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BSI Standards Publication

Plastics — Parameters comparing the spectral irradiance of a laboratory light source for weathering applications to a reference solar spectral irradiance

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TECHNICAL REPORT

ISO/TR 18486

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Plastics — Parameters comparing the spectral irradiance of a laboratory light source for weathering applications to a reference solar spectral irradiance

Plastiques — Paramètres de comparaison de la distribution spectrale d'une source de lumière de laboratoire pour les applications de vieillissement et d'une distribution spectrale solaire de référence

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ISO/TR 18486:2016(E)

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Foreword

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The committee responsible for this document is ISO/TC 61, *Plastics*, Subcommittee SC 6, *Ageing, chemical and environmental resistance*.

Introduction

Laboratory radiation sources generate radiation which is intended to simulate a defined „reference sun“ as perfect as possible, where the fitting to the spectral irradiance in the materials sensitive range is most important. So far, the fitting is described verbally only, e.g. standards concerning artificial weathering, and the user has to decide for himself if the spectral irradiance $E(\lambda)$ indicated by the producer of the laboratory radiation source agrees suitable enough with the „reference sun“ for his specific application or, occasionally, the classification describes the fitting to a wanted „reference sun“ only insufficiently (e.g. for standard weathering tests).

This Technical Report deals with a procedure for the determination of objective factors characterizing the grade of fitting in quantity.

One procedure describes the grade of fitting of a laboratory radiation source to the defined reference sun for specific spectral ranges. A second procedure results in characterizing parameters for the respective wavelength ranges, incorporating known action spectra.

Plastics — Parameters comparing the spectral irradiance of a laboratory light source for weathering applications to a reference solar spectral irradiance

1 Scope

This Technical Report specifies a calculation method which allows calculating a parameter which compares the spectral irradiance of a laboratory radiation source for weathering application to a reference solar spectral irradiance.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
spectral irradiance
E_λ
radiant flux per unit area per wavelength interval

Note 1 to entry: It is measured in watts per square metre per nanometre ($W \cdot m^{-2} \cdot nm^{-1}$).

2.2
action spectrum
description of the spectral efficiency of radiation to produce a particular polymer response (specific property change of a specific polymer) plotted as a function of the wavelength of the radiation

Note 1 to entry: Data of an action spectrum are specific to the polymer but independent from the radiation source, also named spectral sensitivity.

3 Symbols and abbreviated terms

$E(\lambda)_{ref.}$ spectral irradiance of reference sun ($W \cdot m^{-2} \cdot nm^{-1}$)

$E(\lambda)_{source}$ spectral irradiance of laboratory radiation source ($W \cdot m^{-2} \cdot nm^{-1}$)

$E(\lambda)_{scaled}$ scaled spectral irradiance of laboratory radiation source ($W \cdot m^{-2} \cdot nm^{-1}$)

$s(\lambda)$ action spectrum

4 Significance

Not for all applications of simulated solar radiation (laboratory radiation source) the total sun spectrum is needed. For economic reasons, therefore, it is advisable to simulate only that spectral range being of importance for the respective process or in cases of application where the object's heating has to be observed in close limits, e.g. with biological objects. In this case, both VIS and IR radiation have to be eliminated to a great extent (see Table 1).

Table 1 — Compilation of laboratory radiation sources for different spectral ranges and examples for their applications

Solar simulators for	Examples for application
UV (A+B)	photochemistry, photo dermatology
UV-A	photo dermatology, testing of polymeric material
UV + VIS	testing of polymeric materials
UV + VIS + IR	testing of technical materials or components including thermal stress
VIS + IR	thermal stress of the object, in most cases without photochemistry

Due to the many technical types of laboratory radiation sources, no general characteristics for comparing the spectral irradiance to the reference solar radiation can be given. It is only possible to indicate the comparison for a given wavelength range or for a certain application whose action spectrum is known.

5 Requirements

Historically, CIE 85:1989, Table 4[9] has been used as the benchmark reference spectrum distribution for weathering applications. However, CIE 85[9], which was published in 1989, has several disadvantages: global solar spectral energy distribution starts at 305 nm, the increments are rather rough and the calculation code is no longer available. Therefore, reference spectral irradiance should be used which are calculated with the SMARTS2 model[10] (e.g. ISO/TR 17801, ASTM G177).

For the calculations, a spectral resolution of 1 nm is required.

NOTE CIE is currently revising CIE 85[9] to provide a reference spectrum in the necessary 1 nm resolution.

The spectral irradiance of the solar simulator $E(\lambda)_{source}$ or the scaled laboratory radiation source spectrum $E(\lambda)_{scaled}$ is required with a spectral resolution of 1 nm.

6 Calculation methods

6.1 Characterizing parameter for a wavelength range

6.1.1 Choice of the wavelength range

A wavelength range of $\lambda_1 \leq \lambda \leq \lambda_2$ for the characterizing fitting should be selected. The wavelength range should be larger than 10 nm.

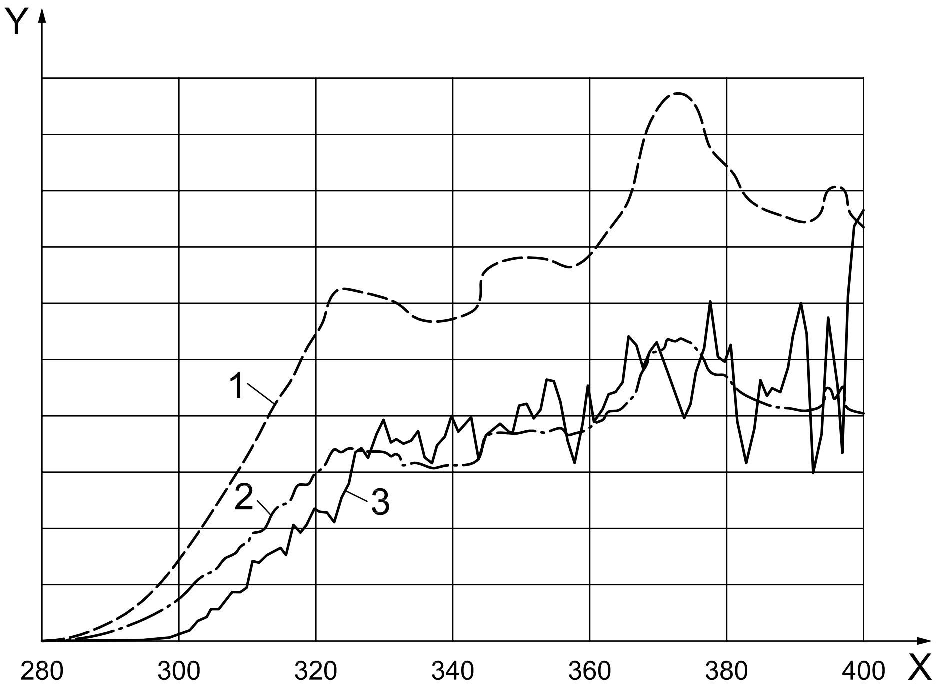
NOTE Table 1 shows examples of relevant wavelength ranges.

6.1.2 Scaling condition

The spectral irradiance of the laboratory radiation source $E(\lambda)_{source}$ is scaled according to the reference sun distribution $E(\lambda)_{ref.}$, in the chosen wavelength range (for example, see Figure 1).

Swap equation terms.

$$\int_{\lambda_1}^{\lambda_2} E\left(\lambda\right)_{ref.} d\lambda = \int_{\lambda_1}^{\lambda_2} E\left(\lambda\right)_{scaled} d\lambda \qquad (1)$$



Key

1 reference sun $E(\lambda)_{ref.}$

2 laboratory radiation source $E(\lambda)_{source}$

3 scaled laboratory radiation source $E(\lambda)_{scaled}$ according to 6.1.2

X wavelength in nm

Y spectral irradiance (au)

Figure 1 — Example for scaling according to 6.1.2

6.1.3 Characterizing parameter $f_{\lambda 1\text{-}\lambda 2}$ for a wavelength range

The characterizing parameter $f_{\lambda 1\text{-}\lambda 2}$ for the wavelength range $\lambda_1 \leq \lambda \leq \lambda_2$ is calculated by Formula (2):

$$f_{\lambda_1-\lambda_2} = \frac{\int_{\lambda_1}^{\lambda_2} \left| E(\lambda)_{scaled} - E(\lambda)_{ref.} \right| \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} E(\lambda)_{ref.} \, d\lambda} \times 100 \qquad (2)$$

NOTE For an ideal fitting of $E(\lambda)$ to a reference sun, the parameter f reads $f = 0$. The higher the number, the worse is the fitting.

6.2 Characterizing parameter for a known action spectrum

6.2.1 Choice of the wavelength range with action spectrum

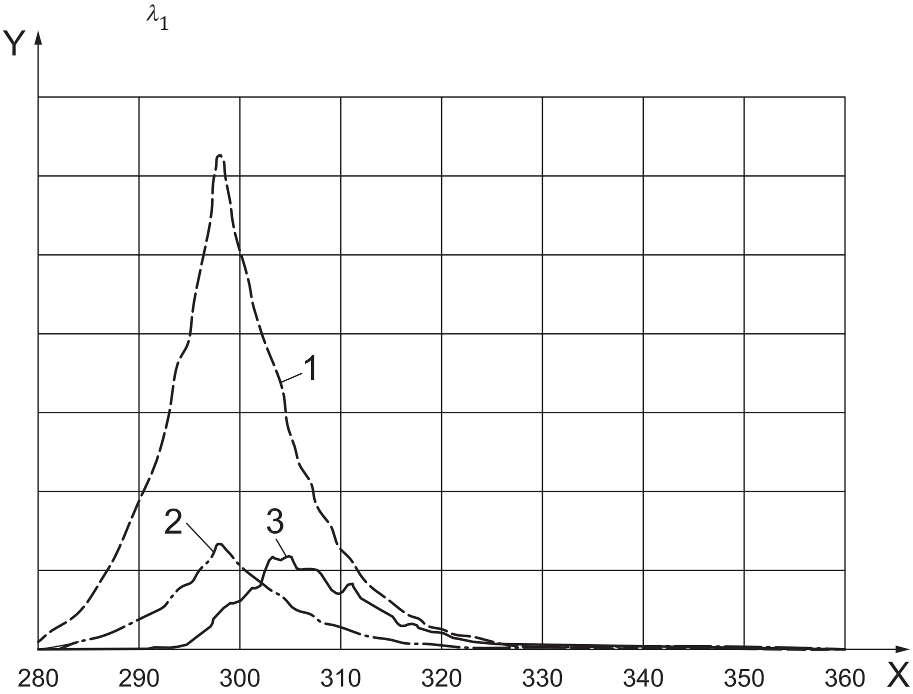
A wavelength range of $\lambda_1 \leq \lambda \leq \lambda_2$ for the characterizing fitting should be selected.

For the selected wavelength range, the action spectrum should be known in the spectral resolution of 1 nm.

6.2.2 Scaling condition with action spectrum

In case the action spectrum $s(\lambda)$ for the photochemical process to be tested is known, the scaling conditions is (for example, see Figure 2) as given in Formula (3):

$$\int_{\lambda_1}^{\lambda_2} E(\lambda)_{ref.}\, s(\lambda)\cdot d\lambda = \int_{\lambda_1}^{\lambda_2} E(\lambda)_{scaled}\, s(\lambda)\cdot d\lambda \qquad (3)$$



Key

1 reference sun $E(\lambda)_{ref.}$ multiplied by $s(\lambda)$

2 laboratory radiation source $E(\lambda)_{source}$ multiplied by $s(\lambda)$

3 scaled laboratory radiation source $E(\lambda)_{scaled}$ multiplied by $s(\lambda)$ according to 6.2.2

X wavelength in nm

Y spectral photochemical irradiance (au)

Figure 2 — Example for scaling according to 6.2.2

6.2.3 Characterizing parameter $f_{s(\lambda)1\text{-}s(\lambda)2}$ with action spectrum

A characterizing parameter $f_{s(\lambda)1\text{-}s(\lambda)2}$ for the significant wavelength range $\lambda_1 \le \lambda \le \lambda_2$ for a photochemical process characterized by an action spectrum $s(\lambda)$is calculated by Formula (4):

$$f_{s(\lambda)1-s(\lambda)2} = \frac{\int_{\lambda_1}^{\lambda_2} \left| E(\lambda)_{scaled} - E(\lambda)_{ref.} \right| \cdot s\lambda \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} E(\lambda)_{ref.}\, s(\lambda)\cdot d\lambda} \times 100 \qquad (4)$$

NOTE For an ideal fitting of $E(\lambda)$ to a reference sun, the parameter f reads $f = 0$. The higher the number, the worse is the fitting.

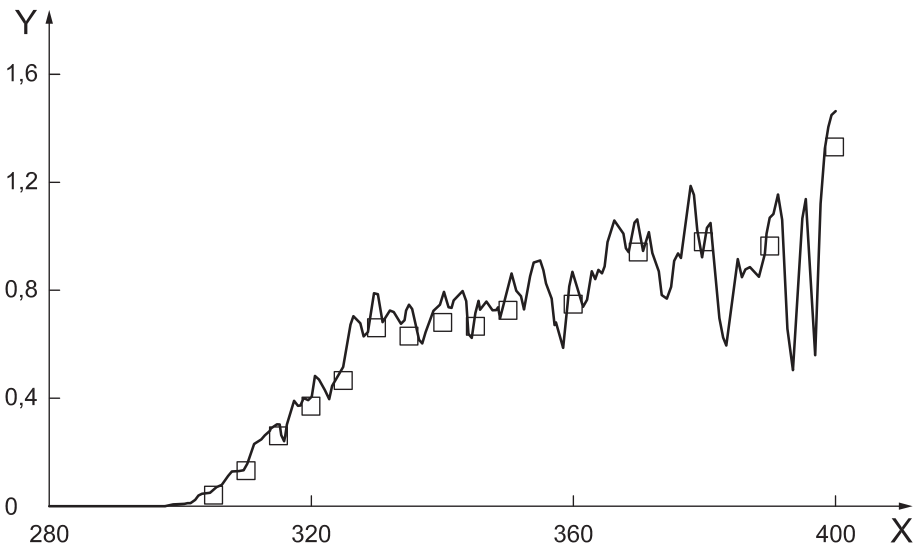
If the parameter $f_{s(\lambda)}$ for a photochemical process is characterized by an action spectrum $s(\lambda)$, it makes sense to integrate over the entire active wavelength range. In this case, the parameter should be named f_S.

Annex A
(informative)

Examples for parameters of some commercially available solar simulators

Laboratory testing of materials with the simultaneous and cyclic stress factors of natural solar radiation, sample temperature and rain/humidity (weathering) is usually carried out in accordance with standard test methods. The applied standards (e.g. ISO 4892-1, ISO 4892-2, ISO 4892-3 and ISO 4892-4) contain a “reference spectrum” for natural solar radiation. The CIE 85:1989, Table 4[9] has been used for this for more than 20 years.

A recalculation of this reference spectrum with SMART2[10] was suggested in 2008.[11] Another spectrum of a reference sun for weathering calculated with SMART2[9] is available in the ASTM G177. The recalculation of CIE 85, Table 4 as Reference [11] is used as an example for laboratory weathering material testing (see Figure A.1). Examples of calculated parameters according to the methods described in 6.1.2 and 6.1.3 are shown in Table A.1. The lower the characteristic factor, the better the fitting to the reference sun is. The best fitting for the entire UV wavelength range is obtained for filtered xenon radiation and in the range below 360 nm for the fluorescent lamp UV 340, whereby the quality of the fitting for xenon radiation depends on the selected filtering. This is important because the weathering test result depends on the interaction of three critical factors: irradiance (and the quality of the selected fitting for the wavelength range of interest), temperature and moisture (in the form of humidity, condensation and/or water spray) The variation range of the characteristic factor for filtered xenon radiation specified in Table A.1 approximately corresponds to the tolerance range of the xenon spectral irradiance in common laboratory weathering standards (for example, ISO 4892-2 and ISO 16474-2) for simulated daylight.



Key

1 with SMART2 recalculated CIE No. 85, Table 4[11]

2 original data from CIE No. 85, Table 4[9]

X wavelength in nm

Y irradiance in W·m2·nm-1

Figure A.1 — Reference global solar UV spectral irradiance recalculated CIE 85, Table 4[11] and global solar spectral irradiance according CIE No. 85, Table 4[9]

Table A.1 — Calculated characteristic factors describing the grade of fitting the spectral irradiance of different laboratory radiation source to the recalculated CIE No.85, Table 4[11] reference sun

Wavelength range (nm)	Sources applied in weathering		
	Filtered xenon	Fluorescent UVA340	Carbon arc
290 to 319	8 to 40	8 to 17	58
320 to 339	9 to 20	8 to 9	15
340 to 359	7 to 11	9 to 11	36
360 to 400	15 to 18	55 to 77	43

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