GUIDELINES

# Documenting Painted Surfaces for Outdoor Painted Sculptures

## A Manual of Laboratory and Field Test Methods

Julia Langenbacher and Rachel Rivenc

with contributions from Anna Flavin

Getty Conservation Institute

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## A Manual of Laboratory and Field Test Methods

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The Getty Conservation Institute (GCI) works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research, education and training, field projects, and the dissemination of information. In all its endeavors, the GCI creates and delivers knowledge that contributes to the conservation of the world's cultural heritage.

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Cover: Red paint coupon with color target on aluminum substrate. © J. Paul Getty Trust

# Contents

# 1. Introduction

Conservators entrusted with the maintenance and conservation of outdoor painted sculptures (OPS) are confronted with acute challenges. By definition, OPS are exposed to harsh and uncontrolled environments and thus are highly prone to rapid deterioration and a wide range of paint coat failures.[1] Conservation treatments on OPS often involve the full repainting of the sculpture, frequently preceded by the removal of all earlier coats of paint, or stripping. Sculptures created in the 1960s, for instance, may have already undergone several cycles of stripping and repainting. In these conditions, it is of utmost importance to have mechanisms or safeguards in place to ensure that the color, texture, and gloss levels used for the repainting correspond to those intended by the artist and that the new surface reproduces the original one as accurately as possible.

In an expert meeting convened in 2012 by the Getty Conservation Institute (GCI) to discuss the issues and challenges associated with the conservation of OPS,[2] it was suggested that one response to this problem would be to implement a system of paint coupons[3] to document their original or intended appearance. Paint swatches or coupons create a physical reference that is far more reliable than paint codes or color charts, since products are routinely discontinued and formulations modified. Coupons can be stored in a way that minimizes change, and they can be compared and distributed among professionals. Once prepared, their appearance can be measured and recorded in a consistent, reproducible, and comparable way. One of the recommendations issued as a result of the meeting was to create in the long term a repository of physical paint coupons, accompanied by supporting documentation.[4] For the short term, it was recommended that guidelines be developed for producing, characterizing, and documenting these paint coupons.

These paint coupons can be described best as the target appearance for conservators to match when implementing a conservation treatment. To acquire this target appearance status and become the gold standard for conserving artists' OPS, the coupons must be approved by Artists' Estates, Foundations and Studios (EFS). The GCI has started to collaborate with a number of EFSs to produce approved paint coupons and serve as a repository for the coupons while building a database to host related information.

While paint coupons are a reliable way of characterizing the surfaces of OPS, they do have some limitations. They are valuable for monochrome, opaque, and uniform coatings, but their effectiveness may be limited for special paints, such as those that are translucent or metallic, or for nonuniform surfaces with marks or modifications applied by the artist.

The paint coupons, stored indoors in archival conditions yet made of materials devised for the outdoors, should have excellent durability. The appearance of some coupons, however, will ineluctably change over time, although differently and definitely at a slower rate than the identical paints applied outdoors. Therefore, it is essential to document the appearance of the paint coupons when still new by measuring color, gloss, and other relevant characteristics.

Because the method by which a paint coupon is prepared can affect its appearance and because the method by which its appearance is measured can affect the data recorded, it is important to do both in a consistent and reproducible manner. Although the methods of coupon preparation presented here are mostly applicable to OPS on metal substrates, the methods proposed for documenting the coupons can be extended to OPS on other substrates (concrete, GRP)—as long as the final appearance accurately represents the target appearance.

This document presents the guidelines that the GCI has elaborated, based on ASTM and ISO standards, paint industry practices, and consultations with experts in the fields of industrial paints and OPS conservation, for the production and documentation of paint coupons.

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[1] Beerkens and Learner 2014; Considine 2010.
[2] Learner and Rivenc 2015. The report can be downloaded at http://www.getty.edu/conservation/publications_resources/pdf_publications/cons_20th_outdoor_sculpture_mtg_report.html.
[3] A paint coupon is a substrate covered with paint, usually of dimensions small enough to be handled and meant to represent a particular color or appearance.
[4] This was recommended as part of an overall strategy to create resources for conservators, including also a database with information on artists, fabricators, archives, etc.

It builds on industrial standards to propose a protocol that meets the requirements of the various fields involved in the replication of paint coatings and aims to standardize the procedure as much as possible by adopting methods most widely used for industrial applications.[5] Although developed with the goal of producing EFS-approved paint coupons to serve as references for intended appearance and for long-term storage, these guidelines can be used by any anyone wishing to document a paint surface, for example, on the occasion of a repainting or when commissioning a new OPS. The guidelines allow for the creation of consistent coupons and the building of a useful set of data about the paint coupons and the surfaces to which they refer. Further, they enable the exchange, circulation, and comparison of data within the field.

[5] Cf. ASTM 2011, 2012b, 2015b; ISO 2004; Tator 2015; Grossman and Patton 2006.

# 2. Preparation of Paint Coupons: Materials and Techniques

A completed paint coupon consists of a substrate and a combination of coatings, generally a primer and a top coat and possibly a clear coat.

For every coupon prepared, detailed records should be kept. The data to record include the materials used, all tools and their use (spray gun, air pressure, flow rate, distance to object, etc.), film thickness, any deviations, the date, and the person who performed the application.

## 2.1. *Substrate*

Metal test panels, such as Q-PANELs produced by Q-Lab, can imitate metal substrates present in many OPS. For solely visual assessment, the difference between metals is negligible. Aluminum panels are a lightweight alternative to steel and are less likely to corrode in most environments. Pretreatment of aluminum panels with chromate[6] is recommended by the manufacturer to improve the paints' adhesion and resistance to underfilm corrosion. Hence chromated aluminum panels with a smooth surface finish are suggested as standard substrates.[7]

The dimensions of the panels are governed by the specific use. The standard industrial size applied for laboratory accelerated aging tests of coatings (Q-Lab panel type AL-36) is 3 × 6 inches. However, a larger surface is beneficial for visual assessment and makes the capture of color and gloss measurements easier. For this purpose, the paint industry commonly uses panels measuring 4 × 12 inches (type AL-412); this size still allows for easy handling and storage.[8]

In addition, plain white paper charts are often provided by paint manufacturers for color matching purposes. Recommended for OPS coatings are standardized charts (e.g., Leneta Company Inc., BYK-Gardener GmbH) measuring 8⅝ × 11¼ inches (219 × 286 mm) and with a thickness of 14 mil (0.36 mm) (type WK) (fig. 1). Charts containing fluorescent additives should be avoided.

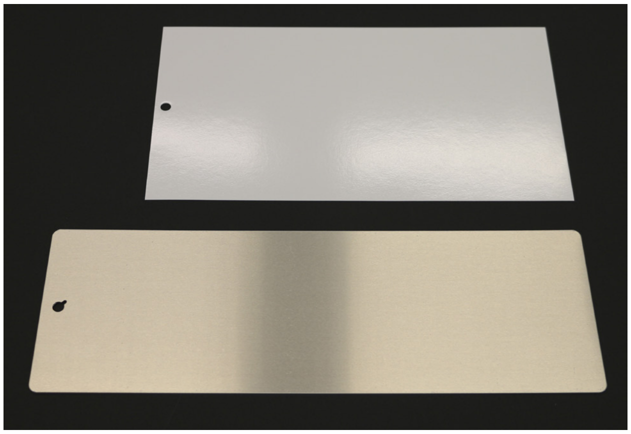

**Fig. 1.** Standard Leneta WK white paper chart and Q-Lab aluminum panel AL-412 can be used as substrates for reference paint coupons.

Tests performed at the GCI to compare the influence of both types of substrates on the final appearance of paint coupons indicated that the substrate had only a minor impact on the appearance generally; however, compared to aluminum panels, slightly higher color and gloss deviations for top coats on paper charts were recorded due to the slightly more irregular surface of the paper. Hence more rigid substrates should ensure better reproducibility of gloss and color measurements.

In addition, paper charts do not usually include the complete stratigraphy as used on aluminum panels, which will also lead to less representative and reproducible surfaces. Nevertheless, they can be used for paint-outs as a cost-effective alternative to metal substrates for the purpose of quick color comparison (fig. 2).

**Fig. 2.** Example of four paint coupons provided by a paint manufacturer for color matching on Marc Di Suvero's sculptures.

[6] Other anticorrosion treatments may be acceptable.

[7] The recommended panels type AL are made of an alloy 3003 H14 with the designation AlMn1Cu. They have a thickness of 0.025 in. (0.64 mm). These panels are classified after ASTM Material Specification B209, B449-Class 2, and ISO Panel Specification 209-1, 1514, 10546-Class 3. It is important to use standardized and controlled test panels to guarantee a uniform and consistent test surface.

[8] For visual evaluation of paint coats, coupons measuring 12 × 12 inches or larger may be useful, but these are expensive to produce and cumbersome to store and handle.

## 2.2. *Primer / Intermediate Coat*

A very common layering system for OPS comprises a zinc-rich primer as corrosion protection on the metal substrate, followed by an intermediate primer coat and the application of at least one layer of a colored top coat, which may be protected by a final clear coat. The application of the first zinc-rich primer does not affect the appearance of the top coat provided that an intermediate primer layer is applied prior to the top coat. For this reason and because the zinc-rich primer layer increases considerably the weight of a paint coupon, its application on coupons is considered unnecessary.

By contrast, tests performed at the GCI showed that the application of an intermediate primer or base coat prior to the top coat can affect the appearance to a certain degree when compared to a top coat applied directly to a substrate. (The primer helps smoothe the surface.) Comparing primed and unprimed test panels, no significant alteration in color was documented,[9] but the use of primer resulted in slightly higher gloss measurements, and even small differences, below 3 gloss units (GU), were perceived visually.

For this reason, the application of one primer coat on the metal surface is suggested for standardized paint coupons. However, the decision on whether to apply a primer should be determined by whether a primer is necessary to reproduce the original or intended appearance. The use of a colored primer may affect the appearance, depending on the covering power of the paint. Again, the decision should be based on the required final appearance.

It can also be beneficial to mask off a small section of the coupon when applying the primer (less than one inch wide). This makes the presence of the primer immediately apparent when assessing the coupon visually and enables the measurement of the film thickness of the primer and top coat separately.

The appropriate application technique and film thickness recommended by the paint manufacturer in its technical data sheets (TDS) should be followed, unless these are incompatible with reproducing the artist's original or intended appearance.

## 2.3. *Top Coat*

The top coat should preferably be applied using the information on application techniques and film thickness found in the paint manufacturer's TDS, unless the artist who made the OPS has specifically deviated from these recommendations to achieve a specific appearance.

Tests performed at the GCI indicated that brushed and rolled paint coats yielded large deviations in gloss measurements, depending on the roller or brush used. Spray application to the thickness specified by the TDS was found to yield a much more consistent result, especially on aluminum substrates. Thus spray-painted aluminum coupons with a uniform surface are recommended as reference standards, as they can provide reproducible color and gloss measurements, unless a brushed or rolled surface is being documented. In that case, ideally different sets of coupons should be prepared, one with a sprayed application to enable reproducible measurements on the surface and the other to reflect the technique used on the OPS.

Spray applications can sometimes result in an orange peel effect. It should be confirmed with the EFS approving the coupons if this effect is intended, or at least acceptable to the artist.

For paint coupons on paper charts, the draw-down bar method guarantees the most uniform surface and should be used as the standard technique. In addition, brushes, rollers, or spray guns can be used to create additional coupons and match the artist's technique.

## 2.4. *Clear Coat / Finish*

A final clear coat affects the appearance considerably. It can change the color depth and saturation, gloss, and surface topography. It impedes the evaluation of a top coat, but at the same time it is essential to reflect the appearance of the sculpture on which a clear coat has been applied. Thus if a clear coat has been used by the artist, it is recommended that a set of coupons including top coat and clear coat be prepared for a visual assessment and final measurements. In addition, it is beneficial to produce a second set of coupons that includes primer and top coat but omits the clear coat in order to serve as a reference standard for the paint color. The same recommendations apply for other finishing techniques, such as polishing.

## 2.5. *Quantity*

Multiple paint coupons should be prepared as "master standards" on chromated aluminum panels of 4 × 12 inches representing a comparable layering structure and reflecting the surface found on the OPS. These master standards are considered actual references for OPS and are used to document the appearance, but, in order to

[9] With the limitation that the study included only black and white paints and a white primer.

avoid unnecessary wear of the surfaces, they should not be used for routine evaluations or taken out of storage.

Instead, the GCI recommends preparing additional coupons, referred to as working standards, of 3 × 6 inches to perform color matching on site and to facilitate loaning. When possible, the GCI aims to collect four to six master standards and at least ten working standards.

It is not recommended to use paint-outs on paper charts as master standards for the reasons outlined above. However, in some cases they might be the only practical option and thus may be considered for documentation purposes. Here as well, multiple coupons with dimensions of 8⅝ × 11¼ inches should be collected.

**Recommendations for the Preparation of Paint Coupons**

**Materials**

- For metal test panels
  - Aluminum panels (master standards), chromated, 4 × 12 inches, type AL-412
  - Aluminum panels (working standards), chromated, 3 × 6 inches, type AL-36
- For paper test panels
  - Paper charts, white, one side sealed, 8⅝ × 11¼ inches, type WK, no fluorescent additives

(See Appendix 1 for manufacturer information.)

**Application**

- Replicate the stratigraphy of the sculpture, with the exception of zinc primer. This will most likely result in the substrate being coated with one primer layer, a top coat, and, if applicable, a clear coat.
- Apply spray coats in appropriate film thickness, according to TDS. If other techniques (e.g., brushing, rolling) were used by the artist to produce the intended appearance, additional coupons should be prepared in the same manner. The draw-down method is the most appropriate for paper charts.
- Document all materials and equipment, along with film thickness and any deviations; note date and person performing the application.

# 3. Evaluation and Documentation of Monochrome Painted Surfaces

All paint coupons should be photographed and the color, gloss, and film thickness measured. Common identification and cataloging information should be recorded as well. It is also recommended that the manufacturer's TDS and material safety data sheets (MSDS) be kept for all applied coatings as part of the documentation file.

## 3.1. *Photography*

Photography is an essential part of documentation. In order to provide an accurate record and for qualitative comparison, the photographic procedure must be color managed, consistent, and reproducible. Exact photographic color accuracy or reproduction is difficult to achieve, therefore photography cannot and should not take the place of monitoring with gloss and color measurements. General recommendations for photographic equipment and settings are given below, followed by a section on image processing. Under certain circumstances video recording may also be useful for documenting a specific application technique that produces a particular finish or texture.

### 3.1.a. Equipment and Procedure

Optimal results can be achieved by using a high-quality digital camera with an up-to-date sensor. A full-frame sensor can provide an excellent capture, and an APS-C sensor may provide a very good quality capture. A lens that provides a normal perspective is recommended in order to avoid distortion. Whenever possible, a fixed focal length lens (prime lens) should be used.

Ensure that the camera remains in a fixed position by using a tripod or copy stand (see figs. 3 and 4), and trigger it remotely in order to eliminate camera shake. In addition, remote capture software can be utilized to capture the images via a camera tethered to a computer. The camera should be set to manual mode, with camera RAW as the capture format. Follow the camera manufacturer's specific instructions to create a custom white balance for each lighting situation.

Each image should include a color target, preferably with the manufacturer's provided numerical color values in both RGB and CIELAB (e.g., X-rite ColorChecker Mini or Passport, Image Science Associates ColorGauge). The RGB (red, green, and blue) values[10] are defined and standardized and are essential for color balancing.

Two daylight balanced light sources are needed (e.g., LEDs, speedlights, studio strobes). Each light head should provide or be modified (e.g., attached softbox,) to provide a broad, diffuse light source. A copy stand can also be used if it provides adequate illumination. It is

**Figs. 3 and 4.** Photography setup with copy stand with two different lighting setups.

[10] Note that RGB values are always dependent on a specific color space such as Adobe RGB or sRGB. See Frey and Warda 2011, 78.

important to avoid contamination from any ambient light sources, therefore it is best to execute the capture in a completely darkened space with no surrounding reflective material. Neutral matte gray paper or cloth is recommended as a background.

For the standard documentation of a paint coupon, position each light source at an angle of approximately 45° from the sample to ensure that reflections are minimized and that surface texture is not exaggerated. Other configurations such as raking light can be used to observe and document particular surface features and textures such as orange peel or wrinkles. A patterned light source can also be used to examine geometric attributes such as gloss, orange peel, and distinctness of image.[11] Techniques such as applying ultraviolet light may be beneficial to document certain material properties (e.g., when a clear coat is applied).

It is always best whenever possible to adjust the intensity of the light source to arrive at the optimal exposure settings. Generally, setting the ISO sensitivity to 100 or lower will ensure the most accurate color reproduction and image noise will be less prevalent. Depending on the specific camera, ISO 200 to ISO 400 may render acceptable results but color may not be as accurate.

The aperture (f-stop) and the shutter speed should be set based on an accurate light meter reading. The in-camera light meter determines exposure based on reflected light; therefore, accuracy may be affected by a number of variables. The use of an external incident light meter is highly recommended as it reads the light that falls on the object and is not influenced by the reflectivity of the object or the background. For even greater accuracy, some light meters can be calibrated for use with a specific lens and camera combination. Optimal sharpness will be achieved with an aperture at or near f/11. When utilizing continuous light sources (e.g., LEDs), shutter speeds may need to be slower than those required for speedlights or studio strobes. Be especially aware of unwanted ambient light that can contaminate the color. Longer shutter speeds will also create unwanted digital noise. When using speedlights or studio strobes, refer to the camera manual and set the camera shutter speed to the recommended synchronization speed.

[11] Distinctness of image (DOI) is a quantification of the deviation of the direction of light propagation from the regular direction by scattering during transmission or reflection. It is used to characterize the visual appearance of high-gloss surfaces.

### 3.1.b. Image Processing

In order to view the colors of an image file as accurately as possible, computer monitor calibration is essential. In addition, be aware of the monitor's environment: light or glare from a window may prevent the ability to view reproduced colors accurately.

All photographic data must be processed and output in exactly the same manner regardless of the capture date. Following the image capture, the proprietary camera RAW formats should be converted to Adobe Digital Negatives (DNGs) using imaging processing software (e.g., Adobe Camera Raw application,[12] Adobe DNG Converter). DNG files are not finished products; adjustments are required to ensure the most accurate reproductions possible. White balance, color management, lens correction, removal of chromatic aberration, sharpening, exposure correction, and bit depth and color space selection must be made by using image editing software (e.g., Adobe Camera RAW application). The consistent selection of a particular camera profile is also essential. As an additional step, custom DNG camera profiles can be made by using X-rite's ColorChecker Passport application.

Once all adjustments to the DNG file have been completed, a Master TIFF File should be created with the following specifications: 16 bit, uncompressed, Adobe RGB color space, in the original pixel dimension. This file should never be altered. If changes are needed, refer back to the DNG file, make the needed adjustments, and replace the Master TIFF File.

The JPEG file format is not appropriate for documentation purposes as it compresses the data upon capture and automatically applies a color space, sharpening, and other potentially unwanted manipulations. A JPEG capture typically does not provide accurate color. In situations where the Master TIFF File is not practical due to its size and format (e.g., PowerPoint presentation, printed report, or publication), a derivative JPEG can be created from the Master TIFF File. It should be created in the Adobe RBG color space. Upon final archiving of the project, retain the DNG and the Master TIFF File. Other derivatives may be discarded.

[12] Besides the free and openly documented nature of Adobe DNG, it has the advantage that metadata and further processing information are written directly to the file rather than being externally filed. This makes it possible to open and access the information on different computers without the need to apply a proprietary software.

**Recommendations for Photography**

- Use a quality digital camera with either a full-frame or APS-C sensor, set to Manual mode.
- Fix the camera position with a tripod or copy stand.
- Use a normal perspective lens, preferably prime.
- Use a remote trigger device or remote capture software and tether the camera to a computer.
- Set up a controlled photography environment using daylight-balanced, diffuse illumination.
- Photograph against a neutral matte gray background.
- Create and set a custom white blanace prior to shooting.
- Include a color target in each photo.
- Set ISO sensitivity to 100 or lower whenever possible. Do not exceed ISO 400.
- Use an external light meter to determine aperture and shutter speed.
- Take additional photographs with different illumination angles to capture special conditions (gloss, surface texture, etc.).
- Capture RAW, convert RAW to DNG, adjust color, exposure, white balance, and other attributes using imaging software (e.g., Adobe Camera RAW application).
- Create a Master TIFF File: uncompressed, 16 bit, Adobe RGB, with original pixel dimension.
- Create JPEG derivatives in the Adobe RGB color space from the Master TIFF File for situations where the Master TIFF File is not practical due to its size and format. (JPEGs are not as accurate with regards to color and should not be considered an archival format.)
- Archive DNG and Master TIFF File.

## 3.2. *Color*

The trained human eye is a very sensitive tool for perceiving color differences. Therefore, the surfaces to be color matched should be assessed visually side by side. Color perception is highly subjective, however, and differs depending on the observer, the object's surface, and the viewing conditions, including illumination and background.[13] Therefore, it is important to measure the color and gloss of an object with instrumental methods.

It has to be noted that the paint coupon and the surface it references may not be exactly identical. For the matching procedure, it is thus important to set tolerance ranges by defining the limits for acceptable deviations from the target surface. Some EFSs may assign numerical values to this tolerance to deviation; others may want to visually assess such differences on a case-by-case basis.

Various models exist for the evaluation of color, and they are not necessarily compatible.[14] As a result, difficulties in transferring color values between different systems can arise, for example, when color data are only known in a specific proprietary format. In an attempt to unify the documentation of paint coupons and OPS, the application of the CIELAB color coordinate system model is recommended. The CIELAB model is widely used among conservators as well as in the paint, plastic, and textile industries. In the CIELAB color space the L*, a*, and b* coordinates are calculated from tristimulus values,[15] where L defines the lightness,[16] a* correlates with red (positive values) and green (negative values), and the coordinate b* expresses yellow (positive values) and blue (negative values). From these values the color difference ΔE can be calculated, where different formulas exist to do so. For better compatibility, we recommend use of the CIEDE2000 formula,[17] which is most commonly applied in the paint industry as specified by ASTM D 2244 and CIE.[18] In addition to L*, a*, b* values, the reflectance curve from 400 to 700 nm at 10 nm intervals (31-point curve) should also be captured to enable future color matching. The instrument illuminating and viewing geometry should also be documented.

[13] Berns 2000; Nassau 1998; Hunt and Pointer 2011.

[14] For instance, the print industry commonly applies the RGB color model, whereas color control for manufacturing processes and the monitoring of objects in art and science usually rely on the CIE system (Commission Internationale de l'Eclairage / International Commission on Illumination). Moreover, several color order systems specifically designed by one state institution or company, e.g., NCS (Natural Colour System® based on perceptual color model) or Pantone® Inc. (based on CMYK model) are available, yet lack universal applicability.

[15] The CIE tristimulus values X, Y, and Z are applied to describe a color and are considered to be the amount of three matching visual sensations, required to match the color of the stimulus under consideration. Hunt and Pointer 2011, 28.

[16] L* of 100 corresponds to a perfect white; L* of 0 indicates a perfect black.

[17] In 1976 the CIE developed a color difference equation referred to as CIE 1976, which was improved in 1994 (i.e., CIE94). Subsequently, the formula was modified and corrections were implemented, which led to the now recommended CIEDE2000 formula. CIE 2001; Fairchild 2005.

[18] ASTM 2015a; CIE 2004.

**Fig. 5.** Handheld spectrophotometer used here for on-site color measurements on an outdoor painted sculpture.

Before collecting data from reference coupons it is beneficial to define as many parameters as possible for the operation of the spectrophotometer. The following settings are adopted from general CIE recommendations[19] and the international standards ASTM E 805, ASTM E 1164, ISO 11664, and SAE J1545.[20]

A spectrophotometer with an integrating sphere[21] and the related data processing software should be used if possible; handheld, noninvasive instruments are user-friendly and are already common tools among conservators and conservation scientists (fig. 5). To guarantee data translation when using instruments from different manufacturers and to ensure compatibility with future software changes, it is good practice to export all data as CSV format into a spreadsheet software program like Microsoft Excel or Apache OpenOffice Calc.

We recommend applying the CIE 10° standard observer and the illuminant D65 (color temperature of 6504K), which represents average daylight. CIE illuminant A should be used to check for metamerism.

For most purposes it is sufficient when the instrument's photo detector covers a wavelength range from approximately 380 to 780 nm and samples at an interval of 5, 10, or 20 nm.[22] Many instruments are equipped with interchangeable apertures; in general a wide aperture is recommended, especially when the surface is very uneven. Care has to be taken to document and apply the same aperture for subsequent measurements.

Normally spectrophotometers equipped with an integrating sphere can measure color using two different illuminating and viewing geometries simultaneously, that is, the SPIN (specular component included, i.e., including the reflected gloss) and the SPEX (specular component excluded, i.e., only the reflected color of the object) modes. It is recommended that measurement be taken with both SPIN and SPEX. However, if one does not have access to an instrument with an integrating sphere, the geometry used should be recorded accurately. The results recorded in SPIN mode are often recommended for color control, in particular where gloss is captured separately, as described below.[23]

Prior to the first measurement a calibration procedure should be performed in accordance with the manufacturer's manual. Because slight differences exist between instruments, in addition to internal calibration, calibration should be performed on calibration tiles such as spectralon tiles, NPL tiles, or a cyan or green tile (red and yellow tiles should be avoided as they are prone to thermochromaticity). This is also useful for monitoring the instrument after it has undergone calibration. Instrument calibration should be checked once a year or more frequently if needed.

In general, it is recommended that multiple measurements (bare minimum of three) be conducted on different locations of the coupon and to calculate the mean from all results. This procedure reduces the probability that local irregularities are affecting the readings. Under certain circumstances, for example, when the surface is very uneven, more measurements should be performed in order to obtain a better mean or average. The collected data should be evaluated applying statistical methods, as described in Appendix 2. In addition to colorimetric and spectral date, the instrument conditions (geometry, aperture) should be recorded.

Even when following precise fabrication and measurement procedures, it is sometimes very difficult to repeatedly achieve the same color and gloss values, meaning the same exact positions in the color space as well as on the gloss scale. When defining acceptable deviations from the target surface, the numerical

[19] CIE 2004.
[20] See ASTM 2012a, 2012c; ISO 2007b, 2007c, 2008, 2012, 2014c; SAE 2014.
[21] A hollow sphere covered with diffuse white reflective coating to guarantee uniform light scattering. In combination with a specular port these instruments can be used to include or exclude the specular reflection during the measurements. Berns 2000, 85.
[22] Hunt and Pointer 2011, 108 f.
[23] Both illuminating and viewing geometries yield comparable results for matte surfaces; however, when applied on glossier surfaces, differences between SPIN and SPEX emerge. The SPEX mode applies a gloss trap so that mainly the diffuse reflection is measured. This evaluation correlates more to the way colors are perceived visually. The SPIN mode includes the specular component together with the diffuse reflection, which yields results for the color only while minimizing differences in gloss and surface texture. SPIN is therefore recommended for color matching and is more precise when different instruments are applied. Nassau 1998, 68 f.; Hunt and Pointer 2011, 104 f.

tolerances for change in color or gloss (i.e., maximum change acceptable to represent an artist's surface) need to be set initially by visual assessment and can thereafter be quantified with measurements, although it is much easier to measure and express acceptable deviations numerically for gloss than for color. Tolerance to deviations in color and gloss should ideally be defined for each artist's OPS appearance to be replicated in concert with the artist or the artist's representatives.

**Recommendations for Color Measurements**

- Employ a spectrophotometer with an integrating sphere.
- Apply CIELAB color space, capture L*, a*, b* values as well as the reflectance curve from 400 to 700 nm at 10 nm intervals (31-point curve).
- If color differences need to be calculated for matching or documentation, the color difference formula CIEDE2000 should be used (automatically done by many data processing softwares).
- Observer: CIE 10° standard observer.
- Illuminant: D65 (average daylight, 6504K). To check for metamerism, repeat measurements for CIE illuminant A.
- Geometry: capture both SPIN and SPEX if possible; SPEX is preferable if only one is available, but in any case document which geometry was applied.
- Calibrate the instrument prior to first measurement according to manufacturer's manual and using calibration tiles.
- Take multiple measurements (minimum of three) per coupon.
- Export data to spreadsheet and calculate statistics; report instrument model, settings and pertinent procedure, along with date and person performing the measurements.
- For special paints (e.g., metallic, fluorescent) the instruments and techniques need to be adjusted.

## 3.3. *Gloss*

The evaluation of appearance involves not only color but also geometric properties such as gloss, haze, or translucency. The interaction of these visual properties is complex and affects the observers' color perception. Although it might not be possible to fully document all the parameters affecting this perception and their

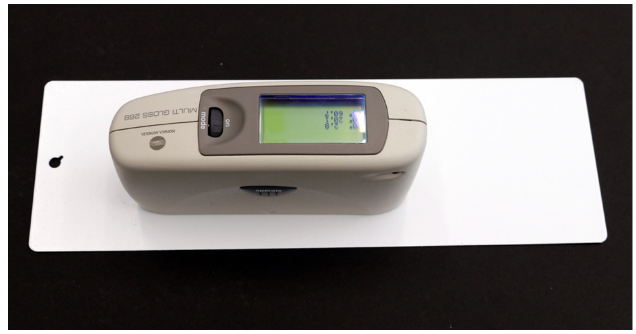

**Fig. 6.** Example of handheld glossmeter used to document the gloss of paint coupons.

interaction, it is recommended that specific features such as color, gloss, and surface texture be documented using a standardized procedure to produce results representative of a specific paint system.

For the documentation of opaque paint coupons, gloss should be measured at the geometries of 20°, 60°, and 85°, applying a glossmeter (fig. 6) or goniophotometer in accordance with ASTM D 523 and ISO 2813.[24] The results should be expressed in GU. The 60° geometry is used in order to determine which angle is the most applicable. The 20° geometry should be applied for high-gloss surfaces with more than 70 GU at 60°. The 85° geometry is applied to matte surfaces with less than 10 GU at 60°. The 60° geometry is used to evaluate and compare medium-gloss surfaces.

The glossmeter should be calibrated using a ceramic tile of 45 GU. It is recommended to apply the same procedure as that described in the section on color; multiple measurements (minimum of three) and a periodical instrument calibration are essential, along with statistical evaluation of the collected data (see Appendix 2). However, pronounced surface textures can influence the gloss values, so in these cases the number of readings should be increased and the orientation of the instrument with respect to the directionality of the surface should be indicated. Coatings with directional textures (e.g., brushstrokes) should be measured parallel as well as perpendicular to the pattern.

Additional aspects of reflection, such as haze or orange peel, and distinctness of image may be relevant for medium- and high-gloss coatings, in which case a goniophotometer would be useful although probably not necessary for most applications.[25] As discussed in the section on color, tolerance thresholds for acceptable deviation in gloss should also ideally be set by EFS.

[24] See ASTM 2014b; ISO 2014a.

[25] Hunter 1975, 65 f. Further instructions on the performance of goniophotometers can be found in Rhopoint Instruments Limited n.d.

**Recommendations for Gloss Measurements**

- Use a gloss meter.
- Record gloss measurements at 20°, 60°, and 85°; use 60° to intercompare values, 20° for high-gloss surfaces and 85° for matte surfaces.
- Express results in gloss units (GU).
- Calibrate instrument prior to first measurement according to manufacturer's manual and using 45 GU ceramic tile.
- Take multiple measurements (minimum of three) per coupon.
- Export data to spreadsheet and calculate statistics; report instrument model, settings, procedure, operator, and date.

## 3.4. *Surface Topography / Texture*

A complete analysis of visual properties might not be practical or possible, but color and gloss measurements are very helpful tools for documenting the surface of OPS in many cases, particularly for uniform, opaque surfaces. A specific surface pattern like brushstrokes can affect the perception of color and specular reflection of opaque coatings. To minimize these deviations, both instrumental and complementary visual examinations are recommended.[26]

To observe specific features and match the appearance of paint coupons against a standard, it is recommended that controlled illumination conditions (artificial daylight)[27] in variable angles be applied, which can be done in an assessment booth specified by ASTM D 1729-96, ASTM D 4449, and ISO 3668.[28] It is especially recommended to follow ASTM D 1729-96. However, it is important to distinguish between the matching of color and the matching of gloss, applying different illumination and viewing angles. The visual assessment should be accompanied by digital photography, details on the procedure of which can be found above. In addition, as paints for OPS are developed for outdoor application, the coupons should also be examined alongside the OPS during different daylight settings, where it is important to also capture different angles.

It is useful to document the visual assessment using standardized terminology to achieve precise communication of color, gloss, and overall appearance by following specific standards used in conservation surveys[29] and by the paint industry.[30]

**Recommendations for Visual Assessment and Color Matching**

- View and photograph coupons in a controlled environment (e.g., assessment booth) with simulated average daylight as diffuse illumination (e.g., illuminant D65), using standards such as ASTM D 1729-96.
- Use a neutral matte gray background.
- Change viewing and illumination angle during observation.
- Document specific surface features (e.g., orange peel).
- Perform additional evaluation and color matching comparisons outdoors against the reference after repainting.

## 3.5. *Film Thickness*

It can be beneficial to examine and document additional physical properties (e.g., film thickness, hardness) or the chemical composition of a paint coat, although, evaluation and documentation of appearance is the determining factor for paint replication. However, studies have proven that appropriate film thickness is not only essential for the stability of a coating, but it can also play a crucial role in reproducing the desired appearance. It is recommended to measure the film thickness on paint coupons in accordance with ISO 2808[31] and to verify that the coatings are applied within the tolerances set by the manufacturer. This should be performed for all coatings on the coupons.

Various methods of evaluating the thickness of an organic coating are available and can be roughly divided into measurements of dry film thickness (DFT) and wet film thickness (WFT). Several procedures for evaluating the DFT exist, but many are destructive or unfeasible because they can only be performed on free films. One

[26] Various methods to analyze surface topography, mainly imaging techniques or surface profilometry, are applied in different industries, but they are time-consuming and beyond the scope of this project. Further, they often lack correlation with the human visual system (influence of viewing distance, sample size, etc.).
[27] Additional illumination (e.g., Illuminant A) may be useful to check for metamerism of paints.
[28] ASTM 2009, 2015c; ISO 1998.

[29] Lavédrine, Fournier, and Martin 2012, 295 f.
[30] ASTM D 16 – Standard Terminology for Paint, Related Coatings, Materials, and Applications; ASTM 2014a; ASTM E 284 – Standard Terminology of Appearance; ASTM 2013d; ISO 4618: Terms and Definitions; ISO 2014b; Fitzsimons and Parry 2015.
[31] ISO 2007a.

**Fig. 7.** Ultrasonic thickness gauge applied to measure the paint DFT of a coating after curing.

nondestructive method is the application of a thickness gauge in accordance with ASTM D 6132,[32] which is placed directly onto the fully cured coating surface for the reading (fig. 7). A calibration procedure related to the substrate has to be performed prior to the first measurement and multiple readings (minimum of three) should be taken, so that a range of film thickness can be recorded and averaged.


**Fig. 8.** Notched gauge or comb used to measure the WFT during paint application.

A second option is to measure the WFT of an organic coating by relatively simple mechanical means defined in ASTM D 1212 and ASTM D 4414[33] and subsequently convert the results to predict the DFT, or vice versa.[34] The results may not be as accurate or sensitive as the ultrasonic gauge but are very useful in determining the approximate film thickness. The measurements can be easily taken during the application procedure and allow for the adjustment of the paint application. Various low-priced metal gauges, called notched gauges, combs (fig. 8), or wheels are available and need to be put in contact with the wet film immediately after the application. Multiple measurements should be taken and reported together with the gauges' specifications. Note, however, that WFT measurement methods are mostly destructive.

**Recommendations for the Evaluation of Film Thickness**

- Measure either DFT or WFT of each coating after it is applied.
  - DFT: employ a thickness gauge (nondestructive method) on fully cured paint films to get the most accurate results.
  - WFT: measure WFT in a simple manner with a notched gauge or wheel and use it to calculate the approximate corresponding DFT. These methods damage the film.
- For both methods, take several readings and record thickness range and average.

[32] ASTM 2013c.

[33] ASTM 2013a, 2013b.

[34] Two formulas exist to calculate DFT resp. WFT. The first formula is applied when no thinner was used: DFT = WFT x percentage of solids by volume (cf. TDS / MSDS). The second formula involves the addition of a thinner: DFT = WFT x (volume solids / 1 + percentage of thinner by volume). Corbett 2015, 271.

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# Appendix

## Appendix 1. Suppliers

### Aluminum Panels

Q-Lab Headquarters & Instruments Division
800 Canterbury Road
Cleveland, OH 44145, USA
Phone: +1-440-835-8700
Fax: +1-440-835-8738
info@q-lab.com
http://www.q-lab.com

Q-Lab Europe, Ltd.
Express Trading Estate
Stone Hill Road, Farnworth
Bolton, BL4 9TP England
Phone: +44-1204-861616
Fax: +44-1204-861617
info.eu@q-lab.com

### Paper Charts and Film Applicators

Leneta Company, Inc.
15 Whitney Road
Mahwah, NJ 07430, USA
Phone: 201.847.9300
Fax: 201.848.8833
sales@leneta.com
www.leneta.com

BYK-Gardner GmbH
Lausitzer Strasse 8
82538 Geretsried, Germany
Phone: +49 8171 3493-0
Fax: +49 8171 3493-140
info.BYK.Gardner@altana.com
www.byk.com

## Appendix 2. Statistical Methods

The procedure for both color and gloss measurements includes multiple readings at different locations on each coupon to collect data on the overall surface. For each dataset the average (mean), median, and standard deviation (STDEV) should be calculated. The mean values of the readings at different locations provide an overview of the data collected. The median indicates the center of the dataset and is relatively unchanged by outliers, thus giving a more accurate picture of the data. The median values should be used for the final evaluation. STDEV describes the variation in a dataset and can give important information about the precision of the measurements, in addition to pointing out irregularities. In certain circumstances it may be beneficial to also compare minimum and maximum values within one dataset.

Besides the calibration procedure, it is important to quantify the performance of an instrument by evaluating the precision.[35] One way of defining precision is to evaluate the repeatability by calculating the Mean Color Difference from the Mean (MCDM). The latter is defined as the average color difference between a set of readings and the average of that set of readings.[36]

[35] For more details on precision and accuracy of measurements, see Berns 2000, 95 f.
[36] ASTM 2012d.