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Understanding Interfaces

Using the PCA 200 handheld contact angle goniometer for fast surface energy analysis

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Reliable product performance often starts with controlled substrate surfaces. In industrial practice, surface quality control must not only provide meaningful information on wetting- and adhesion-relevant properties, but also fit into fast and robust production workflows. This whitepaper discusses contact angle measurement and surface energy analysis as practical tools for evaluating surface condition after cleaning, activation, or pre-treatment. Particular focus is placed on fast on-site measurements with the PCA 200 handheld contact angle goniometer as an alternative to conventional test ink evaluation, highlighting how quantitative, automatically documented surface data can support routine quality control in coating processes and related applications.

Surface quality control as a key factor in coating performance

The performance of a coating is strongly influenced by the condition of the substrate surface prior to coating application. Insufficient cleaning, contamination, or inadequate surface treatment can lead to poor wetting, reduced adhesion, and ultimately coating failure. As a result, surface preparation is a critical step in many industrial coating processes.

Typical surface preparation steps, such as cleaning, activation, or pre-treatment, are applied to modify the surface properties of the substrate in order to promote uniform wetting and reliable adhesion of subsequent coatings. However, the effectiveness of these preparation steps cannot be assumed and must be verified. Performing quality control after surface treatment and before coating application is therefore essential to ensure consistent coating quality (Figure 1).

Surface preparation processes are designed to intentionally alter the condition of a surface. Quality control must therefore focus on detecting whether the desired surface modification has been successfully achieved. In industrial coating environments, quality control methods must not only provide reliable and objective results, but also meet practical requirements. Measurements should be fast, robust, and suitable for routine application directly on components or large substrates.

These demands highlight the need for surface quality control approaches that can be efficiently integrated into production workflows while providing meaningful information on surface condition. Consequently, the selection of appropriate surface-related quality parameters and corresponding measurement approaches is of central importance for modern coating processes.

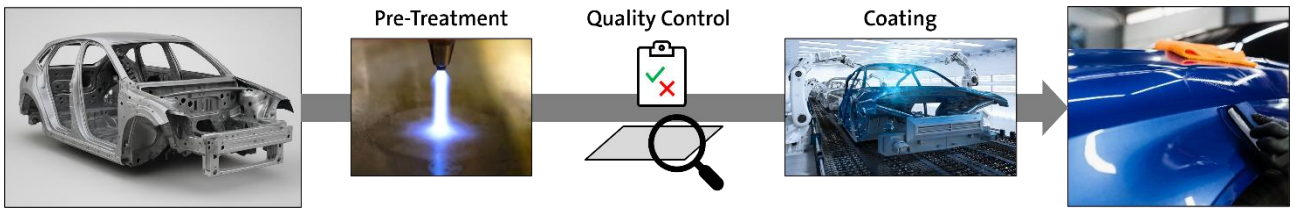

Figure 1: Illustration of a typical coating process workflow including surface pre-treatment, surface quality control, and coating application. Verification of surface properties after pre-treatment and prior to coating is essential to ensure reliable coating performance.

Contact angle and surface energy as relevant quality control parameters

For quality control it is necessary to evaluate surface properties that change as a result of the performed surface preparation steps. One of the most direct and practically relevant effects of such changes is the wetting behaviour of a surface, which strongly influences subsequent coating and adhesion processes. Wetting behaviour can be described quantitatively by the contact angle, which provides a sensitive and application-oriented measure for detecting changes in surface condition caused by cleaning, contamination, or surface treatment, and, hence, for assessing surface quality.

It should be noted, however, that the contact angle does not represent an intrinsic property of the solid surface alone. According to Young's equation[1]

$$\sigma_s = \gamma_{sl} + \sigma_l \cdot \cos\theta \qquad (1)$$

the measured contact angle θ is determined by the balance of the solid surface energy σ_s, the solid–liquid interfacial energy γ_{sl}, and the liquid surface tension σ_l (Figure 2). Consequently, contact angle values depend on both the surface properties of the solid and the liquid used for the measurement, and may therefore vary for the same surface when different liquids are applied.

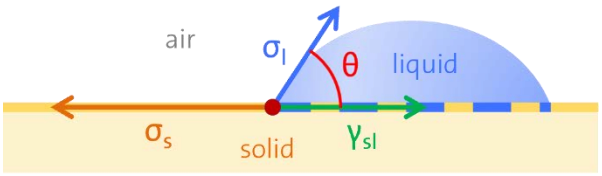

Figure 2: Contact angle at the solid–liquid–air interface illustrating Young's equation.

In contrast, the surface energy is a liquid-independent and characteristic property of the solid surface. Surface energy can be subdivided into different contributions, such as dispersive and polar components (σ_s^d and σ_s^p), which reflect the chemical nature of the surface and its interaction potential with other materials. As illustrated in Figure 3, these components, and particularly their ratio, determine the extent of possible interactions between a solid surface and a contacting material and are therefore directly related to the observed adhesion behaviour.[2]

As just discussed, contact angle and particularly surface energy are practically relevant and well-established parameters for surface quality control in coating processes. The determination of these parameters can be realised using different measurement approaches, which are addressed in the following section.

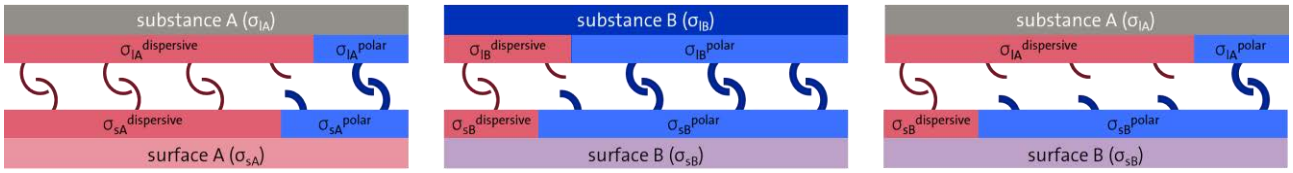

Figure 3: Schematic illustration of two solid surfaces A and B with different ratios of dispersive and polar surface energy components interacting with two substances A and B that also exhibit different σ^d/σ^p ratios. When the ratios of dispersive and polar components are similar (left and middle), a high interaction potential is obtained. In contrast, dissimilar σ^d/σ^p ratios (right) result in a reduced interaction potential.

Measurement approaches for surface quality control

Approach 1: ***Use of test inks as a simplified approach for surface energy determination***

Test inks represent a simple and widely used approach for the estimation of the surface energy of solid substrates. The method is based on the application of a set of test inks with defined and different surface tension values (Figure 4, left).

During testing, the inks are applied to the solid surface, and the wetting behaviour is visually evaluated. A direct measurement of the contact angle is not possible using this approach. Instead, the method makes use of the general relationship between the surface tension of a liquid and its wetting behaviour on a solid surface with a given surface energy. With decreasing surface tension of the applied liquid, the resulting contact angle becomes smaller.

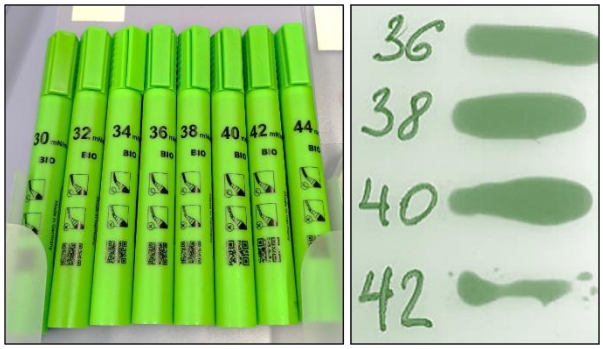

Figure 4: Test ink set (left) and illustration of the test ink application procedure on a solid surface (right).

At sufficiently low surface tension, the liquid spreads on the surface, corresponding to a contact angle of 0°. In this case, Young's equation (1) simplifies, as cos 0° = 1. If the solid–liquid interfacial energy is neglected, the surface energy of the solid can be approximated by the surface tension of the spreading liquid.

For this reason, the inks of a test ink set are applied sequentially in order of decreasing surface tension until the ink that no longer contracts on the surface is identified (Figure 4, right; from bottom to top). The surface tension value of this spreading ink is then taken as an approximate value for the surface energy of the solid substrate.

Approach 2: ***Optical contact angle measurement and subsequent calculation of surface energy***

If surface energy is not only to be estimated but determined quantitatively, contact angles must be measured and wetting behaviour must be evaluated beyond a qualitative assessment. Optical contact angle measurements provide this information by determining the contact angle formed between a test liquid of known surface tension and the solid surface under investigation. The physical basis of this approach is again given by Young's equation (1), which relates the measured contact angle to the surface energy of the solid.

In contrast to the test ink approach, the interfacial energy between solid and liquid is not neglected. Instead, it is described using a mathematical model. A widely used and well-established approach is the Owens-Wendt-Rabel-Kaelble (OWRK) model[2]

$$\gamma_{sl} = \sigma_s + \sigma_l - \{2 \cdot [\sqrt{(\sigma_s^d \cdot \sigma_l^d)} + \sqrt{(\sigma_s^p \cdot \sigma_l^p)}]\} \quad (2)$$

which expresses the interfacial energy γ_{sl} as a function of the dispersive and polar components, σ_l^d and σ_l^p, of the liquid surface tension σ_l, and the corresponding components σ_s^d and σ_s^p of the solid surface energy σ_s.

While the dispersive and polar components of the test liquids must be known, the respective components of the solid surface energy are calculated from the measured data. Since there are two unknown quantities, namely σ_s^d and σ_s^p, contact angle measurements must be carried out for at least two different test liquids. The total surface energy σ_s is finally obtained as sum of its determined dispersive and polar components.

From a metrological point of view, optical contact angle measurements are realised by applying a defined liquid droplet to the surface and evaluating the shape of this sessile drop in a projection image from the side. Hence, a typical measurement setup comprises a liquid dosing system for controlled droplet formation and an optical system with a camera and an oppositely positioned light source for high-contrast imaging. Moreover, dedicated software is used for image evaluation and contact angle determination as well as for subsequent surface energy calculation.

One implementation of the described measurement principle is found in advanced laboratory-based instruments, as, for example, in the goniometers of the OCA series from DataPhysics Instruments. Such instruments offer a wide range of options, including the use of various exchangeable dosing systems or special sample chambers for controlling ambient conditions like temperature or humidity; they also enable a wide variety of methods to be carried out besides surface energy determination.

For surface quality control purposes, many sophisticated measurement options are not required. In fact, samples are preferably tested directly on-site, rather than taking them to the laboratory. Compact handheld contact angle goniometers, like the PCA 200 from DataPhysics Instruments (Figure 5), constitute a convenient solution for this requirement. The low-weight, battery-powered device comprises two pressurised test liquid cartridges filled with water and diiodomethane (Figure 5 middle). After positioning on the surface, a single click on the measuring button initiates an automatic procedure: First, the two liquids are simultaneously dosed onto the surface forming two sessile drops; then an image of the

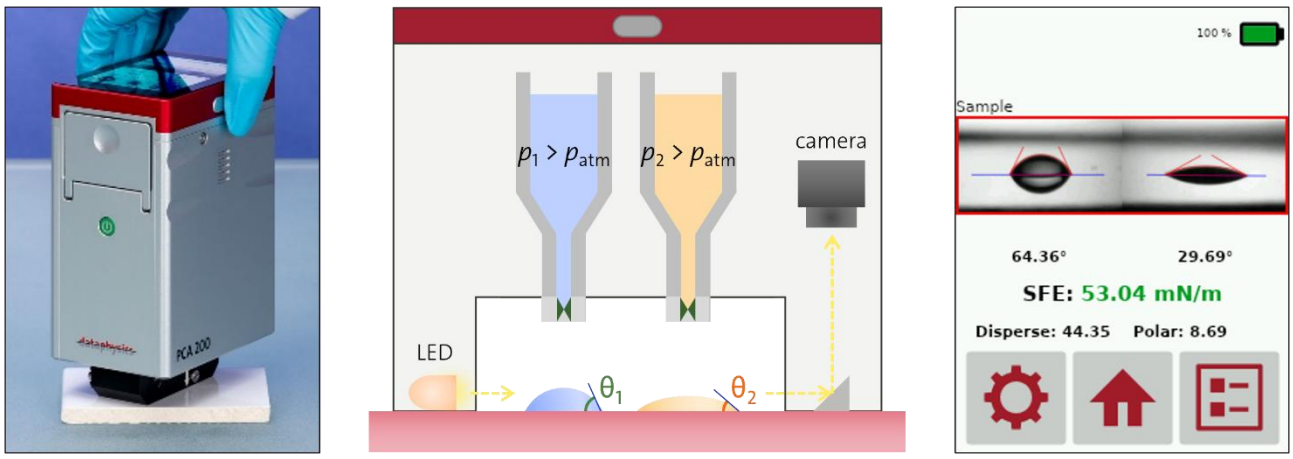

Figure 5: Handheld goniometer PCA 200. The schematic representation in the middle shows two pressurised test liquid cartridges and the optical elements for capturing drop images (note that, in reality, the two drops are side by side, not one behind the other). The result presentation on the instrument display is shown on the right.

drops, which are illuminated by an LED light source, is captured by an integrated camera over a prism. The device incorporates a mini-computer with analysis software and result storage as well as a full-colour touchscreen where the obtained surface energy is displayed within seconds (Figure 5 right). For seamless use also by inexperienced QC staff, it is possible to reduce the displayed result to a simple colour-coded "ok" / "not ok" upon pre-set acceptance values. An integrated barcode scanner can be used for quick and unambiguous sample identification.

Contact angles measured with the handheld device are in good overall agreement with those measured using a laboratory goniometer. This is illustrated by comparative contact angle measurements on four representative technical substrates, namely a hydrophobic surface, a silicon wafer, a polyethylene film and a copper sheet, with water and diiodomethane as typical test liquids for surface energy determination. Figure 6 summarises the results and supports the suitability of handheld goniometers for quantitative on-site surface characterisation.

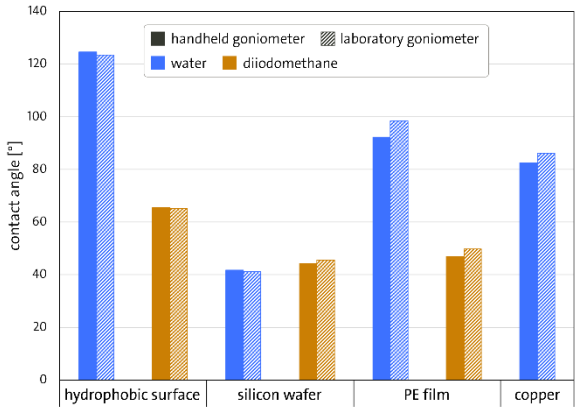

Figure 6: Comparative contact angle measurements on four substrates using a handheld and a laboratory goniometer.

Practical comparison of on-site quality control approaches: Test inks vs. PCA 200 contact angle goniometer

In order to compare different approaches for surface quality control under practical on-site conditions, the surface energy of four representative technical substrates was determined using test inks as well as the handheld contact angle goniometer PCA 200. The investigated materials included a plastic card, a varnished surface, an aluminium plate, and a silicon wafer.

Figure 7 provides an overview of the tested samples and illustrates the surface areas required for the respective measurements. Here, a first clear difference between the two approaches becomes apparent: The two test liquid droplets applied by the handheld goniometer are small and confined to a surface area of approximately 10 × 5 mm². In contrast, test ink evaluation requires a significantly larger area, since several inks with different surface tension values have to be applied sequentially until spreading is observed. Hence, the total area required for applying five to seven test inks on the example substrates ranged from approximately 30 × 20 mm² to 45 × 20 mm².

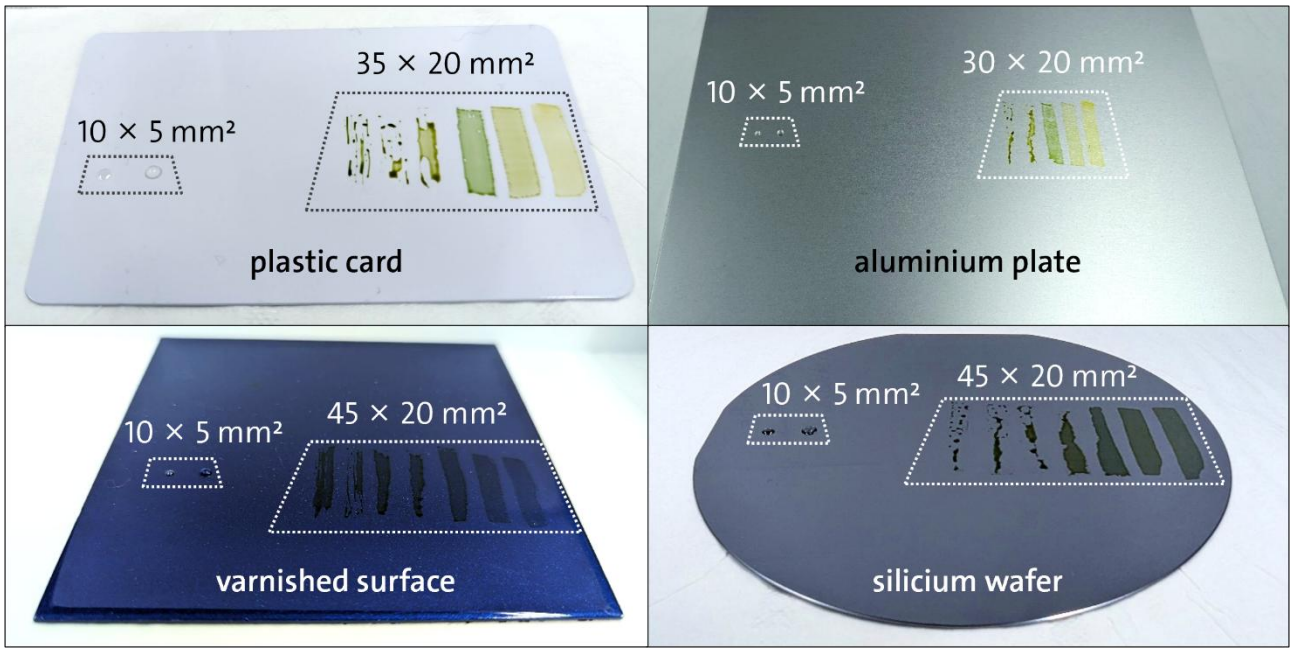

Figure 7: Overview of the investigated substrates and illustration of the surface areas required for on-site surface quality control using the handheld contact angle goniometer (left) and test ink evaluation (right).

The resulting surface energy values obtained by both methods are summarised in Figure 8. Using test inks, a surface energy of 34 mN/m was obtained for both the plastic card and the varnished surface, while a value of 32 mN/m was determined for the aluminium plate and the silicon wafer. More precise results are not possible due to the discrete nature of the test ink method as the possible result values are limited to the surface tension values available in the employed test ink set. As a consequence, different materials may yield similar surface energy estimates, even though their surface properties differ.

In contrast, the handheld contact angle goniometer provides quantitative surface energy values with high resolution, allowing even small differences between samples to be resolved. More importantly, the method not only yields total surface energies but additionally their dispersive and polar contributions, since a model based on these contributions is used for the solid–liquid interfacial energy rather than neglecting it as in the test inks approach. This may also explain why the values obtained with the goniometer are generally higher than those determined using test inks. Figure 8 shows that there are indeed pronounced differences between the polar contributions of the investigated substrates' surface energies. These differences are not accessible using the test inks approach, yet are highly relevant for assessing surface interactions and adhesion behaviour in coating applications.

Beyond the absolute measurement results, practical aspects are of particular importance for on-site quality control. Test ink evaluation relies on visual assessment of the wetting behaviour, which introduces a degree of subjectivity and operator dependence. Moreover, results must be documented manually, which can be prone to errors. Handheld contact angle measurements, on the other hand, provide objective, automatically evaluated results that are stored digitally and can be traced back to individual samples.

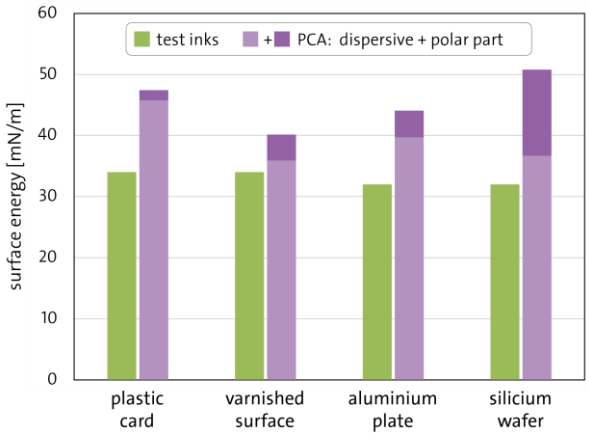

Figure 8: Comparison of surface energy values obtained using test inks (green) and a handheld contact angle goniometer (purple) for different technical substrates. In addition to total surface energy, the handheld goniometer PCA 200 provides the dispersive (light purple) and polar (dark purple) contributions.

Further aspects to consider include the time required to carry out a quality control measurement as well as subsequent cleaning steps that might be necessary. The test inks approach requires several inks to be applied one after the other, which makes the procedure comparatively time-consuming. For the example substrates described here, the time required ranged between 45 s for the plastic card and the aluminium plate, 60 s for the silicon wafer and up to 80 s for the varnished surface. In contrast, the automated measurement procedure of the handheld goniometer is considerably faster, with results obtained in about 3 s. Another advantage is that the test liquid droplets applied with the goniometer are very small, so that they can evaporate or easily be removed. The applied test inks, in contrast, contaminate much larger surface areas, as was described above. Hence, more extensive cleaning may be required before further processing.

Overall, the described practical comparison between test inks and the handheld goniometer PCA 200 for surface energy determination in quality control demonstrates clear differences between the two approaches in terms of required measurement area, result value resolution and informational content, as well as with respect to operator dependence, result documentation, and time and cleaning requirements. An overview of those differences is given in Table 1.

Table 1: Comparison of on-site surface quality control approaches

Aspect	***Test inks***	***PCA 200 contact angle goniometer***
Measurement principle	Estimation of surface energy based on visual evaluation of wetting behaviour	Model-based calculation of surface energy based on optical contact angle measurements
Used liquids	Set of test inks with defined surface tensions (often in steps of 2 mN/m)	Two or more test liquids with known surface tension including its components
Obtained result	Total surface energy only	Total surface energy together with surface energy components (dispersive, polar)
Result type and resolution	Discrete surface energy value, limited to the surface tension values of the used test inks	Quantitative surface energy value with high resolution (continuous values)
Required measurement time	Comparatively long (here: 45–80 s), due to sequential test ink application	Short (~ 3 s), due to automated measurement procedure
Operator influence	High (visual assessment)	Low (automatic evaluation)
Documentation	Manual	Automatic digital storage
Required measurement area	Relatively large area (~ 30 × 20 mm² to 45 × 20 mm²), due to sequential application of multiple inks	Very small local area (~ 10 × 5 mm²) for placement of two small liquid droplets
Surface contamination and required cleaning	Significant; ink residues remain which often requires cleaning	Minimal; small droplets evaporate or are easily removed without extensive cleaning
Suitability for routine QC	Limited	Well-suited

Summary and Conclusions

This whitepaper has addressed the determination of surface energy as a key parameter for surface quality control in coating processes, with a particular focus on practical measurement approaches suitable for on-site use. After outlining the relevance of surface wetting and surface energy for assessing surface condition and adhesion behaviour, different approaches for surface energy determination were discussed and compared.

Optical contact angle measurements were shown to provide a quantitative and physically well-founded access to surface energy based on Young's equation and established evaluation models. In contrast to simplified approaches such as test ink evaluation, contact angle measurements allow surface energy to be determined with higher resolution and, in addition, enable the separation into dispersive and polar contributions. This additional information is particularly relevant for assessing surface interactions and adhesion performance in coating applications.

A practical comparison demonstrated that the compact handheld contact angle goniometer PCA 200 from DataPhysics Instruments enables quantitative surface energy analysis directly on-site, without the need to transfer samples to the laboratory. Due to the small required measurement area, automated evaluation, digital documentation, and short measurement times, the handheld device is well suited for routine quality control in production environments. The automated and time-efficient measurement procedure allows surface energy to be determined rapidly within just a few seconds.

Overall, the presented results show that the handheld contact angle goniometer PCA 200 represents an effective tool for fast, quantitative surface energy analysis in surface quality control, complementing or replacing simplified methods where higher information content, objectivity, and efficiency are required.

References

[1] T. Young, *An Essay on the Cohesion of Fluids*, Philosophical Transactions of the Royal Society of London, **95** (1805), 65–87.

[2] D. K. Owens, R. C. Wendt, *Estimation of the surface free energy of polymers*, Journal of Applied Polymer Science, **13** (1969), 1741–1747.

Note on the origin of this whitepaper:

This whitepaper is an adapted version of the paper *'Using a Handheld Contact Angle Goniometer For Fast Surface Energy Analysis'*, written by Dr. Michaela Laupheimer[1], originally published in the proceedings of the American Coatings Conference 2026 in connection with the corresponding conference contribution by Daniel Scholz[1] and Paul Simutis[2].

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