

Gloss Measurement

Abstract

Gloss measurement is an important factor in quality control to guarantee a consistent and uniform gloss of any product. The visual perception is depending on the observer, illumination and viewing conditions as well as on material and product properties. In order to measure gloss objectively instrumental measurement is performed with a gloss meter. Dependent on the gloss level and the application different geometries and functions are needed. The following article reviews visual perception of gloss, measurement principle of a gloss meter, when to use which measurement geometry and gives practical hints for special applications and how to deal with limitations.

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1 Gloss measurement to guarantee consistency

Gloss effects are based on the interaction of light with the physical properties of an object. In addition, gloss is influenced by the physiological evaluation of the observer. The first impression of a product is strongly influenced by its surface quality. For many products a homogenous and consistent gloss is considered as a decorative quality parameter and is influenced by many production process parameters.

There is no doubt the human eye is by far the best optical instrument to evaluate gloss. The human eye can differentiate, without any problem, lightness differences between 1 and 10 million [1]. Nevertheless, the visual surface evaluation is insufficient because of the following variables:

- Undefined evaluation conditions
- Judgement is dependent on the mood of the observer
- Different observers have different visual acuity

To guarantee a reliable and practical quality assurance, it is necessary to describe the gloss of surfaces with objective, measurable criteria. Gloss measuring devices have been used in the industry since 1930. Special gloss effects resulted in the development of new measurement systems with better correlation to the visual evaluation [2, 3, 4].

2 Visual perception of different gloss levels

Gloss and color are visual sensations perceived when evaluating a surface. We evaluate the capability of a surface to reflect incident light into the specular direction, i.e., light sources or objects are reflected. The gloss impression is influenced by the following parameters (Fig. 1):

2.1 Surface properties

- Material (e.g. coatings, plastic, metals)
- Surface topography (e.g. smooth, rough, structured)
- Degree of transparency
- Substrate

2.2 Illumination

In order to evaluate gloss, it is necessary to have a direct illumination. A diffuse illumination causes diffuse reflection resulting in decreased gloss impression.

2.3 Observer

Visual evaluation is dependent on the visual acuity (physiology) and the mood of the observer (psychology). We visually evaluate a surface by focusing our eye either on the reflection of a light source or on the surface itself [5]. Both types of evaluation influence the overall gloss impression:

Appearance				
Focus on Surface		Focus on Reflected Image		
Waviness, Orange Peel		Image Forming Quality		
Longwave	Shortwave	DOI	Gloss	Haze

By focusing on the reflected image of a light source (Fig. 2), the distinctness of image is evaluated [6]. The reflected image of the light source may appear brilliant or dull (specular gloss). The outlines of the reflected image can be distinct or blurred (image clarity) or a halo can surround the reflected image (haze).

By focusing on the surface, we also get an impression for structure size and form (Fig. 3). These structures can be seen as a wavy pattern of light and dark areas. In the industry, this wavy pattern is often referred to as orange peel.

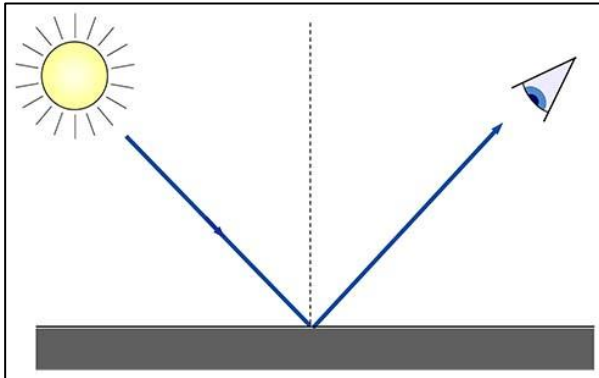


Fig. 1: Components of gloss perception:
Light source, Surface, Observer

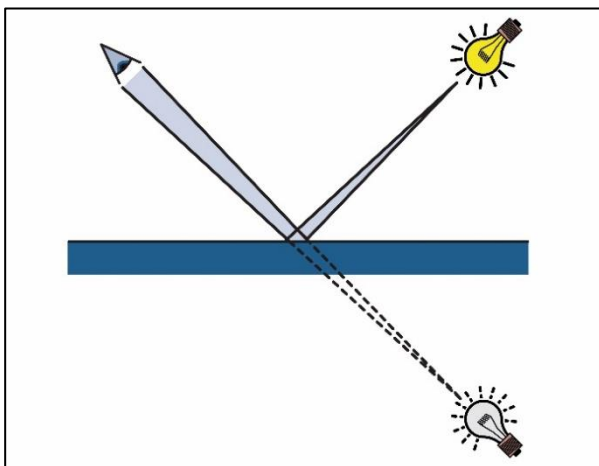


Fig. 2: Focus on reflected image

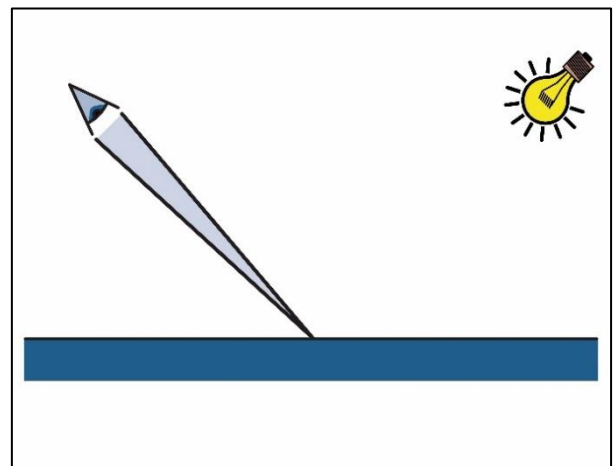


Fig. 3: Focus on surface

3 Reflection behavior of surfaces

Gloss is a subjective impression and not a physical property of the surface. Specular reflection, part of the overall gloss impression influenced by the reflection properties of the surface, can be physically and objectively measured.

3.1 High gloss, flat surfaces

In case of flat, high gloss surfaces, the law of reflection is valid:

Angle of illumination = Angle of reflection (Fig. 4).

Those types of surfaces are also considered image forming, as the image of a reflected object can be seen distinctly.

The light is reflected at the first surface into the specular direction of reflection. The intensity of the reflected light is dependent on the angle of illumination and material properties (refractive index).

- Metals: high intensity, hardly angle dependent
- Non-Metals: lower intensity, dependent on angle of illumination and refractive index of material

In case of non-metals, part of the illuminated light penetrates the material and is selectively absorbed or diffusely scattered dependent on the color of the pigment. The diffusely scattered light comes out of the material and gives us the impression of a specific color (Fig. 5). This diffuse component is equally distributed in all spatial directions.

3.2 Semi gloss surfaces

In case of rougher surfaces, the light is not only reflected in the direction of specular reflection, but also diffusely reflected in other directions (Fig. 6).

The capability of a surface to reflect an object is strongly reduced. The more evenly the light is distributed in all directions, the less intense the specular component will appear and the less glossy the surface will look. A special effect of matt surfaces, called Sheen, can be observed when viewing at almost grazing angles: in a range of 80° or larger the surface begins increasingly to look shiny.

3.3 High gloss surface with haze (reflection haze)

If there are microscopic defects on a high gloss surface, there will be some diffused light of low intensity adjacent to the specular reflection (Fig. 7). Most of the light will be reflected in the specular direction resulting in a high-gloss and distinct, image forming appearance which seems to be covered with a hazy or milky film.

3.4 DOI versus Gloss on high gloss surfaces

Fine structures close to the resolution of the human eye (approx. 0.1 mm), i.e. in a range of a few microns up to around 1 mm, influence the image forming quality of a surface. Richard Hunter [2] called this type of gloss Distinctness Of Image (DOI), its impact to the visual perception can be described as sharpness of reflected edges. Specular gloss measurement is dependent on reflected light intensity and the refractive index of the material, while DOI is a relative measure and correlates better to the perceived brilliance of high gloss finishes.

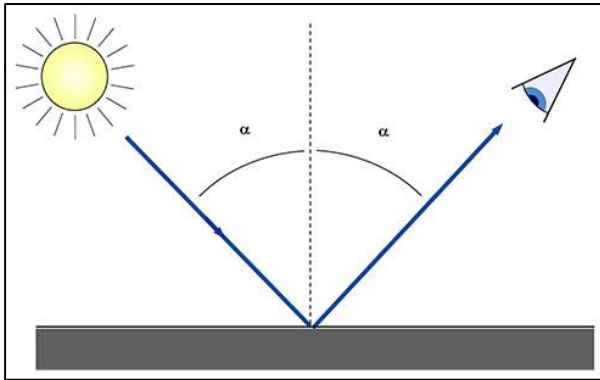


Fig. 4: Specular reflection on 1st surface

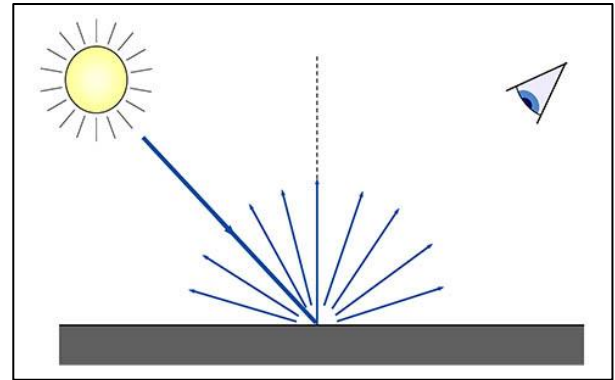


Fig. 5: Diffuse scattering from the material

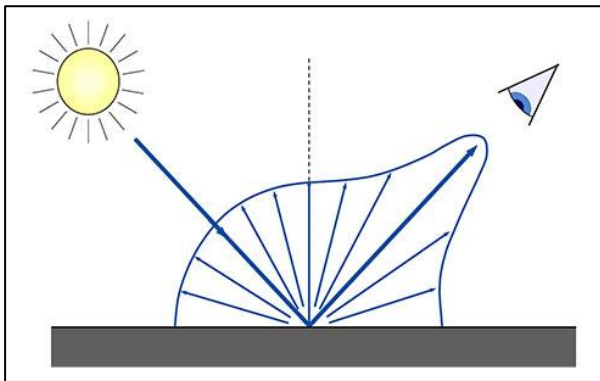


Fig. 6: Semi gloss - diffuse scattering from surface

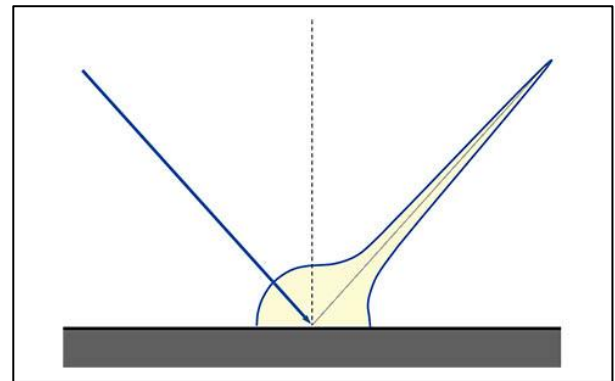


Fig. 7: Reflection haze

4 Gloss meter

4.1 Measurement principle

The principle of a gloss meter is based on the measurement of the specular component of the reflected light (Fig 8). The intensity of reflected light is measured in a specific angle range which is limited by an aperture "AP".

The light source illuminates the surface by passing through another aperture "AP1" (Fig. 9). A photoelectronic detector measures the light passing through aperture "AP2".

The measurement of the gloss value is a relative measurement. The measurement results are related to a highly polished, black glass standard with a defined refractive index of 1.567. This black glass standard has an assigned specular gloss value of 100 (calibration).

In order to obtain comparable results, measurement device and operation were defined in international specifications: ISO 2813, ASTM D523, JIS Z 8741 and DIN 67530 [7, 8, 9, 10].

The specifications define the following parameters:

- Geometric conditions (angle of illumination and reflection, aperture angle, light source and detector sensitivity)
- Calibration procedure
- Measurement procedure
- Application and limitations (e.g. curved surfaces)

4.2 When to use which measurement geometry?

The angle of illumination highly influences the measurement results. In case of coatings, plastics and allied products, part of the illuminated light is reflected on the first surface and a part penetrates the material. The greater the angle of illumination, the greater the amount of reflected light. In order to obtain good differentiation of the whole range from high to low gloss surfaces, three different angles of illumination, -i.e. three different measurement ranges were defined (Fig. 10):

- 20° high gloss surfaces
- 60° semi gloss surfaces
- 85° low gloss surfaces

In order to obtain a clear differentiation over the complete measurement range from high gloss to matte, three geometries, i.e. three different ranges are standardized. A single measurement geometry, such as 60°, may not provide instrument readings of gloss that correlate well with visual observation when comparing different gloss levels. Therefore, international standards provide for measurement at different angles of incidence. The choice of geometry depends on whether one is making a general evaluation of gloss, comparing high gloss finishes or evaluating low gloss specimens. The 60° geometry is used for comparing most specimens and for determining when the 20° or 85° geometry may be more applicable. The 20° geometry is advantageous for comparing specimens having 60° gloss values higher than 70. The 85° geometry is used for comparing specimens for near grazing shininess. It is most frequently applied when specimens have 60° gloss values lower than 10.

In a case study 13 samples were visually ranked from matte to high gloss and measured with the three specified geometries. In the steep slope of the curves, the differences between the samples can be clearly measured, while in the flat part the measurement geometry no longer correlates with the visual perception (Fig. 11).

In addition, industry specific geometries were established:

- 45° Ceramic, plastic and plastic films (ASTM C346, -D2457, JIS Z8741)
- 75° Vinyl siding and paper industry (ASTM D2457, - D3679, JIS Z8741, Tappi T480)

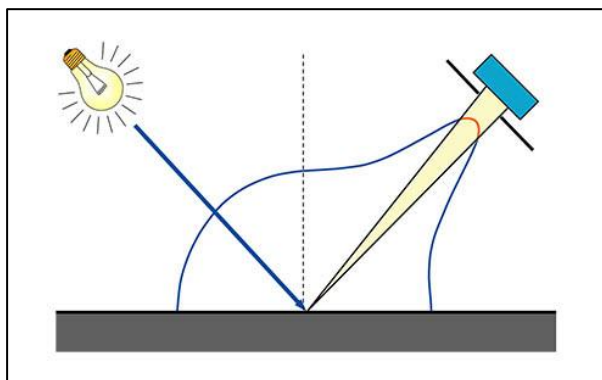


Fig. 8: Measurement of the specular component

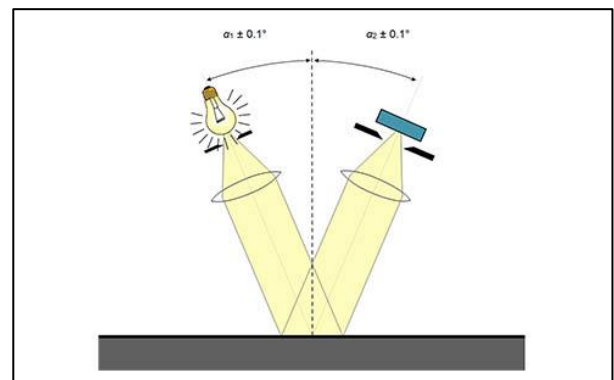


Fig. 9: Principle of a gloss meter

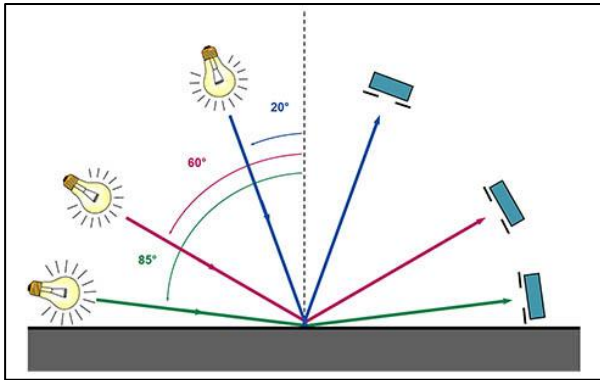


Fig. 10: Standardized geometric conditions

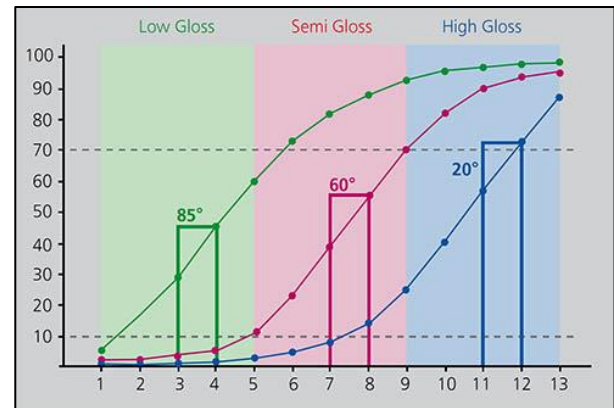


Fig. 11: Specular gloss values dependent on measuring angle

5 Gloss measurement of special applications

5.1 Gloss measurement of transparent films or sheets

Besides transparency, high quality films require defined reflection properties, regardless if they are brilliant glossy packaging or non-glare films for LCD use. The internationally standardized method for measuring gloss illuminates the sample under a defined angle and detects the reflected light intensity. At transparent materials, a part of the illuminating light penetrates the surface. The transmitted light is reflected at the rear surface within the material and is partly transmitted into the direction of the sensor (Fig. 12).

This additional reflection is dependent on the background used and has a significant impact on the measurement. To minimize this influence, it is recommended to use a black, matte background, e.g. paper board, and it is important to always use the same background. It is additionally challenging when the samples are very thin and don't form a really flat surface under the gloss meter. Therefore, often a vacuum plate is used to make sure no air bubbles or wrinkles distort the measured gloss results.

5.2 Gloss measurement of mat and structured finishes

The interior design of e.g. automobiles is getting more and more important in the purchasing decision. A big challenge is to achieve a "feeling" of high value and at the same time minimize cost. Therefore, a variety of materials are used and need to be harmonized. As a starting point master standard plaques are manufactured with usually a flat and several grained areas. These are sent to the suppliers as their target to achieve with actual production parts. In order to guarantee a uniform look among the various materials very tight tolerances are specified. Instead of working with absolute gloss numbers, the supplier production QC needs to be based on the signed-off part and only the differences are checked. This procedure eliminates the reproducibility error as gloss is measured relatively on the same type of material and same surface. Therefore, a difference of 0.3 gloss units from part to part can be considered as a significant difference.

Typical tolerances: 60° Gloss: < 5 GU +/- 0.3 to 0.5

BYK-Gardner's micro-gloss S meters with improved technical performance for 60° gloss in the low gloss range (0-20 GU) enable reliable QC of such tough specifications. The excellent repeatability of +/-0.1 can be guaranteed due to our patented calibration procedure and the excellent temperature stability of the measuring results.

5.3 Gloss measurement of large surface areas

On products with large surface areas, homogeneity is an important quality characteristic. Typical applications are to evaluate gloss variation on vinyl sidings or flooring laminates. Therefore, the BYK-Gardner glossmeter offer a so-called continuous mode. This mode allows to perform continuously measurements with a user-definable time interval, while the unit is moved over the large measurement area. The user can directly see on the display the gloss value of each reading. After having scanned the surface area the micro-gloss offers statistics such as average and min-/max-values which can be used to define the gloss uniformity.

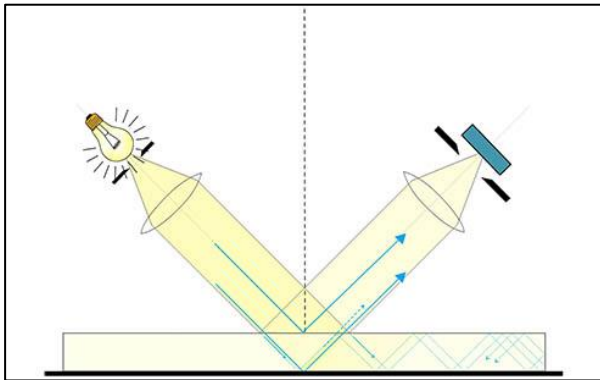


Fig. 12: Multi-reflection within transparent or translucent materials on a defined background

6 Limitations of gloss measurement

6.1 Gloss of curved surfaces

The classic gloss meters are basically intended for measurement on flat surfaces. Convex or concave curvatures change the direction of reflection in a similar way to optical lenses or mirrors [Fig. 13] and thus falsify the result of the gloss measurement. Some products have such a small curvature that comparative measurements are possible with an appropriate tolerance. Investigations to this effect were already carried out in the 1970s, where the deviations were kept below about 5% for radii over approx. 50 - 80 cm [11]. Of course, these deviations depend above all on the material, gloss level and geometry; the higher the gloss level, the greater the effect of curvature. Tilting is also a significant factor, so that the use of a positioning device is recommended.

6.2 Structured surfaces

Reflectivity and gloss are based on the interaction of light with the physical properties of the sample surface. The intensity is dependent on the material and the angle of illumination. The measurement results of a conventional glossmeter are related to the amount of reflected light from a black glass standard with a defined refractive index. The classical gloss meter does not include the effects of structure or complex gloss behavior of 3D-surfaces.

The new spectro2profiler [13] employs a photometric stereo technique for estimating surface normals to calculate a 3D topography of the surface. The surface normals are calculated by observing the surface with different illumination directions. Using the shape from shading, the surface curvature is estimated, and the height map of the object can be calculated. The result is a real 3D topography of the measured object surface.

6.3 Spatial gloss variation

Cast shadows and areas that are invisible to the measurement detector can falsify the result of specular gloss measurement. Moreover, the perception of gloss does not only depend on specular gloss but also on the observed contrast between specular highlights and diffusely

reflecting surface areas. A conventional gloss meter is not capable to capture more complex reflective behavior such as spatially distributed reflections e.g. high reflecting hills next to low reflecting valleys which occur in leather-like structures.

The new spectro2profiler [13] offers a camera-based technology to capture the spatial distribution of reflectivity. An in-line illumination setup eliminates cast shadows, invisible areas and perspective distortions so that the measurement is independent of orientation (Fig. 14). The camera acquires 2D reflectivity images, allowing more detailed analysis of reflectivity distributions of a surface.

To assess the overall appearance of an object, it is necessary to measure surface structure and reflectivity in parallel, as they are mutually interdependent, but are combined for an overall visual assessment. Because our eyes are only capable to acquire 2D information, the human visual system reconstructs 3D information of objects in our brain using shading and reflections. That means, the perceived depth of a structure is dependent on the reflection behaviour on the hills and valleys. Since the spectro2profiler uses the same camera and lens system for the acquisition of 3D topography and 2D reflectivity data, it is possible to combine the data of both measurement principles. Thus, the reflection of hills and valleys can be separated. The difference between reflection of hills and valleys, describes the contrast and perceived depth of a structured surface.

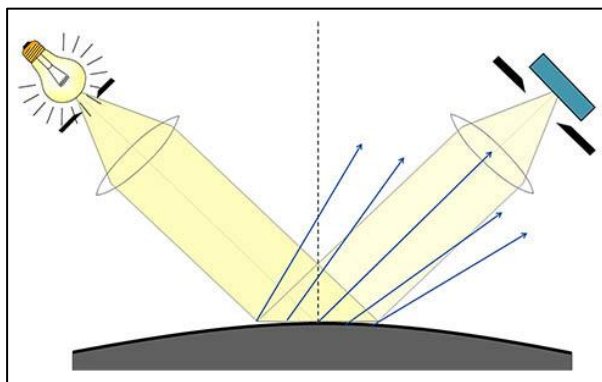


Fig. 13: Light distribution by curvature

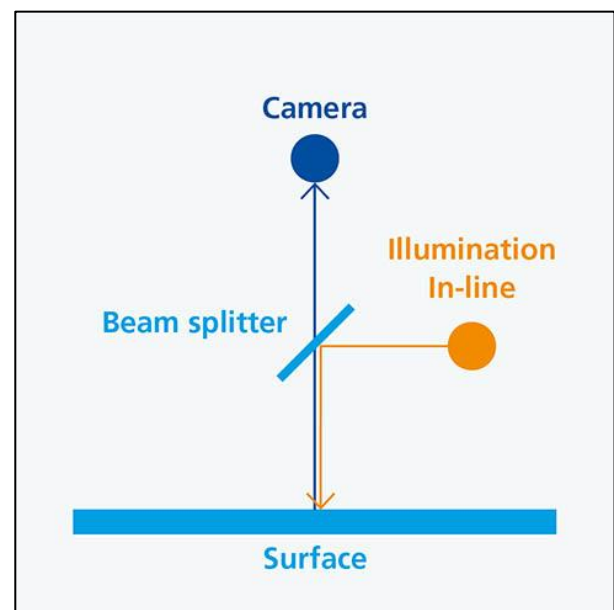


Fig. 14: Setup of spatial resolved reflectivity measurement

7 Summary

The visual impression of gloss is like color, a multi-dimensional parameter. For many years, glossmeters have been used to measure the specular reflection in lab and QC applications. In order to characterize the entire visual impression of gloss, it is necessary to measure additional gloss parameters like haze and orange peel. BYK-Gardner offers a complete line of appearance measurement devices to objectively determine specular gloss, haze and orange peel that are designed for applications in the lab as well as in the field.

8 Literature and Standards

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