Article Identifier
DOI: 10.22032/dbt.58676
URN: urn:nbn:de:gbv:ilm1-2023isc-039:2

60th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 4 – 8 September 2023
URN: urn:nbn:de:gbv:ilm1-2023isc:1

STUDY OF THE EFFECT OF MATTING AGENTS ON THE MEASURABILITY OF GEOMETRICAL OBJECTS

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1. ABSTRACT

Optical metrology has witnessed remarkable advancements over the past few years and increased its applications in many different fields. This study focuses on the effects while using a form of matting to reduce reflective effects to improve the measurements. However, challenges such as surface reflections and illumination issues must be addressed to ensure error-free measurements. Both the effectiveness of these surface treatments and the associated deviation of the values get investigated. In addition, data from three measurement devices are used to obtain the required values with state-of-the-art accuracy. The experimental analysis of the effectiveness of the different matting methods takes at least 13 distinct methods and products into account.

2. INTRODUCTION

Optical metrology, an advanced and highly regarded technology that has continually pushed the boundaries of technical innovation, has recently seen a remarkable increase in its range of applications. In the past, many tasks could only be measured in a tactical manner. However, the field has undergone profound improvements, allowing optical measurements to be made seamlessly and quickly for tasks previously limited to tactile approaches. While the expansion of application areas has contributed to this development, it is primarily due to continued advances in accuracy, increased flexibility, and decreasing cost per measurement. Other benefits, in addition to those already mentioned, include improved handling safety and ease of use. By eliminating tactile components, these systems can be operated by inexperienced operators after appropriate training, resulting in less downtime due to probe breakage or the need to retool for different measurement tasks. Despite these advantages, there are disadvantages to consider, such as susceptibility to optical interference, disturbing lighting, or surface reflections. Metrology systems typically work by detecting or assigning clearly identifiable optical features such as edges, holes, or curvatures. To fully utilize the capabilities of metrology systems, error-free measurement is essential and can be achieved by using tools such as matting to reduce the effects of reflections.

Applications such as quality assurance, digital design or reverse engineering all depend on accurate measurements. Unacceptable deviations due to large amounts of applied material or persistent measurement problems result in significant additional costs or even incorrect measurements. The possibilities and limitations or dependencies of different matting parameters or matting agents are discussed and investigated in this paper.

3. CLEANING OF MEASUREMENT SURFACE

Regardless of the media chosen, cleaning with isopropyl alcohol and a cloth is possible in all cases. However, cleaning without sublimation may be necessary, in which case delicate geometries pose a problem. A final cleaning should be possible in any case, because depending on the test object, a return to the production cycle may be necessary, considering the degree of cleanliness in the different industrial sectors. In this case, sublimation is the simplest method, as manual cleaning is more difficult and time-consuming, especially for more complex geometries. In the case of large and simple objects, cleaning is unproblematic as it can be done with a cloth. A further basis for decision-making is, of course, the expected number of objects over a defined period of time. Depending on the type of matting used, automated cleaning may not be feasible, whereas ejection from the regular cycle for a few hours can be easily integrated into the measurement cycle.

4. MEASUREMENT DEVICES

4.1 Atos Core (GOM)

The ATOS Core system offers the flexibility to manually or automatically adjust the camera view, including exposure time. This makes the system ideal for differentiation studies, as it allows similar measurements and manual control. The samples are positioned in a standardized way, on the one hand level, i.e. perpendicular to the ground as seen from the light projector, and on the other hand inclined by 30°. This arrangement is described in more detail in 5.1.3 The illumination in the measuring room is turned off during the exposures to eliminate the influence of extraneous light sources and to make the readings comparable.
The illumination time is automatically determined by the system for each sample using the grid illumination time, since the entire measurement area is set to the optimal illumination time. The illumination times thus determined serve as a guide to the reflectance of the surface. The higher the reflectance, the shorter the exposure time to avoid overexposed areas.

4.2 KEYENCE Profilometer VR-5200

The measurement system was used in the matting agent study to determine the film thickness of each agent. Its necessity is explained in more detail in Chapter 7. The exceptional properties of the profilometer make it ideal for use on reflective surfaces, as there is no reflection on the cleaned surfaces and therefore a clean measurement of the height difference is possible. Non-contact measurement is also the only option here because the agents, whether permanent or sublimating, are usually non-contact and the layer thicknesses are so thin that conventional measuring instruments, such as a micrometer calipers, would not be able to provide a value.

4.3 Rhopoint Flex 60

The purpose of using the Flex 60 is to establish a relationship between gloss and exposure time. The exact data and correlations are discussed in Chapter 6.
The measurement is taken by placing the measuring device on the surface to be examined and then pressing a button, either on the measuring head itself or on the instrument, which triggers the measurement. The instrument stores the data of the measurement, including a time stamp and a consecutive measurement number, in the internal memory. The data can then be transferred to a computer via Bluetooth or USB. The device itself also has a simple evaluation tool that compares the measurement data graphically and displays a graph with the measurement number on the abscissa. This allows a quick evaluation of the data.

5. EXPERIMENTAL ANALYSIS OF THE MATTING

In order to differentiate between different matting agents and methods, it is important to standardize the measurement setup as much as possible so that uninvestigated influences do not affect the measured variables.

5.1 General setup

The study of matting agents and methods is carried out on test specimens using aluminum sheet metal strips. These are bent at 90° on one side and are also marked with a unique nomenclature. The shape is intended to reproduce an adjacent vertical wall, as is often the case with real test objects. In addition, the parts were cleaned with isopropyl alcohol during the preparation process to avoid any unwanted reaction product from substances that may be present on the surface, such as technical lubricants from manufacturing or liquids from contact.
As previously stated, ensuring the comparability of the individual measurements is the most important requirement for the investigation and is thus given significant attention. Although the structure generated by airbrush and spray can are different, they have the same application angle. In addition, the users health is protected by an exhaust system that ensures protection from respirable substances.
The measuring room of the metrology laboratory was used as the location for the setup. The room is air conditioned and already equipped with all the necessary tools and equipment. In addition, the room is separated, which allows undisturbed and safe work, as there is no other person in the room during the application.

5.1.1 Setup for Airbrush

Basically, the airbrush is powered by a small compressor with two water separators and a pressure reducer at the outlet of the pressure vessel.
For testing purposes, the airbrush has been modified with some additive manufactured attachments that allow for a constant air and material mixture (cf. Figure 4.1). The air flow can be adjusted via the rocker, while the wedge statically adjusts the amount of material (coating, matting agent, etc.). Preliminary tests with this setup have shown that an almost full load is a suitable setting for matting. The base element (gray) is clamped to the base body itself by a screw on the back, which pulls the base element together and causes clamping.

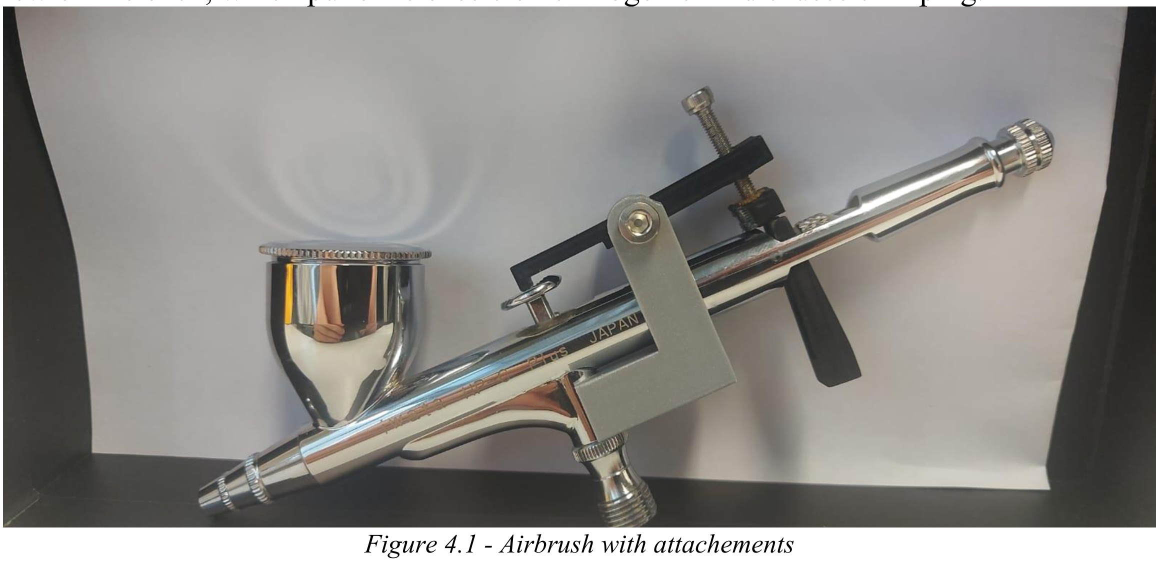

Figure 4.1 - Airbrush with attachements

As with the cans, the sprayed medium was applied at 45° and a constant distance. The samples were painted over in a meandering manner, with the reversal points outside.

5.1.2 Setup for aerosol can

The spray can test setup is shown in Figure 4.2 and consists of the stand, a sample holder, and the extraction system. The can is attached to the stand table with additively manufactured clamps to ensure angular stability. The angle is set at 45° to allow uniform application of the matting agent. The matting agent is applied by individual puffs along the sample, which is repeatedly moved. It is essential that the actuator is fully actuated, otherwise droplets may form or the application may be insufficient or uneven.

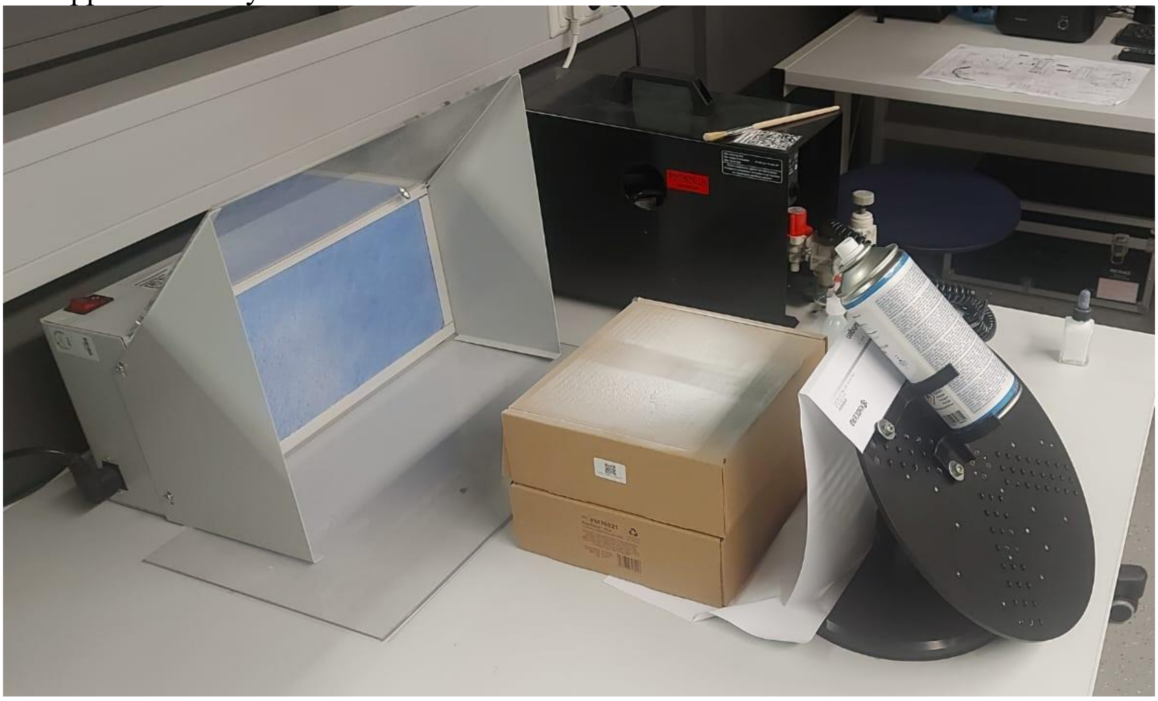

Figure 4.2 - Spray can setup

The samples were also placed at the recommended distance of 150 to 200 mm, as stated in the manufacturer's specifications. This guideline is similar for all manufacturers.

5.1.3 Measurement Setup

The setup for determining the exposure times consists of the ATOS Core 200 and the corresponding tripod, which serves as a base plate. The illumination of the measuring room is inactive during the measurements to avoid unwanted side effects. The measuring head is aligned exactly perpendicular to the base plate and parallel to it by means of an angle measuring device, thus creating a direct illumination from above. Since the scanner itself always adapts the illumination to the object and the reference points, four reference points are applied to the base plate for the test to ensure identical conditions for all samples.
The specimens in Figure 4.3 are photographed from the scanner's point of view, and differences in the reflectivity of the surfaces are already visible in the images. The specimen on the left side of the image lies flat on the base, i.e., the stand base plate, while the specimen on the right is placed on the 30° inclined support body.

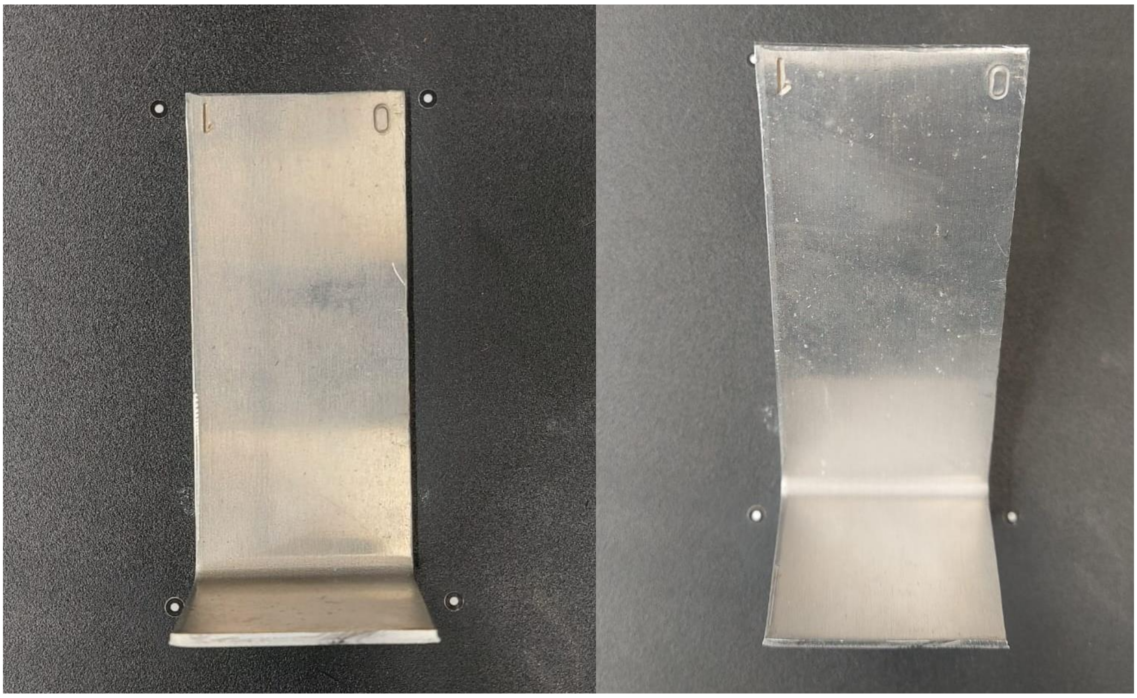

Figure 4.3 - Probes in the view of the scanner

As shown in the pictures, the samples are marked with the abbreviation of the applied agent (from the reading direction on the left) and also numbered consecutively (from the reading direction on the right), so that the gloss values and the reflection reduction can be assigned to each other. In the picture above "O" stands for "Orange", and the number one for the first sample of AESUB's Agent Orange. Similarly, the other samples can also be clearly identified.
Figure 4.4 shows the support body applied under the sample in the measurement setup. The additional angular change takes into account the real measurement tasks, since an absolutely flat measurement is extremely unusual, but an angled measurement is very common.

Figure 4.4 - 3D-Scanner with probe on the 30° support block

6. REFLECTION REDUCTION

Essentially, the purpose of the matting is to reduce reflections that interfere with the measurability and instead create a diffusely reflecting surface. Table 4-1 shows the empirical exposure times determined with the GOM Atos Core 200 at an angle of 0°, in Table 4-1 the angle of the sample is changed by 30°.

Table 4-1: Exposure time at 0°

	Exposure time in [ms]					
Designation	Code	1 horizontal	2 horizontal	3 horizontal	4 horizontal	5 horizontal
Blue	B	2,96	3,25	3,16	3,32	3,25
White	W	2,98	3,04	2,93	4,37	3,02
Orange	O	4,06	3,65	3,85	3,37	4,26
Green	G	2,89	3,12	2,4	2,93	2,31
µ-Scan	M					2,99
Zero	Z	3,08	3,28	3,15	3,32	3,57
AB2	2	5,94	4,7	4,79	8,46	9,96
AB6	6	3,16	9,05	5,3	3,36	4,22
AB P	P	5,24	4,75	4,33	4,6	3,94
3D ScanSpray	H	2,81	2,94	2,95	2,96	2,67
Ti2O	T	2,98	2,93	2,88	2,98	2,95
Steel wool	S	4,02	5,16	4,34	3,12	1,99
Hydrochloric A.	A	3,22	3,11	3,87	3,6	3,16

In the case of the exposure time, the coloring is a second dimension of information transfer, the color green means that no reflection remains at the specified time, yellow that a small one remains, red indicates a reflection that interferes with the measurement. The three most conspicuous means are green, hydrochloric acid and steel wool. These all show unsatisfactory results, since a significant residual reflection is not allowed in the measurement. Only the "3D-ScanSpray" shows average or mixed results. All other agents perform very well, with small outliers.

The fact that the "µ-Scan" shows only one measurement can be explained by previous investigations. Based to their results, the agent demonstrates independence from various influences in terms of its usage, thereby categorizing multiple use and directional dependence as non-critical factors. Therefore, multiple investigations are not necessary since the result is easily reproducible and thus consistent results can be assumed.

Table 4.2 - Exposure time at 30°

	Exposure time in [ms]					
Designation	Code	1 @ 30°	2 @ 30°	3 @ 30°	4 @ 30°	5 @ 30°
Blue	B	9,97	11,42	6,57	11,86	8,53
White	W	7,59	10,16	7,93	9,76	9,65
Orange	O	8,39	8,01	13,82	12,59	14,74
Green	G	7,1	8,13	8,7	5,8	7,34
µ-Scan	M					7,89
Zero	Z	10,36	11,34	6,08	10,68	10,01
AB2	2	10,82	9,8	10,85	10,48	10,8
AB6	6	10,08	10,31	12,3	10,65	11,08
AB P	P	14,68	11,72	12,07	6,34	8,28
3D ScanSpray	H	10,04	9,26	7,85	7,8	9,26
Ti2O	T	10,27	9,53	9,23	9,8	9,05
Steel wool	S	9,85	9,44	6,37	8,01	7,59
Hydrochloric Acid	A	10,66	10,52	9,92	8,13	7,21

The pattern of exposure times is different when the sample is tilted by 30° with respect to the ground. The samples were not changed between the horizontal and inclined measurements, they are the same samples and the measurements were taken about two minutes apart.
Except for four of the five hydrochloric acid samples, all of the samples are positive, and some of them have three times the exposure time. These data show that if the reflective properties of the objects are good, the measurement system will determine a long exposure time despite the light color. The threshold is the 10 ms value, below this time it's to dark so get valuable data. This results in high quality measurements as the reference points are also very well illuminated and thus reliably detected by the system.
The outliers of group A can also be plausibilized during execution. The first two samples were treated with 15% hydrochloric acid, the second and third with 10%, and the fifth with the full concentration of 30%. A continuous improvement can be confirmed here.

7. MEASUREMENT OF THE COATING THIKNESS

The profilometer was used to measure the coating thickness. In preparation, the lower surfaces of three specimens were cleaned and placed side by side on the stage. A full surface measurement provides the data base for the coating thickness measurement. The tool for measuring two lines is suitable for this purpose because it removes the surface roughness from the calculation by area interpolation. This would otherwise have an effect with a point-by-point measurement, since the applied materials have a much coarser structure than the aluminum sheet. In addition, the direct line of wiping is not included in the measurement because wiping causes particle clustering, which does not represent the true value of the coating thickness.
Table 4.3 lists the individual and arithmetic values, with the best values highlighted.

Table 4.3 - Thickness measurement

			thickness				
Producer	Designation	Code	1	2	3	Ø	Ranking
AESUB	Blue	B	0,018	0,009	0,013	0,013	
AESUB	White	W	0,01	0,005	0,002	0,005	
AESUB	Orange	O	0,005	0,016	0,01	0,01	
AESUB	Green	G	0,011	0,005	0,016	0,011	
ATTBLIME	µ-Scan	M	0,002	0,002	0	0,002	1
ATTBLIME	Zero	Z	0,011	0,003	0,004	0,004	3
ATTBLIME	AB2	2	0,002	0,004	0,003	0,003	2
ATTBLIME	AB6	6	0,011	0,01	0,016	0,011	
ATTBLIME	AB P	P	0,009	0,005	0,002	0,005	
Helling	3D ScanSpray	H	0,006	0,004	0,003	0,004	3
--	Ti2O	T	0,008	0,001	0,005	0,005	

The values are often in the single-digit micron range, down to small double-digit micron values. This is usually an acceptable deviation for freeform surfaces, but for dimensions that must meet a tolerance, the accuracy is sometimes inadequate. For a "center-to-center" measurement, this may be justifiable in the case of uniform application, but in the case of one-sided application, this assumption is no longer acceptable.

8. MEASUREMENT VALUE COMPARISON

8.1 Exposure time in relation to layer thickness

Based on the premise that matting agents behave like paints and varnishes normally do on surfaces, opacity increases with increasing film thickness. Contrary to the assumption, the measurement results in Table 4.3 reveal that this claim is incorrect, as demonstrated by the µ-Scan-liquid. It indicates that even a minimal film thickness is adequate to achieve satisfactory outcomes. The values below are also two averages with otherwise lowest film thicknesses, but consistently usable results. On the other hand, large film thicknesses do not necessarily result in acceptable exposure times, as shown by the "green" value. The combination of moderate film thickness and acceptable exposure time applies to the other seven mattings.

8.2 Exposure time in relation to gloss value

The exposure time determined in Table 4-1 indicates the residual reflection that the Atos Core 200 has to compensate. This amount is determined directly from the gloss measurement. The correlations in the direct comparison of the two values suggest a direct proportionality, although this is not true in all cases. More specifically, an increased gloss value suggests a high residual reflectance, but this is not necessarily the case. Conversely, a high residual reflectance always represents a conspicuousness in the corresponding gloss value. Examples of this are the values obtained when testing samples treated with steel wool (S) or hydrochloric acid (A). These are not sufficient to evaluate the exposure time and therefore the gloss values are also conspicuous in direct comparison with the desired results. In the case of the values for Ti2O, the analogies are directly recognizable, although the gloss values for the exposure times would not have the same order in a ranking as in the reverse consideration.

9. APPLICATION ASSISTENCE

The following are basic and advanced instructions for airbrush and spray-can matting that can be applied without extensive experience.
There are a few things that should be taken into consideration when preparing for work.

1. Health and safety at work:
   The first of which is the safety of the user and bystanders. Appropriate protective clothing must be worn; the necessary clothing can be found in the data sheet of the product to be used. In addition, it is recommended that the product be used in front of the extraction unit, as this is where excess airborne particles and liquids are removed from the work area.

2. Ensure ideal work conditions:
   The work itself is best performed under appropriate brightness, as only with good lighting is it possible to see if the part has been sufficiently matted in all areas. Most compounds dry quickly after application, but until then it is difficult to see without illumination.

3. Consider estimated measurement time:
   The choice of agent should be based on two factors: the expected scan time, and the size of the part, which is subject to some limitations. The measurement time should be significantly shorter than the sublimation time, if available, otherwise no homogeneous measurement is possible, since already sublimated areas will negatively influence the others. The size of the components is relevant, since the µ-Scan-liquid is applied with a brush, for example, an area that is too large tends to be more cumbersome than with a spray system.

4. Distance and area rules:
   When applying the coating, there are two other issues to consider: full area and constant distance. The full area is determined by the inspection and illumination angles, since adjacent reflective surfaces also make it difficult or impossible to accurately measure matte surfaces. Phantom measurements are the rule rather than the exception, even for partially matted components, so full matting is recommended unless the surfaces are visibly different. In this case, a trial measurement will provide clarity if there is any ambiguity. Constant spacing is essential to maintain surface texture, as too little spacing will result in material buildup (paint noses, wet spots), and too much spacing will not ensure reliable material application.

5. Actuation of the matting:
   One issue with direct application is the position of the valve (airbrush, spray can), as empirical tests have shown that partially opened valves are a complication, as droplet formation or unevenness is the direct result. Only a fully open or actuated valve will provide uniform application.

6. Time and patience:
   A reasonable amount of time must elapse after application, as the products usually dry first and then take full effect. If the surface is still damp, a longer waiting time is required. A period of two to four minutes is practical.

10. Resumé

In summary, the agents available on the market are generally able to deliver on their promises, but there are also over- and underperformers. It is not possible to make a conclusive assessment of the funds, as an even more extensive data base is required, especially for the closely tracked products. This should be carried out with a few agents that stand out as top performers on real components. In addition, other aspects such as the economic, i.e. the price, play a decisive role. In this context, there would also be a place for the yield of the mattings.
In order to give the measurements even more weight, it is necessary to verify them by means of another measuring method, which would then be a tactile measurement.
Within the scope of the work, the interrelationships between illumination time, layer thickness and gloss were considered and accordingly, these were also considered individually. On this basis, it was possible to gain a deeper insight into optical metrology, because the considerations to be made and the resulting results depend to a large extent on the functioning of the measuring systems and the processing of the data. Colloquially, this is called "getting a feel for the equipment," but it is a concatenation of analogies that can be learned after some use and applied to new components. Overall, the data and results indicate a tendency with regard to the selection of agents and parameters. The sublimation time should ideally exceed the expected measurement time by a factor of two or, if possible, a permanent one should be used. Sublimation times sometimes deviate sharply from the manufacturer's specifications if the temperatures are higher or the layer thicknesses are very low. Layer thicknesses should be kept as small as possible if geometric data are to be obtained. For simple surface digitizing, a few micrometers are often not decisive; the user must evaluate this carefully. For very small surfaces or filigree structures, µ-Scan-liquid is recommended, as it can be applied very precisely with a brush and narrow ribs or similar are no problem. The airbrush option uses Ti2O and should be avoided, if possible, because of the possible health effects that could appear after a long term use especially with improper protection.

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