

Transparency Measurement

Abstract

To guarantee consistent and uniform products, transparency measurement is a need. Depending on the application, the product has to meet different requirements in transmission, haze and clarity. The following article describes how these different effects are visually perceived. In addition, practical hints for measuring and analyzing the transparency of special applications are discussed to achieve reliable measurement results.

Table of Contents

1	Introduction.....	2
2	Visual perception	3
2.1	Test object	3
2.2	Observer	3
3	Transmission and scattering on plastics	3
3.1	Homogeneous material with smooth surface	3
3.2	Surface roughness and internal scattering	4
3.3	Appearance of scattering materials	4
3.4	Wide angle scattering (Haze)	5
3.5	Narrow angle scattering (Clarity)	5
4	Overview of Transparency Parameters.....	6
5	Total Transmittance Measurement	6
5.1	Transmittance measurement - Impact of reflectance (ISO method).....	7
6	Transmission Haze Measurement	9
7	Clarity Measurement	9
8	Transparency Measurement of Special Applications	10
8.1	Plastic raw material	10
8.2	Analysis of Taber abrasion test with haze measurement.....	10
8.3	Inner haze versus surface haze	11
8.4	Reliable measurement of very low haze samples.....	11
9	Summary – Instruments supporting visual inspection	12
10	Standards.....	12

1 Introduction

Based on the product's application, transparent materials have to fulfill different requirements (Fig. 1). The optical properties of foils and panels for glasshouses should be highly transparent and homogeneous in light distribution, while packaging foils should display the packed product as clear as possible.

Process variations can have a major influence on the quality. The appearance of the final product is depending on the selected material and the processing conditions. Several parameters can have an impact on the optical properties.

Mass temperature – additives - mass homogeneity - temperature control – compatibility - molecular structure - cooling rate - roller surface – rheology - molecular mass distribution

Objective measurement methods are needed in research and quality control to eliminate uncertainties based on visual assessments.



Fig. 1: Transparent materials have to full fill different optical requirements

2 Visual Perception

Transparency is the interaction between light and physical material properties. Visual perception of transparency is influenced by the observer's judgement. It is performed by observing a test object through the transparent specimen (Fig. 2). Thereby, especially the distance between the objects has a high impact on the visual perception.

2.1 Test object

For visual assessments a standardized test object to be viewed through the transparent film / material should have a high contrast pattern and a defined illumination is to be used. Self-illuminating objects are no good test objects either, as the human eye quickly becomes tired due to the high light intensity.

2.2 Observer

Visual assessments are influenced by the visual ability, the daily condition, and the experience of the inspector.

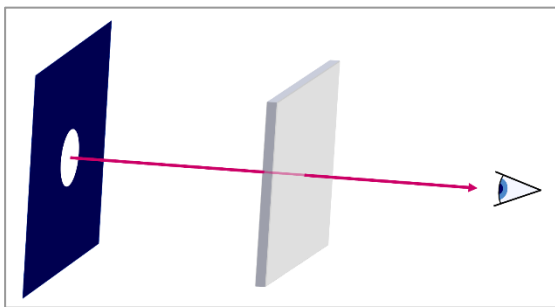


Fig. 2: Visual inspection of transparency

3 Transmission and Scattering on Plastics

Based on material characteristics different effects occur by illuminating a transparent specimen with directed light:

3.1 Homogeneous material with smooth surface

In case of „crystal clear“ material the light will be partly reflected on boundaries between the different materials and the majority of light will pass through the specimen, without any scattering (Fig. 3). The specimen appears high glossy, and “crystal clear”. The ratio of transmitted to reflected light is depending on the material's refraction index and the angle of incidence. The intensity of the transmitted light is decreased by absorption properties of the material and such as dyes or pigments.

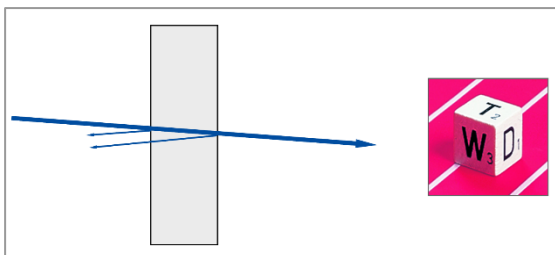


Fig. 3: Transmission and reflection

3.2 Surface roughness and internal scattering

Diffuse scattering is leading to a reduced distinctness of image. Small particles within the material such as air enclosures, poorly dispersed pigments, dust enclosures or crystallization or surface structures are causing scattering (Fig 4).

The amount of scattered light will increase with the number of scatterers in the material or at the surface, whereby the spatial distribution is related on particle size. Smaller sized scatterers will result in a more homogeneous distribution of scattered light, while with increasing size more and more light will be scattered forward within a narrow cone. (Fig. 5).

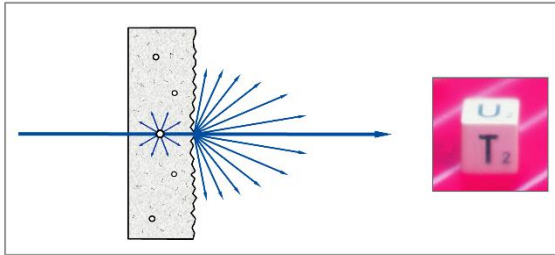


Fig. 4: Diffuse scattering on inner disruptions or surface structures

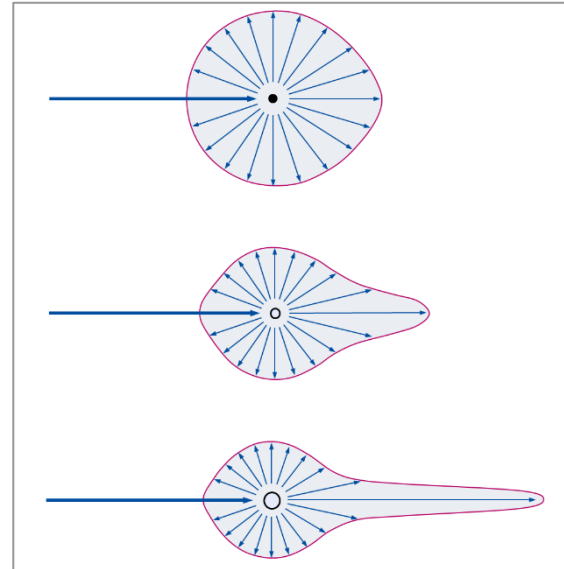


Fig. 5: Spatial distribution of scattered light in relation to particle size

3.3 Appearance of scattering materials

The appearance of the specimen is directly related to its scattering behavior. Depending on the angular distribution of the scattered light, objects viewed through a transparent plastic will appear differently. If light is diffused in all directions with a low intensity it is referred to as wide angle scattering. If light is diffused in a small angle range with high concentration it is called narrow angle scattering. (Fig. 6)

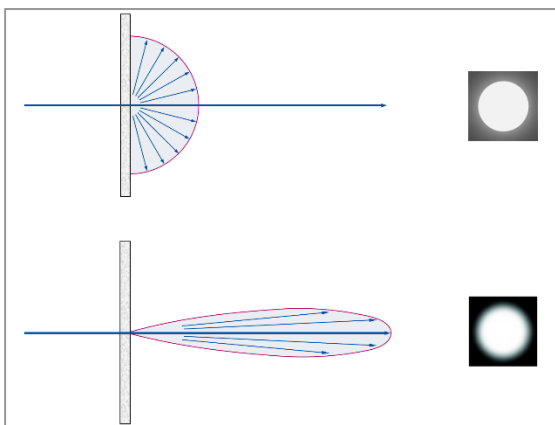


Fig 6: Wide and narrow angle scattering

3.4 Wide angle scattering (Haze)

Wide angle scattering leads to a loss of contrast and a milky, hazy appearance. This effect is also called haze. A black letter, with sharp edges on a white background observed through a hazy specimen leads to a milky impression. That means the contrast between the white background and the black letter is reduced. (Fig. 7)



Fig. 7: Wide angle scattering (Haze) leads to less contrast

3.5 Narrow angle scattering (Clarity)

Narrow angle scattering, light deflection in a small angle range leads to a high concentration of light intensity. A black letter, with sharp edges on a white background observed through a specimen with narrow angle scattering leads to a fuzzy appearance of the letter. The sharp outlines of the letter are distorted, harder recognizable and less sharp. This effect is called clarity and describes how well fine details can be seen through the specimen. A noteworthy behavior and difference to haze is that clarity is highly influenced by the distance between object and transparent material: (Fig. 8)

This effect increases with the distance between sample and observed object.



Fig. 8: Narrow angle scattering is reducing the distinctness of image (Clarity)

4 Overview of Transparency Parameters

The appearance of transparent products can be separated into gloss, color and transparency. Transparency can be described by three effects, total transmission, haze and clarity.

Total transmission is the ratio of the transmitted to the incident light which is reduced by reflection and absorption.

Direct transmission corresponds to the part of the transmitted light passing the specimen without scattering. The remaining part is the diffuse transmittance, consisting of the light passing the specimen with scattering.

Appearance of Transparent Objects	
Total Transmittance	
Direct Transmittance	Diffuse Transmittance

Diffuse transmittance is according to ASTM D 1003 the percentage of the light deviating by more than 2.5° of the incident light beam. Clarity on the other hand is defined for angles less than 2.5°. [1]

Diffuse Transmittance	
Wide Angle Scattering	Narrow Angle Scattering
Haze	Clarity

5 Total Transmittance Measurement

Figure 9 describes the measurement principle for total transmittance. A light source with a nearly parallel light beam is pointing in perpendicular to a specimen placed flush against the entrance port of an integrating sphere. The light strikes the specimen, is partially reflected, absorbed and the remaining part is transmitted in the integrating sphere (I_{TT}). The sphere's interior is coated uniformly with a matte white material to allow diffusion. For measurement of total transmittance, the white cover on the light trap is closed. A detector in the sphere measures total transmittance.

The combination of illumination and detector has to meet the requirements of the 1931 CIE Standard Colorimetric Observer with CIE Standard Illuminant for daylight (CIE-C or -D65). For special applications like automotive glasses Illuminant CIE-A can be required. [1,2, 3, 4]

Total transmittance is calculated in relation to the intensity of the incident light.

$$T = 100 \% \cdot I_{TT} / I_L$$

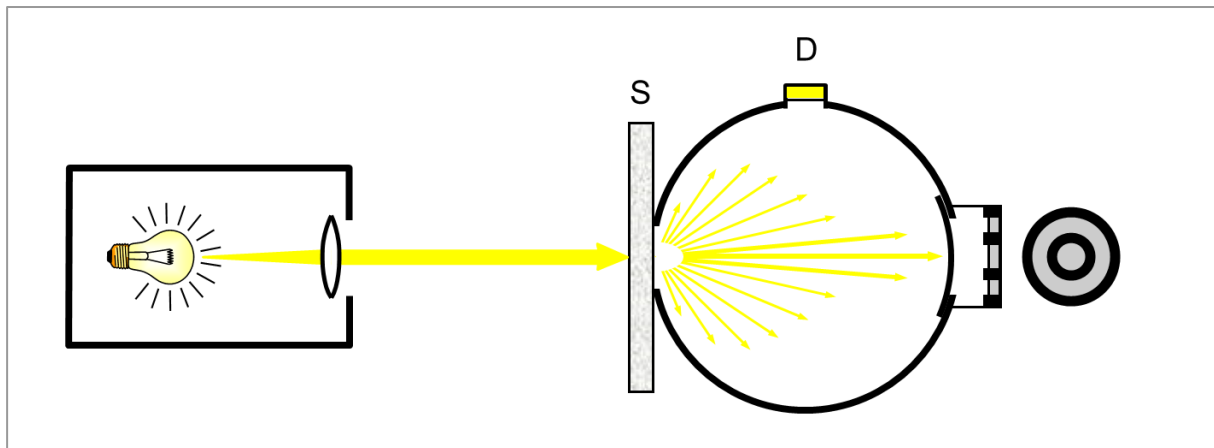


Fig. 9: Total transmission measurement
S: Specimen; D: Detector

5.1 Transmittance measurement - Impact of reflectance (ISO method)

Total transmittance is related to the intensity of the incident light. The intensity of the incident light is determined during 100% calibration. During this calibration step no specimen is placed in front of the integrating sphere and a measurement is done (Fig. 10). The light is scattered in the sphere and a small portion escapes through the entrance port. Whereby during the measurement of the specimen, light what would have escaped during the 100% calibration is partially reflected back into the sphere and increases the intensity on the detector. In other words, the sphere efficiency is increased compared to the calibration as the specimen is in front of the entrance port. This effect can lead to approximately 2% higher total transmittance readings for clear and high gloss samples. [1]

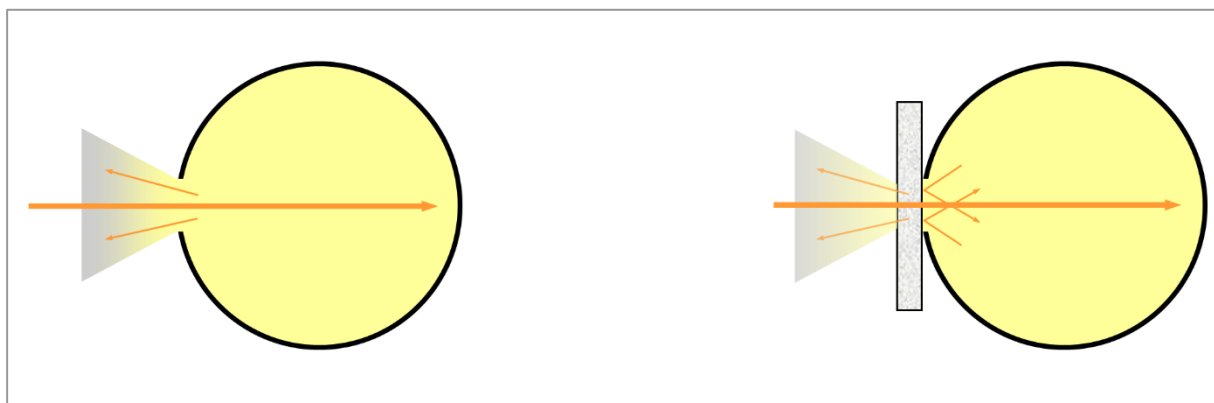


Fig. 10: Uncompensated transmittance measurement
left: Calibration; right: Sample measurement

Therefore, a modified measurement principle is described in the standard ISO 13468. This standard has two parts, each of them is describing a method how to prevent too high readings of total transmittance due to an increased sphere efficiency. [3, 4]

In part 1 the so-called single beam principle is described (Fig. 11). The sphere has an additional opening (compensation port) in perpendicular to the entrance port. During the 100% calibration the specimen is placed on the compensation port. Light is escaping through the entrance port and is partly reflecting at the specimen at the compensation port. During the sample measurement, the same amount of light is escaping through the compensation port and is partly reflecting at the specimen, now placed on the entrance port. The same

sphere efficiency is ensured for calibration and sample measurement. This principle was used previously by the BYK-Gardner haze-gard *dual*. For each determined transmittance value two measurements had to be done. [3]

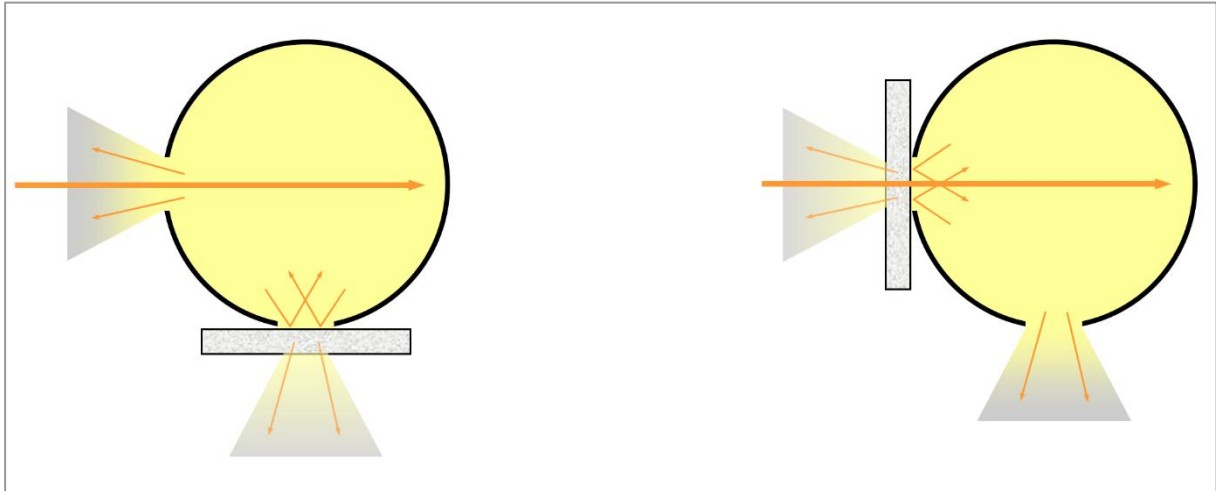


Fig. 11: Compensated transmittance measurement (ISO 13468 1)
left: Calibration; right: Sample measurement

In part 2 of the ISO 13468 a more efficient method is described where the user has to perform only one measurement. This method is called dual beam method and is used by the BYK-Gardner haze-gard *i* (Fig. 12). A second illumination is placed within the sphere. During the 100% calibration an additional measurement is made to detect the actual sphere efficiency. While determining the transmittance of the sample, also a measurement with the second beam is done automatically to detect the change of the sphere efficiency. With this information the transmittance reading can be corrected. [4]

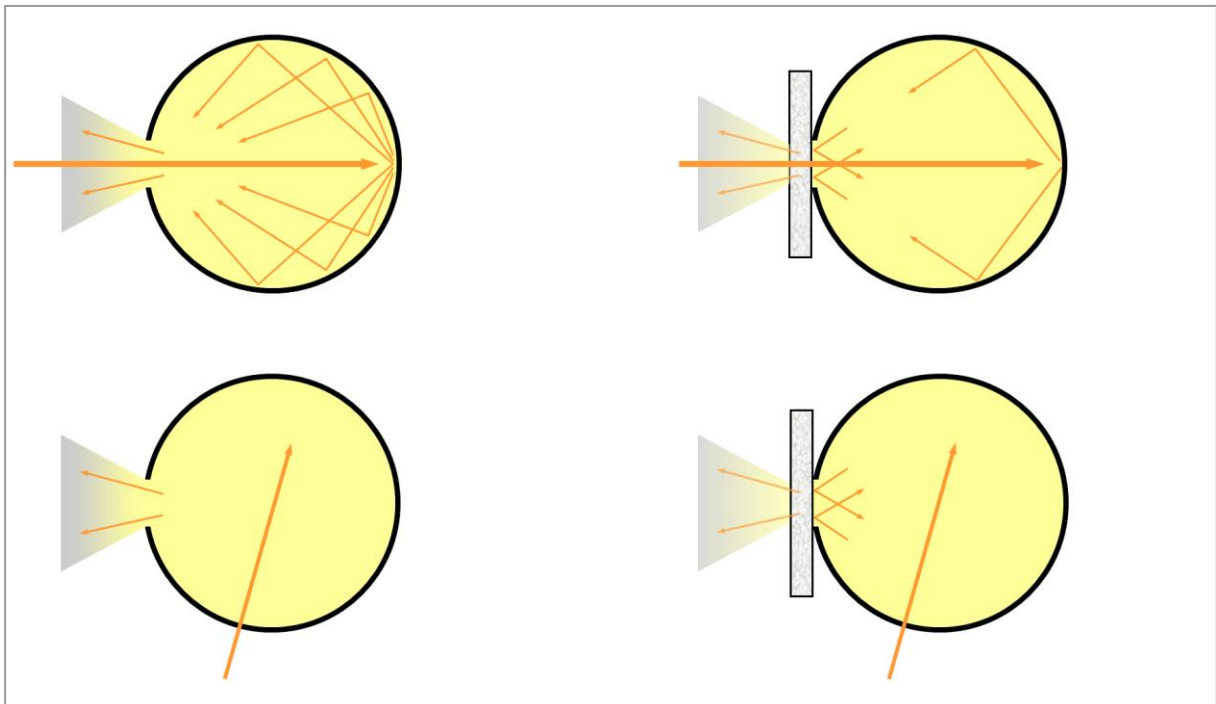


Fig. 12: Compensated transmittance measurement (ISO 13468 2)
left: Calibration; right: Sample measurement

6 Transmission Haze Measurement

To measure haze, the matt white shutter in front of the exit port is opened. The direct transmitted light is eliminated by the light trap. Only the light that in passing through deviates from the incident beam greater than 2.5° on the average is detected. (Fig. 13) [1, 2]

$$\text{Haze} = 100 \% \cdot I_{\text{Diff}} / I_{\text{TT}}$$

The usage of this method is recommended for:

- Haze values < 30% according to standard ASTM D 1003 [1]
- Haze values < 40% according to standard ISO 14782 [2]

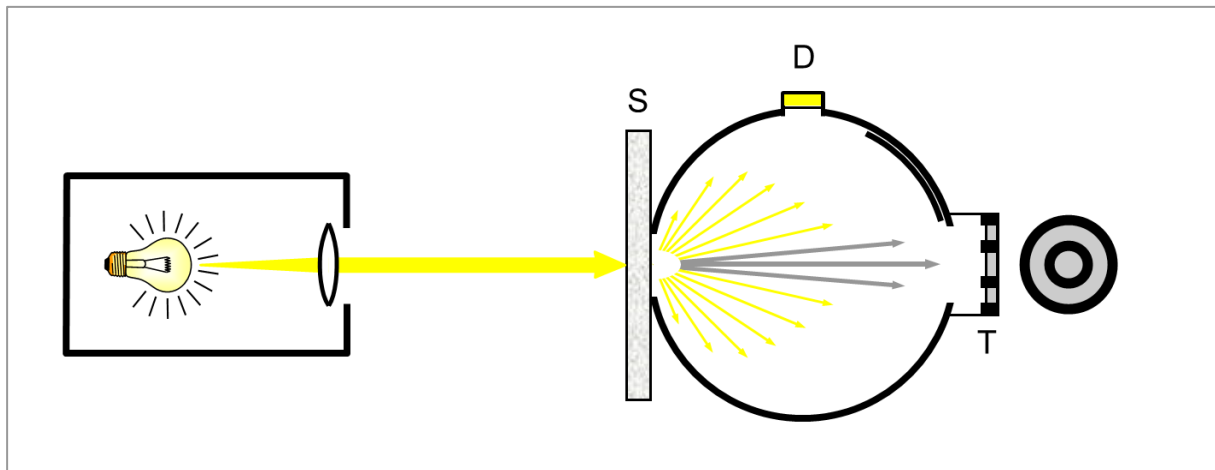


Fig. 13: Haze measurement
S: Specimen; D: Detector; T: Light trap

7 Clarity Measurement

In order to evaluate narrow angle scattering the specimen is placed in front of the illumination unit. A ring- and center sensor are located on the sphere side within the light trap area and are used to measure narrow angle scattering behavior also referred to as Clarity. (Fig. 14).

$$C = 100 \% (I_C - I_R) / (I_C + I_R)$$

A perfectly clear sample has no narrow angle scattering i.e. the light intensity on the ring sensor $I_R = 0$ and the Clarity value $C = 100$. Whereby a high narrow angle scattering leads to less contrast between the two sensors resulting in a decreased clarity value.

The relation between the amount of unscattered light ($I_C - I_R$) and transmitted light ($I_C + I_R$) is expressed in percentage:

- 100 % is good (no narrow angle scattering)
- 0% is bad (The amount of scattered light equals amount of unscattered light).

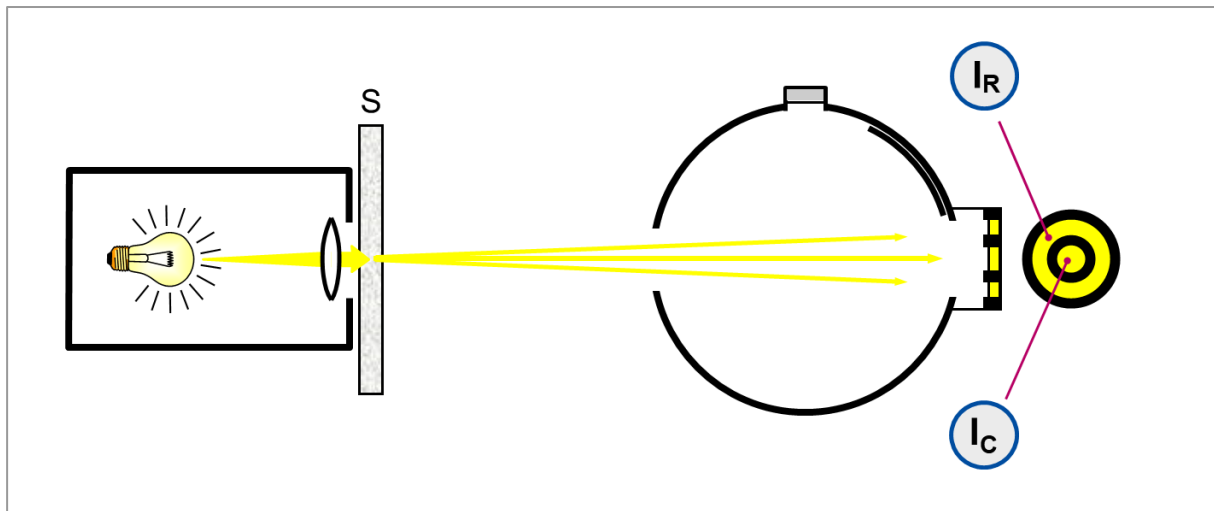


Fig. 14: Clarity measurement
S: Specimen; I_R : Ring sensor; I_C : Center sensor

8 Transparency Measurement of Special Applications

8.1 Plastic raw material

Plastic raw material comes in the form of granules or pellets. In this condition, irregular in shape and size, no decision can be made whether the material will meet all transparency requirements. Therefore, the pellets have to be processed in a standardized procedure. Often molded plaques are used, but also films made with a laboratory extruder are possible. Therefore, it is important to standardize on the sample preparation method such as size, thickness etc. which needs to be documented in the measurement protocol (Fig.15). Sample holders as provided by the haze-gard i are highly recommended to achieve repeatable and reliable measurements.

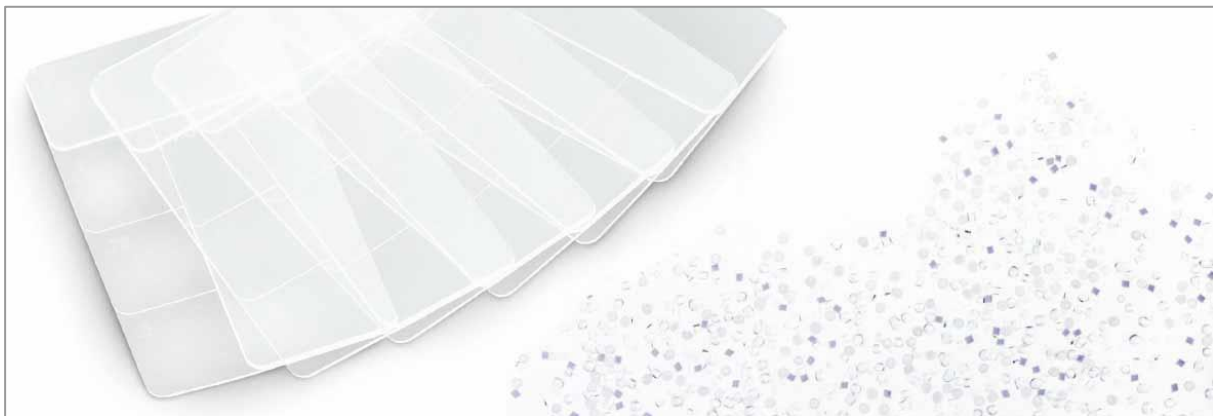


Fig. 15: Standardized molded plaques

8.2 Analysis of Taber abrasion test with haze measurement

Scratches or similar damage to the surface has a large impact on the appearance and transparency of plastics. High resistance against mechanical stress is needed for several applications. A widely used procedure to qualify scratch resistance is the Taber abrasion test according to ASTM D 1044. The specimen is stressed by abrading wheels which are creating a circular track of scratches (Fig. 16). Haze is measured as degree of resistance in relation to the load and rotations (Fig. 17). Depending on the target application abrading wheels with different grain are used. [5]

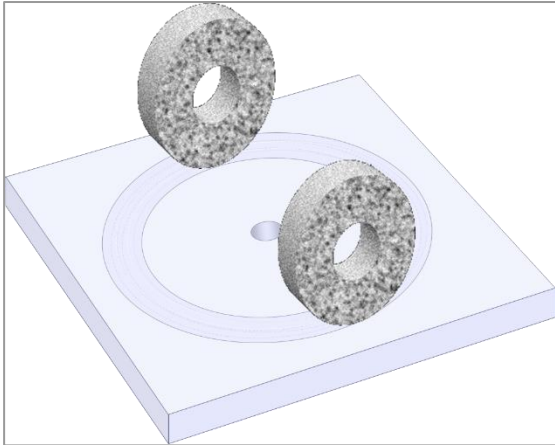


Fig. 16: Taber abrasion; Specimen with abrading wheels

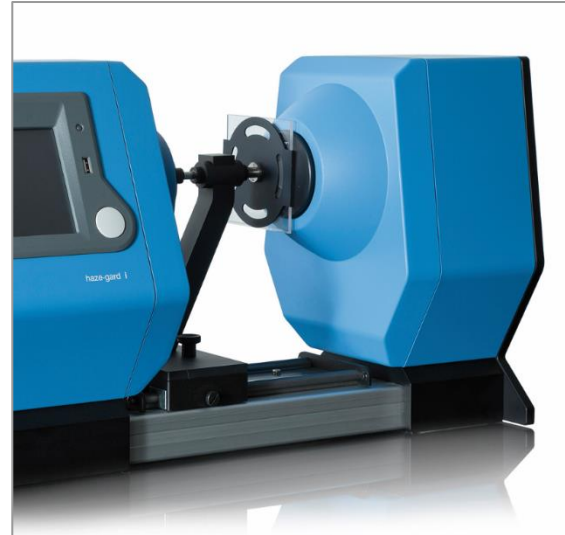


Fig. 17: Taber abrasion sample holder

8.3 Inner haze versus surface haze

For multiple layers or special applications, it can be important to differentiate between inner- and surface haze. Inner haze is caused by internal scatterings, such as voids or pigment agglomerations. Surface haze is caused by structures of the surface, related to melt index or cooling rate. To be able to differ these two effects, following procedure can be used. A cuvette with a liquid having a similar refractive index as the specimen is needed. Now following steps can be performed:

- Measure the specimen to get its “total” haze value
- Place the cuvette with the liquid in front of the entrance port of the sphere and perform a calibration (Fig. 18)
- Insert the specimen into the liquid and take a measurement to get its inner haze value

By having the “total” haze and inner haze value the surface haze can be easily calculated by subtracting these two values.

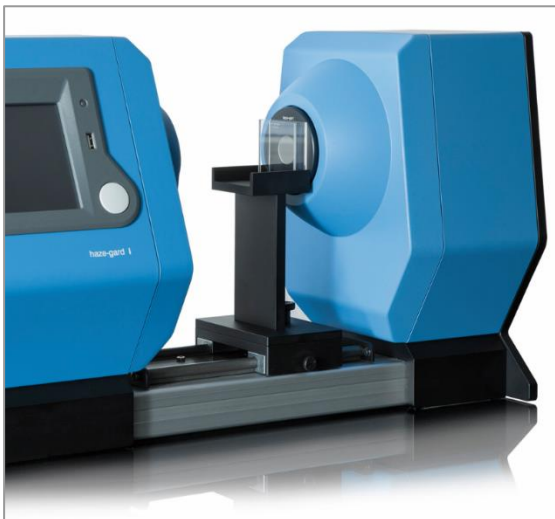


Fig. 18: Cuvette in front of the haze-port for inner haze measurement

8.4 Reliable measurement of very low haze samples

Electronic products such as smartphones are becoming more and more sophisticated. The number of sensors hidden behind the display glass is increasing. Front cameras are delivering more brilliant pictures from generation to generation. And even the display itself

has to surpasses the performance of the former model every time. Therefore, the requirements for display glass have increased with ambitious specifications for transparency: Haze < 0.3.

In order to support this special application with very tight specifications BYK-Gardner developed the haze-gard i Proto guarantee repeatable and reliable measurement data for haze < 0.3. The measurement mode has included internal averaging and additional steps during production to improve the performance for such kind of very low haze readings.

9 Summary – Instruments Supporting Visual Inspection

The human eye is the final judge in evaluating the appearance. In order to take the subjectivity out of the evaluation, objective measurement devices are needed correlating with the visual perception - especially during development of new products and process control.

The BYK-Gardner haze-gard i has a proven measurement technology with excellent visual correlation, compliance to international standards and an unprecedented user experience with easy and fast operation. (Fig.19)

The measurement of total transmittance, haze and clarity ensures a continuous and homogenous quality. In addition, influence of variation in process and material can be investigated with these measured values.



Fig. 19: Transmittance measurement

10 Standards

- [1] ASTM D 1003: "Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics"
- [2] ISO 14782: "Plastics – Determination of haze for transparent materials"
- [3] ISO 13468-1: "Plastics - Determination of the total luminous transmittance of transparent materials" Part 1: Single-beam instrument
- [4] ISO 13468-2: "Plastics - Determination of the total luminous transmittance of transparent materials" Part 2: Double-beam instrument
- [5] ASTM D1044: "Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion"