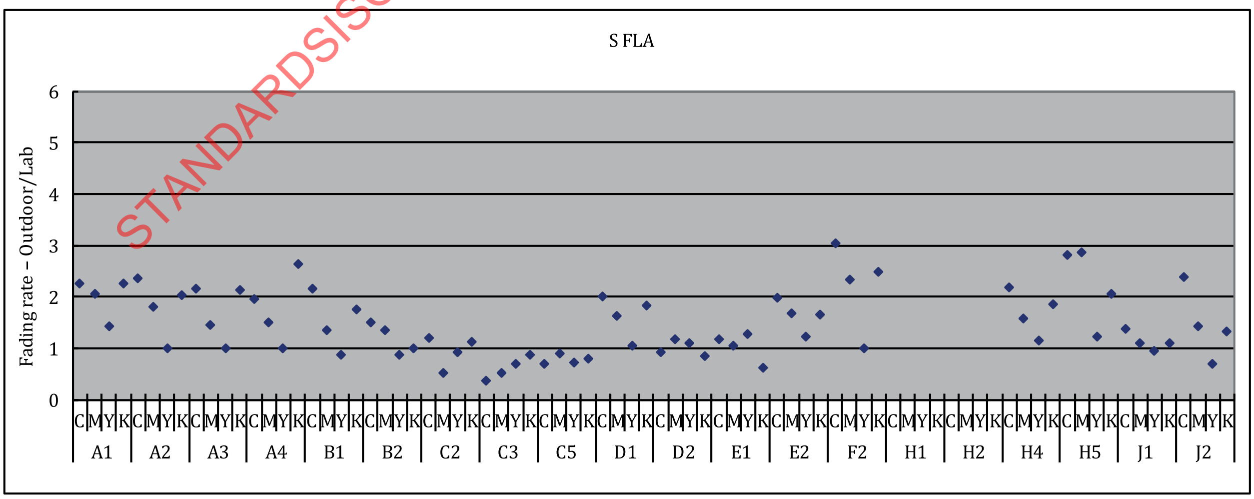



**Figure G.26 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in South Florida**



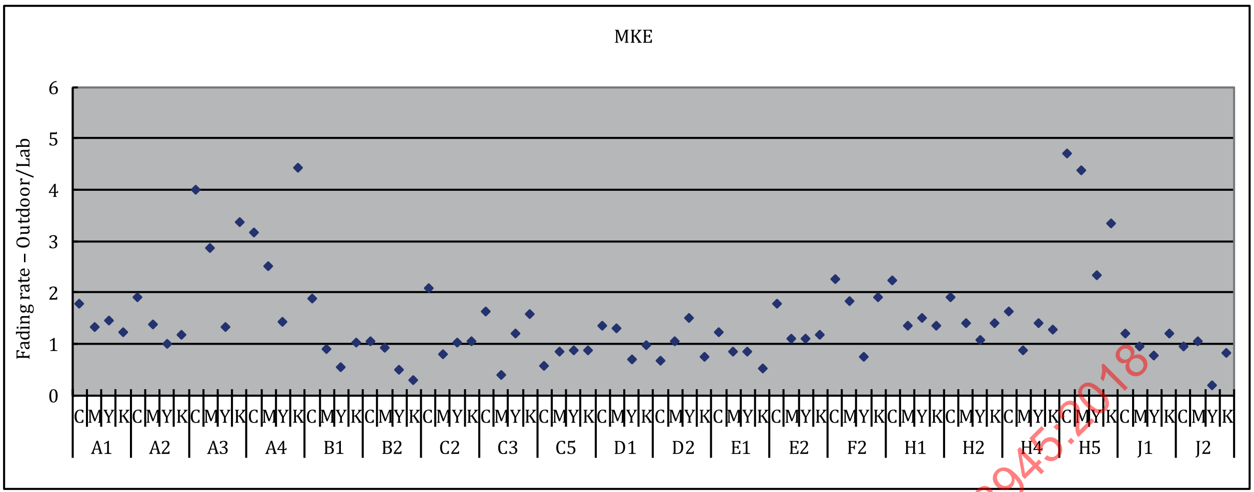



**Figure G.27 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Milwaukee**

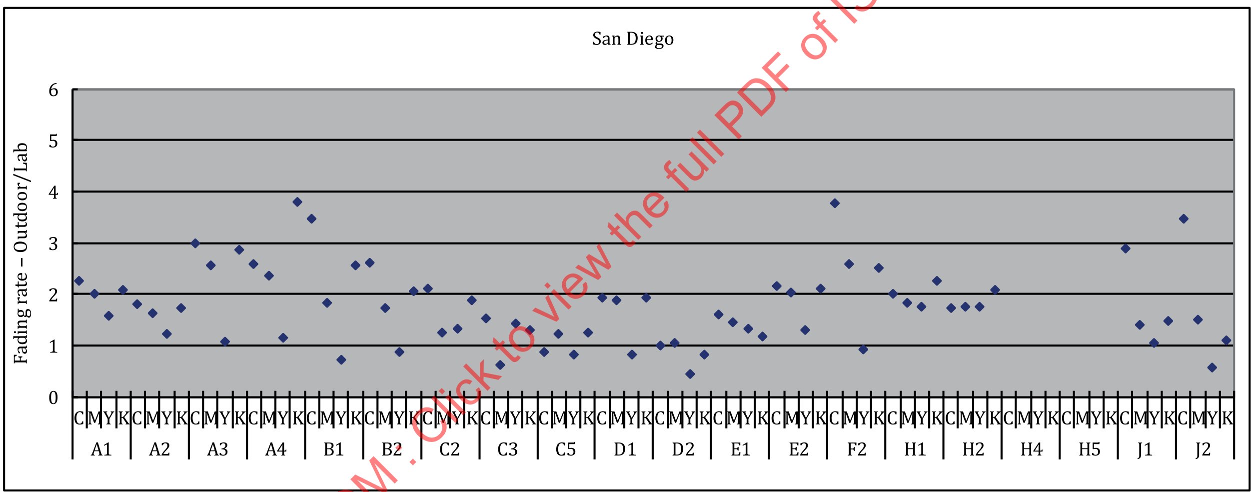



**Figure G.28 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in San Diego**

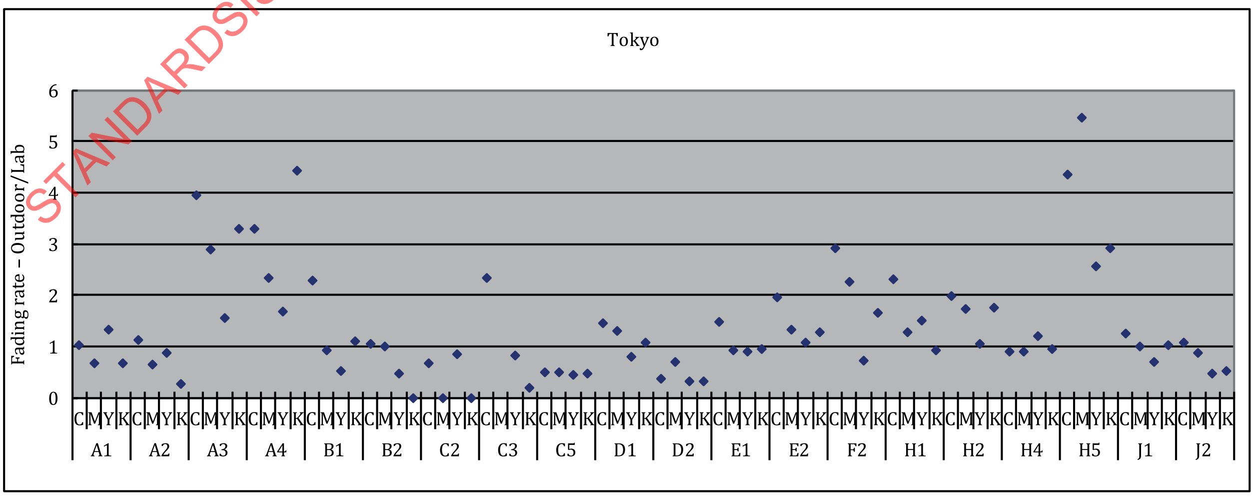



**Figure G.29 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Tokyo**

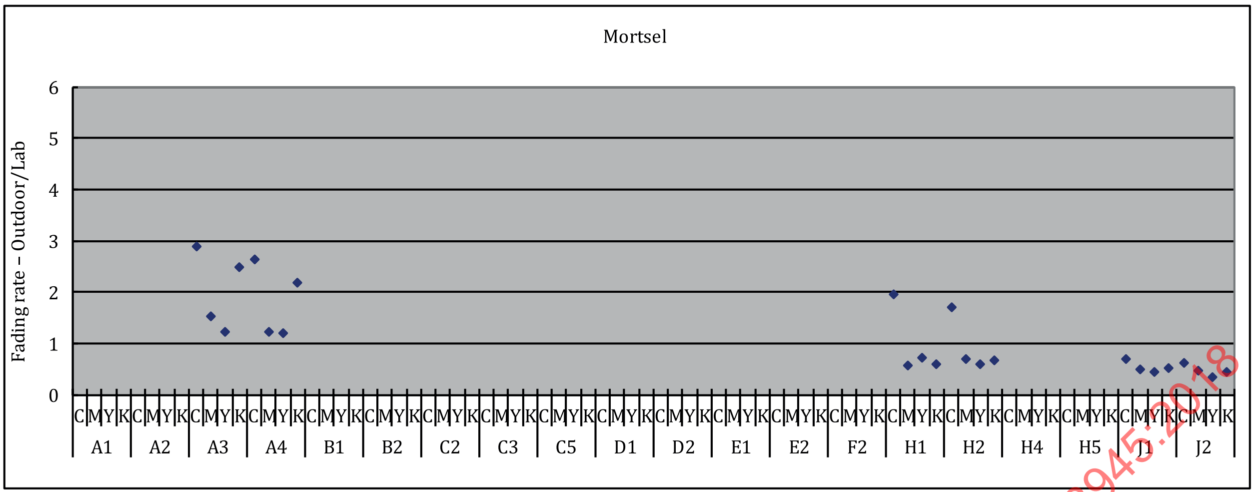



**Figure G.30 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Mortsel**

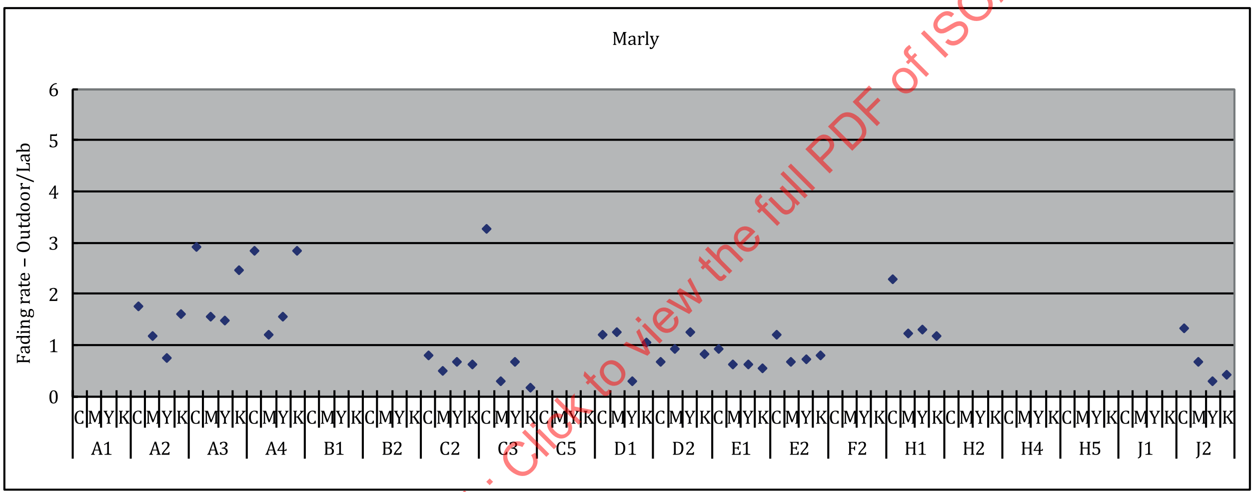



**Figure G.31 — Fading rate ratios (outdoor/ISO 18930 in laboratory) for each material in Marly**

## G.4 Colour shift graphs

Data has been plotted for the process black (CMY) patch with a 1,0 density. The vertical axis is the difference in colour density ratio between two of the primary densities (cyan and magenta, cyan and yellow, or magenta and yellow), and the horizontal axis is the exposure time in the accelerated or outdoor tests. The accelerated tests are in the left column, and the outdoor exposures are in the right column.

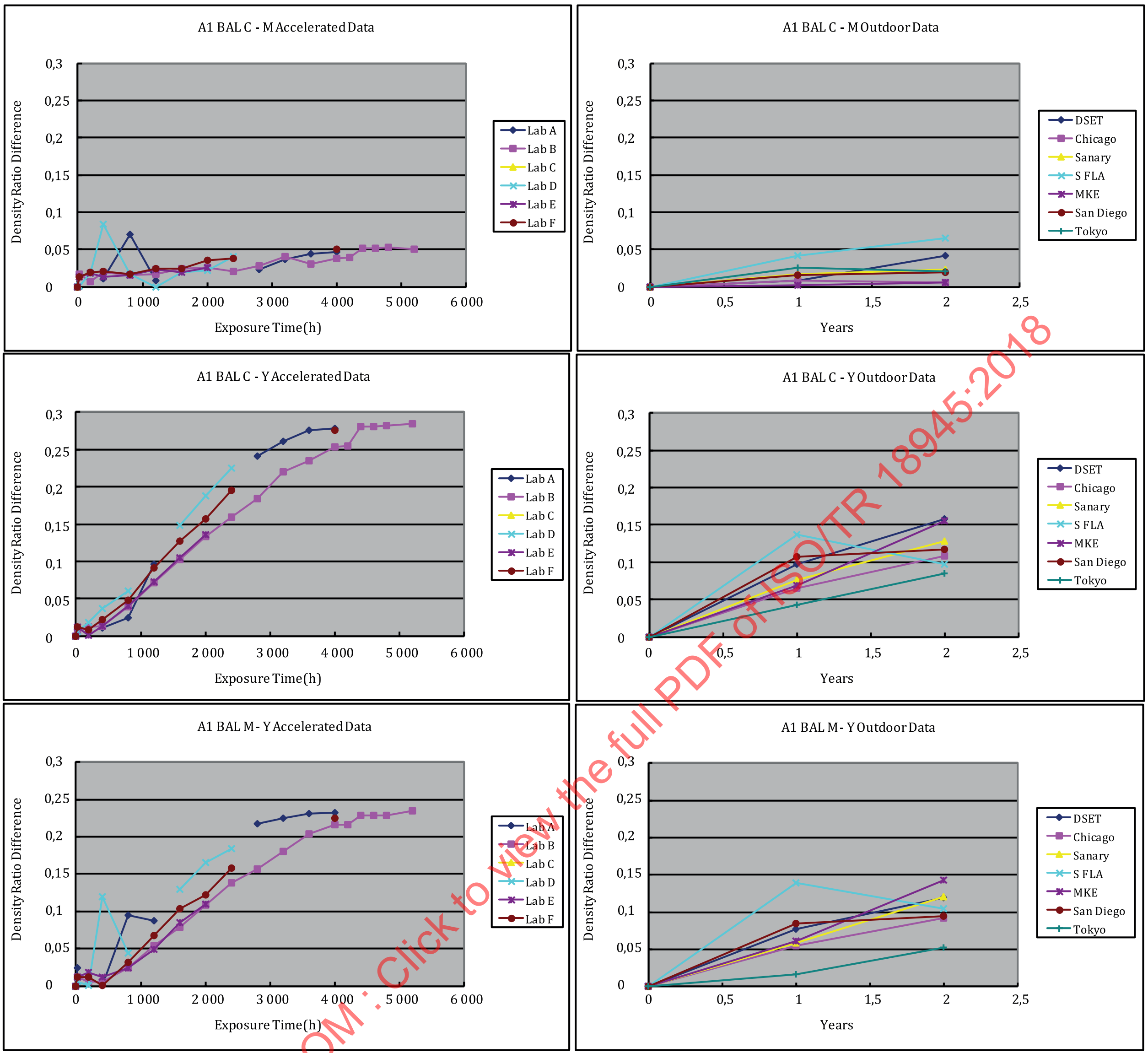



**Figure G.32 — Colour shifts of material A1 in accelerated test (left) and outdoor exposure (right)**

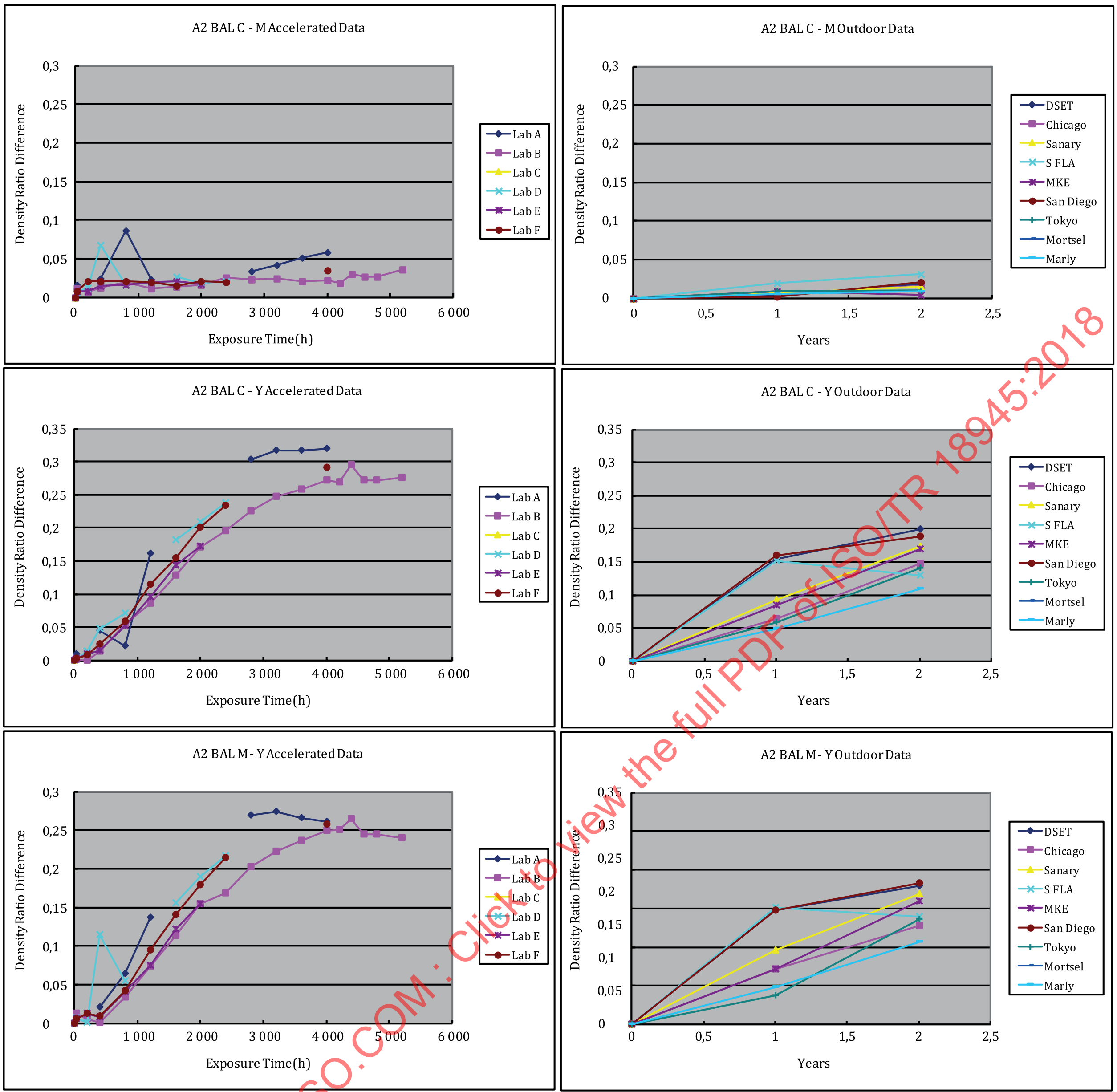



**Figure G.33 — Colour shifts of material A2 in accelerated test (left) and outdoor exposure (right)**

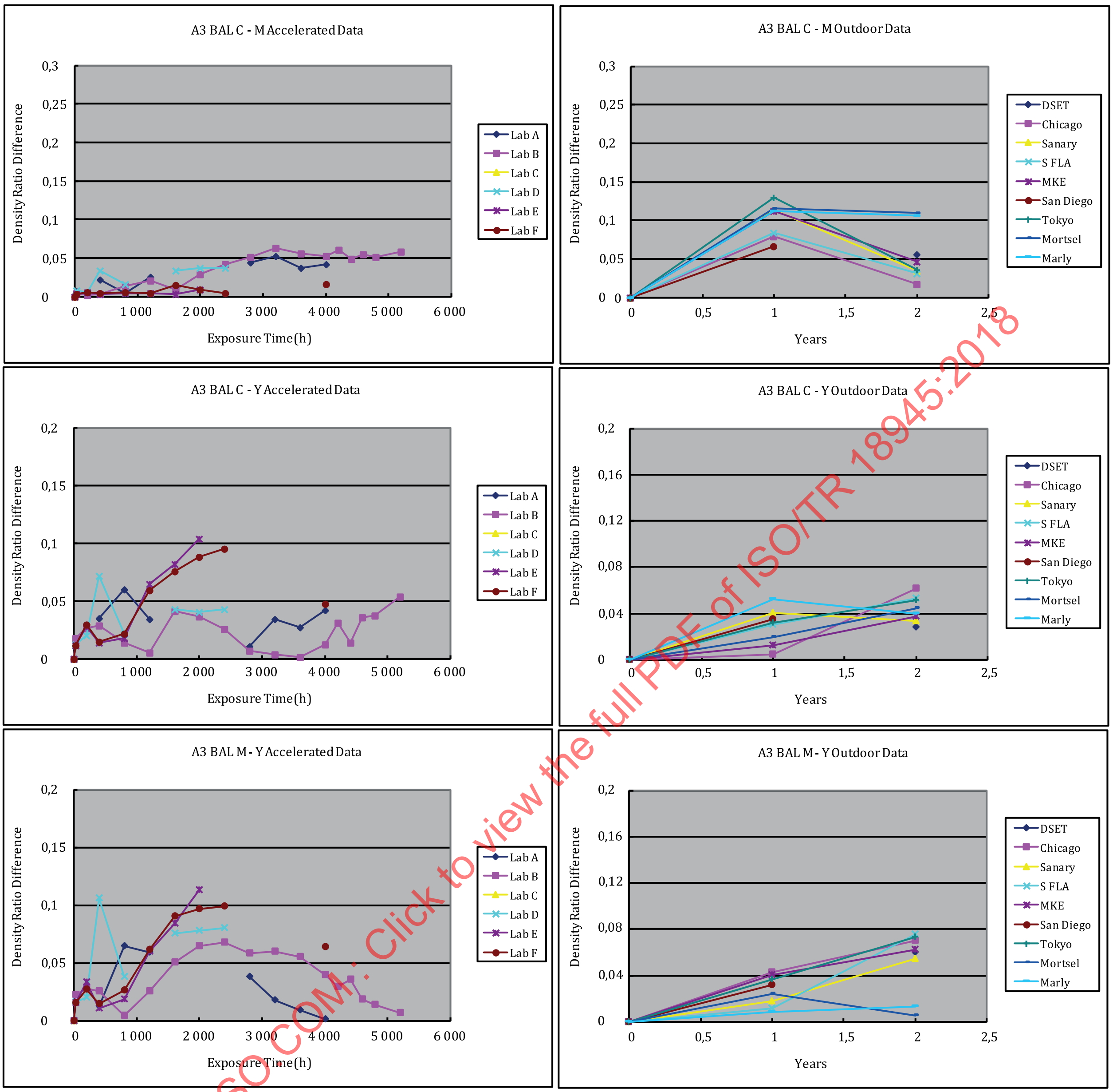



Figure G.34 — Colour shifts of material A3 in accelerated test (left) and outdoor exposure (right)

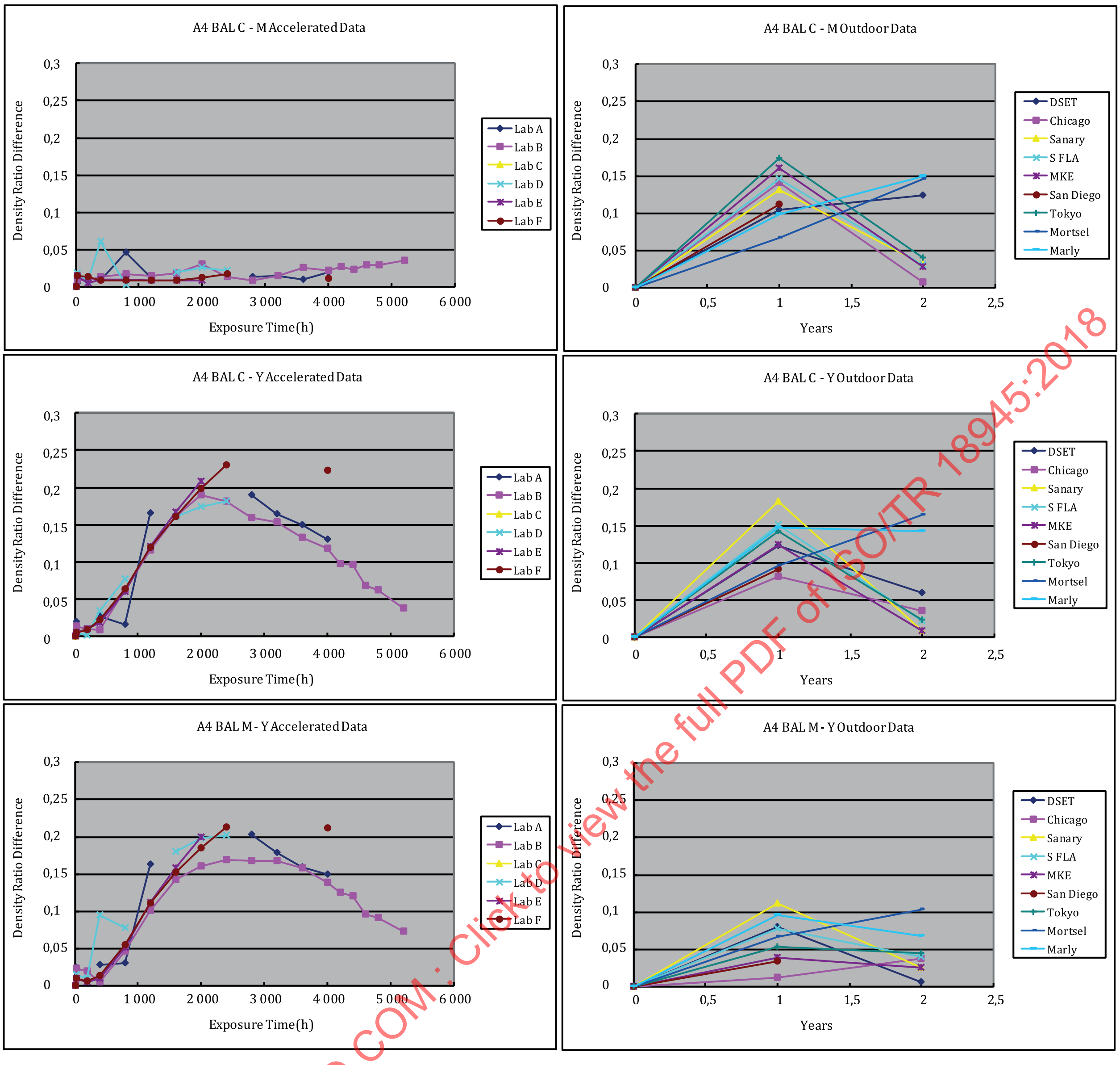



**Figure G.35 — Colour shifts of material A4 in accelerated test (left) and outdoor exposure (right)**

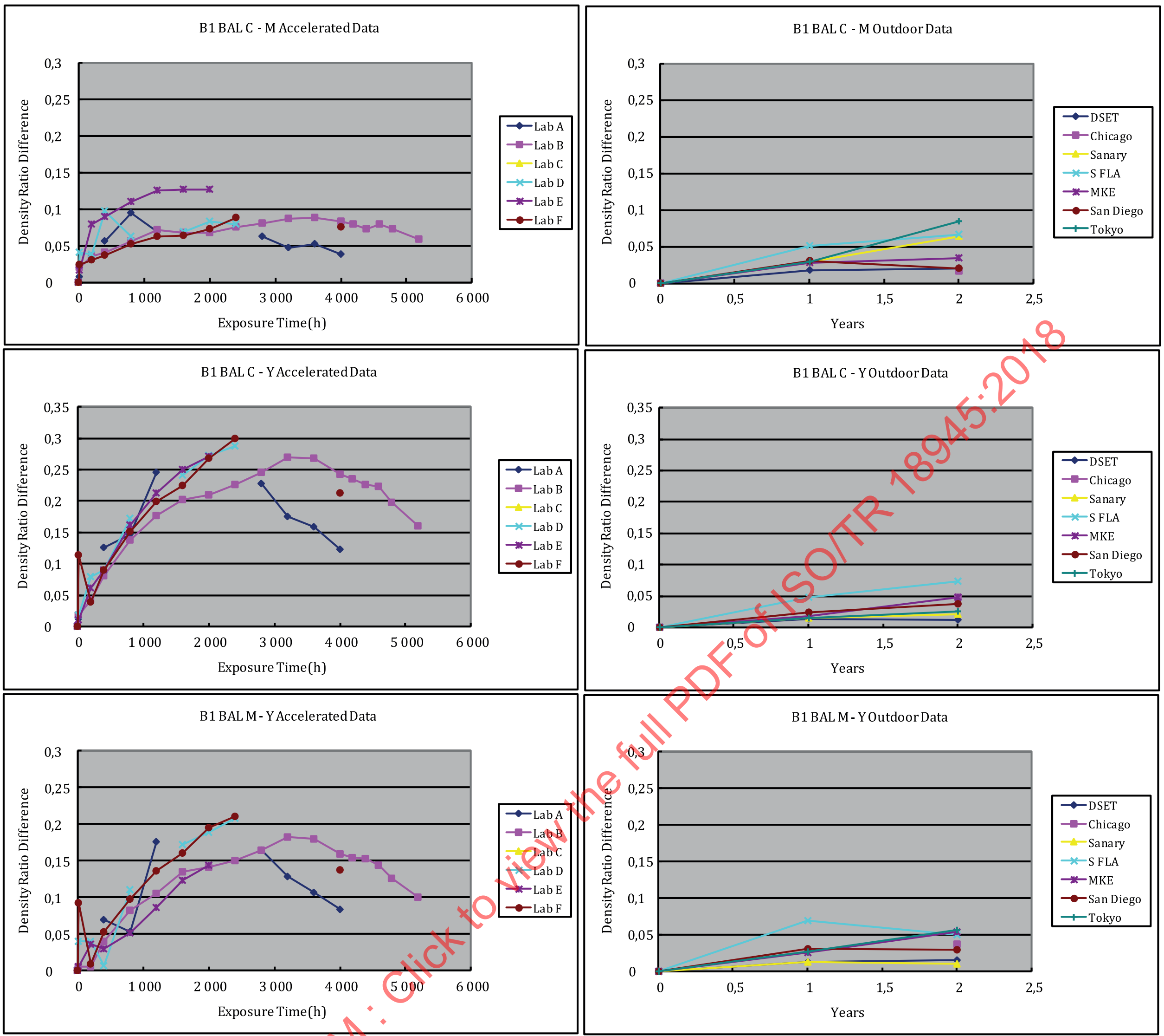



**Figure G.36 — Colour shifts of material B1 in accelerated test (left) and outdoor exposure (right)**

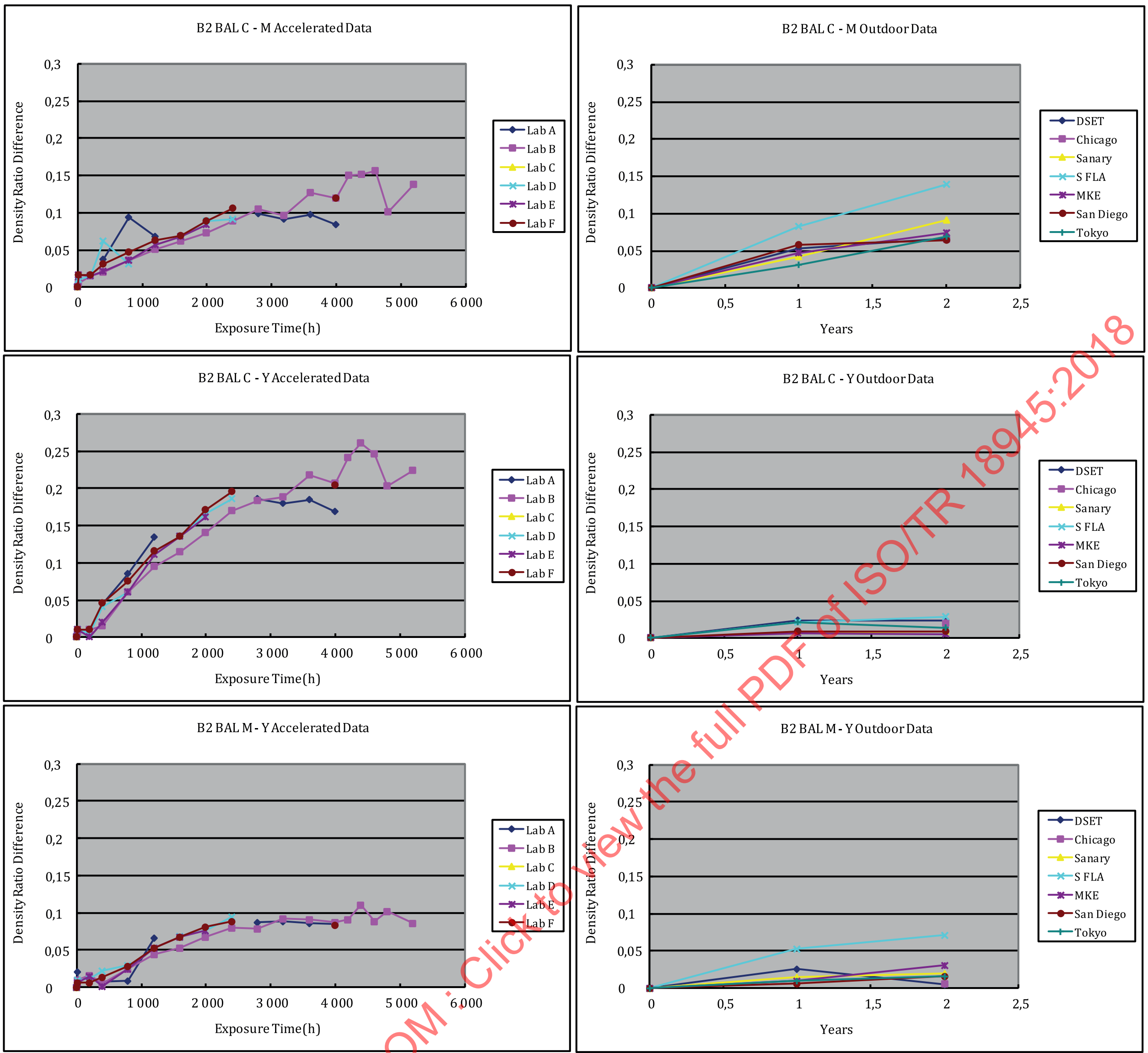



**Figure G.37 — Colour shifts of material B2 in accelerated test (left) and outdoor exposure (right)**

