Why Surface Measurement Matters in Medical Device Manufacturing

Better adhesion, reliable coatings, and validated processes start with understanding surface energy and wetting

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Introduction – it is often about wetting

Surface phenomena are complex, and fundamental to medical device designers and manufacturers. "There is a huge amount of applications and technologies that rely on the properties of the surface and the interface over anything else," said Adam Foster, the theoretical and computational physicist who specialises in the study of surfaces and interfaces at the nanoscale. Often, our relatively simple perception of a surface phenomenon is wetting - the spread and the intimate contact of our adhesives, inks, coatings or other liquids to our solid substrate. Wetting is an important factor both for device manufacture (i.e. for good adhesion) and for device performance (i.e. for coating function).

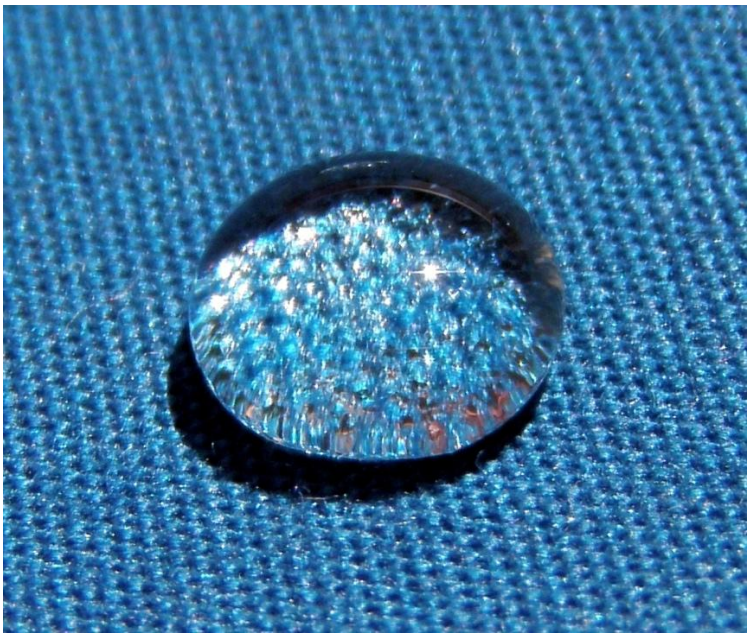


Figure 1 - A water droplet not wetting a piece of cloth

Wetting depends on a relationship between energies. Let's look at this relationship; understanding the factors involved, and what you can do to optimise them, will help you in the design and material selection for a robust and reliable medical device.

Wetting and adhesion
Wetting is a prerequisite of adhesion. Medical device manufacturers rely on adhesion if they are bonding, printing on, or applying functional coatings to their products. Of the many medical devices where bonding or coating is required, good adhesion is the basis of the performance, the longevity, and ultimately, the safety of the device.

A plethora of surfaces
Medical devices are made from many different materials. You'll find familiar ones such as polycarbonate (PC), ABS, PMMA, stainless steel, titanium, glass, and various elastomers. Others are more specialised but also used in MedTech manufacturing — Nitinol for stents and guidewires, PEBA and TPU for flexible tubing and catheters, PEEK for high-strength components, and COP or COC for microfluidic cartridges and drug-delivery systems are examples. Each substrate has its own surface characteristics, which influence how well adhesives, inks, or coatings will wet and adhere.



Figure 2 – Medical devices are made from many different materials

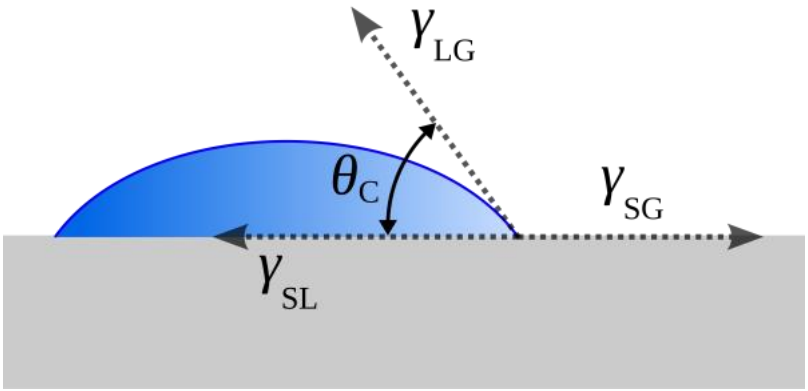
The adhesion to that substrate must be strong enough to withstand the mechanical stresses of use and processing, and reliable enough to perform consistently across batches and over the product's lifetime. "Reliable" means that this performance is repeatable and durable, supported by controlled manufacturing processes and documented evidence that satisfy regulatory expectations for patient safety and device integrity.

Surface properties – surface energy, surface tension and wetting
All substrates have a surface energy (or surface free energy). Surface energy is the excess energy found at a solid's surface, where atoms or molecules have incomplete bonds and a tendency to attract other substances. It represents how much a surface "wants" to interact

chemically or physically with its surroundings. A high surface energy material, such as clean metal, glass, or ceramic, provides many available bonding sites, and so liquids like adhesives, inks, or coatings can spread out and make close, uniform contact. Low surface energy materials, such as polyethylene, polypropylene, or PTFE, have few of these sites and tend to repel liquids, causing them to bead up instead of wetting the surface.

All liquids have a surface tension, a property that reflects how strongly the molecules attract one another. It arises from an imbalance in cohesive forces at the liquid surface, where molecules are pulled inwards by their neighbours. This produces a 'preference' to minimise the liquid surface area and so the higher a liquid's surface tension, the more it resists spreading for a given solid surface energy and the more likely it is to bead up.

Wetting is a prerequisite of adhesion, and for wetting to occur, there must be a balance between the surface energy of the solid and the surface tension of the liquid. Whether a liquid wets a solid, and therefore whether the pairing facilitates proper adhesion, depends on the relationship between these two properties. For wetting to occur, the surface energy of the solid must be greater than the surface tension of the liquid. When this condition is met, the liquid can spread out across the surface, maximising contact and promoting adhesion. If



the surface energy is lower, the liquid beads up and fails to wet, leading to poor adhesion

Figure 3 - Wetting angle: the balance of surface energy and surface tension forces at the solid/liquid interface determine whether a liquid spreads (good wetting, small θ) or beads up (poor wetting, large θ)

Wetting and contact angle

Wettability can be quantified by measuring the contact angle formed where the liquid, solid, and air meet. Using an optical tensiometer, manufacturers can evaluate the wetting of liquids like adhesives, inks and coatings on specific substrates. A smaller contact angle for a liquid droplet indicates better wetting and, typically, stronger potential adhesion. Where wetting is required to a specific substrate, liquids with appropriate surface tension (as well as other factors like rheology) will need to be considered. Understanding this relationship helps manufacturers select and prepare materials to achieve consistent wetting and dependable adhesion.



*Figure 4 – An **optical tensiometer** measures contact angle and allows assessment of surface energy and wetting*

This becomes important in medical device manufacturing when materials with low surface energy are design choices; they can have attractive properties like chemical resistance, flexibility, or biocompatibility which are functionally desirable. Polyethylene, polypropylene, PTFE, TPU, silicone and PEBA are good examples. But their low surface energy makes wetting and adhesion more challenging.



*Figure 5 – **Contact angle measurements** can be made directly on production parts at the point of manufacture*

Surface treatment

To improve adhesion on low surface energy materials, manufacturers can use surface treatments such as plasma or corona discharge. These processes both micro-clean and activate the surface. They remove weak boundary layers like oils, mould-release residues, or organic contaminants, and at the same time modify the surface chemistry to increase surface energy. **Plasma treatment** introduces oxygen- or nitrogen-containing functional groups, creating polar sites that promote stronger chemical interaction with adhesives, coatings, or inks.



Figure 6 – Plasma treatment of polymers used in medical devices activate and micro-clean the surface

The effectiveness and consistency of plasma surface treatment can be evaluated by measuring contact angle before and after processing. This provides quantifiable evidence that the treatment has increased surface wettability, supporting both process development and validation. Recording these measurements creates an auditable link between surface preparation and final product performance, providing objective evidence to support ISO 13485 and FDA 21 CFR 820 requirements. Once surfaces have been treated or cleaned, their readiness can be checked using quick, qualitative or quantitative methods.

Qualitative surface energy assessment

A simple method for assessing surface energy is the use of **Dyne test inks**. These are often supplied in a pen. When the test ink is applied to the surface, the liquid will either form a continuous film (wet) on the surface or pull back into small droplets (not wet). If the Dyne test fluid remains as a film for 3 seconds, the substrate will have a minimum surface energy of that ink value, expressed in mN/m (Dynes). Should the Dyne test liquid reticulate or draw back into droplets in less than one second then the surface energy of the substrate is lower

than that of the liquid itself. The exact surface energy (Dyne level) can be determined by applying a range of increasing or decreasing values of Dyne test fluid.



Figure 7 – Dyne inks, often applied by pen, indicate wetting and can give an assessment of surface energy

As well as quick tests in the lab, Dyne test inks can be used as a “go/no-go” test for the surface energy of treated polymer films prior to printing in medical packaging.

Coatings and adhesion

Coatings on medical devices enhance performance and safety by improving biocompatibility, reducing friction, preventing bacterial adhesion, or delivering drugs. Their success depends not just on chemistry but on how well they adhere to the device and withstand biological and mechanical stress. For example, hydrophilic coatings on catheters reduce friction and infection risk, while drug-eluting stents rely on firm adhesion for controlled release. Poor bonding can lead to delamination, compromising function and safety. Because coated devices face fluids, movement, and sterilisation, the evaluation of contact angle will assist in optimising adhesion, essential during design and quality control.

Coatings – beyond adhesion

But adhesion is only part of the story. For both hydrophilic and hydrophobic coatings, surface wettability also governs how the device performs in biological environments. Measuring contact angle on a coated medical device offers a practical, non-destructive way to evaluate how the coating will behave in real-world use. For hydrophilic and hydrophobic coatings alike, the contact angle reflects surface wetting behaviour - a property closely linked to how a device interacts with biological fluids. In hydrophilic coatings, lower contact angles indicate good wettability, which can improve blood compatibility, reduce protein adsorption, and minimise bacterial adhesion. In hydrophobic coatings, higher contact angles

confirm the desired resistance to wetting, helping to repel fluids and protect underlying surfaces.

Beyond assessing functionality, contact angle measurement is a sensitive diagnostic tool for coating uniformity and consistency. Variations in measured values across a part can reveal uneven coating thickness, incomplete curing, or localised contamination. Monitoring contact angle over time also helps detect surface ageing or degradation, providing early warning of changes that could affect performance or compliance. Because it is quick, repeatable, and quantitative, contact angle measurement supports both process validation and ongoing quality assurance - giving manufacturers objective evidence that each coating meets its intended performance criteria.

Case study – hydrophilic coating performance

Hydrophilic coatings are often applied to improve the wetting and lubricity of polymer medical devices such as urinary catheters. In a recent case study, *Evaluation of Biomedical Coating with Contact Angle Measurements*[1], PVC catheter substrates were dip-coated with a UV-cured hydrogel formulation and evaluated using static water contact angle measurement with an optical tensiometer. Compared with uncoated PVC, the coated samples showed a significantly lower contact angle, demonstrating far greater hydrophilicity - water almost completely wetted the surface.

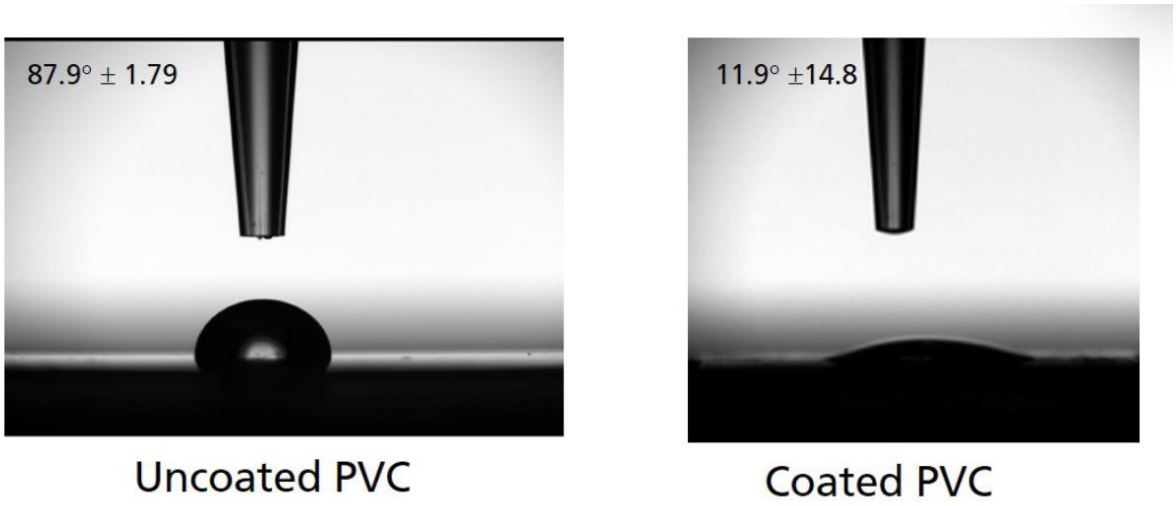


Figure 8 – Coated PVC catheters show a much lower contact angle compared to uncoated, as measured with an optical tensiometer

This increase in wettability was attributed to the hydrophilic functional groups introduced by the coating, which created a stable hydration layer. The hydrated surface reduced frictional resistance during catheter use and limited bacterial colonisation by acting as a physical barrier to adhesion. The study illustrates how contact angle measurement can quickly quantify improvements in surface hydrophilicity and correlate them with clinically relevant performance benefits such as reduced trauma, infection risk, and patient discomfort.

Case study – contact lenses

Wettability is critical to the comfort and performance of contact lenses, as it determines how well the tear film spreads across the surface. Poor wettability can cause lens dehydration, surface deposits, reduced visual performance, and discomfort for the wearer. Silicone hydrogel materials, now common in long-wear lenses for their high oxygen permeability, tend to be less wettable than traditional hydrogels. To overcome this, manufacturers use plasma treatments or hydrophilic coatings to increase surface energy and improve tear film stability without sacrificing oxygen flow.



Figure 9 – Wettability of the contact lens surface affects both the tear film as well as biocompatibility of the lens

Contact angle measurement provides a practical way to quantify lens wettability and to compare the effects of different surface treatments[2]. A captive bubble method offers the best technique to mimic the real-life situation. The contact lens surface is immersed in a liquid throughout the measurement process and so does not dry out. An air bubble is used to measure the contact angles. By analysing advancing and receding contact angles, manufacturers can assess how well a lens supports a continuous tear film during blinking, linking laboratory measurements directly to wearer comfort and biocompatibility.

Regulatory compliance and traceability

Requirements for traceability and process validation in MedTech manufacturing, such as ISO 13485:2016 and FDA 21 CFR 820.75, are rigorous. Where processes like surface preparation or coating cannot be fully verified through post-production inspection, they must be validated and documented with objective evidence. Surface measurement can provide that evidence. Measuring surface energy or contact angle before and after a treatment step quantifies whether a surface has been sufficiently activated or cleaned for bonding, coating, or printing. Instruments such as optical tensiometers offer traceable, repeatable data that can be linked directly to batch records and device history files. Including these results in validation protocols supports both process qualification and ongoing monitoring, giving

auditors and manufacturers confidence that every device meets its defined adhesion and performance requirements.

Modern optical tensiometers, such as the Biolin Scientific Attension Theta series, include software that helps make surface measurement data fully traceable and audit-ready. Each contact angle or surface energy reading is automatically recorded with time, operator, method, and environmental conditions, creating objective evidence for validation records. Standardised measurement protocols minimise operator variation, while built-in statistical tools track process stability over time. Detailed reports with embedded images and calibration data can be exported directly into quality management systems, supporting ISO 13485 and FDA 21 CFR 820 documentation. This transforms contact angle measurement from a laboratory test into a repeatable process-control tool for MedTech manufacturing.

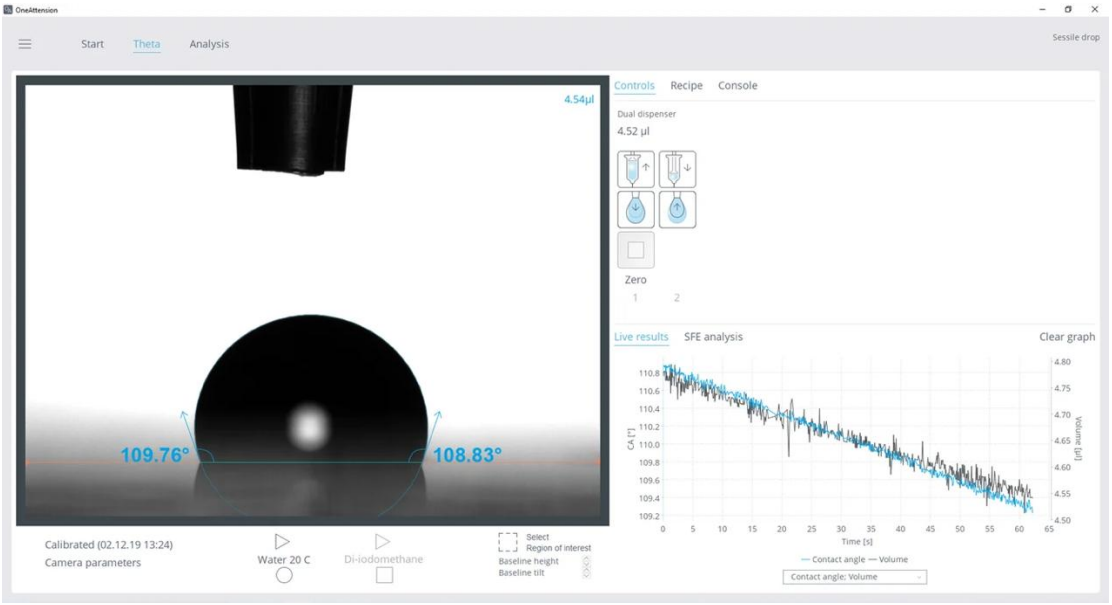


Figure 10 – Optical tensiometer software should facilitate contact angle measurement data collection, recording and analysis

Summary

Understanding and controlling surface properties like wetting is essential to achieving reliable, high-quality medical device manufacturing. Whether bonding, printing, or coating, the interface between solid and liquid phases determines how well materials interact and perform. Measuring surface energy and contact angle provides quantifiable, traceable evidence of surface readiness and performance, helping you validate processes that can't be inspected after assembly. Surface condition is often invisible — yet it drives adhesion, coating reliability, and compliance. Measuring it turns an unseen risk into a controlled parameter that underpins both product quality and patient safety.

About the Authors

Alison Fox, Dyne Testing Sales Manager, Intertronics

With more than 14 years at Dyne Testing, Alison joined Intertronics as part of our acquisition of Dyne Testing in Spring 2024. Her technical expertise in surface preparation and measurement is hugely valuable to our customers in markets such as medical device, electronics, automotive, aerospace and battery – to name a few.

Conor Kelly, Dyne Testing Sales Specialist, Intertronics

Conor is our resident surface scientist. With a BSc (Hons) in Physics from York University, he can often be found delivering demonstrations or trials to our customers in our Technology Centre or sharing his learnings with the wider Intertronics team to support in making customer's applications a continued success.

References

1) *Evaluation of Biomedical Coating with Contact Angle Measurements* – published by Biolin Scientific
2) *How to study the wettability of the contact lens?* – published by Biolin Scientific

Picture credits

Figure 1 - Wikipedia
Figure 2 - Pexels
Figures 3, 4, 8, 9, 10 - Biolin Scientific
Figure 5 - Brighton Science
Figure 6 - relyon plasma
Figure 7 - Dyne Testing/Intertronics

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About Dyne Testing

Dyne Testing, an Intertronics brand, works with you to understand your material properties by supplying you with instrumentation and tools for surface measurement, testing, and analysis. Our surface energy, surface tension, cleanliness, adhesion, coating and substrate thickness and other inspection products are used in industrial applications to provide quality assurance, process optimisation, and performance enhancement. Improve your productivity and profitability.

About Intertronics

We support you with your material choice, process development, ongoing production, and product supply, whether it's the adhesives, coatings and sealants themselves or the equipment you need for application, curing, surface preparation and measurement.

Partnering with you for your bonding and assembly process, we help you to limit risk, boost productivity, and accelerate learning through the expertise and experience of a team that's invested in your success. We work hard to be your favourite supplier by being responsive, supportive and easy to do business with.

Let's start by talking about your application.

More questions?
Please call us on **01865 842842** or email **info@intertronics.co.uk**

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