Evaluation Study:
3D Printing Accuracy of Ultracur3D® DM 2505

Introduction

Additive Manufacturing (AM) is becoming increasingly relevant and important for the healthcare industry. It has a particular resonance with dentistry and with the industries' long use of CAD/CAM technologies AM opens up great potential to be leveraged. Since decades, CAD/CAM technologies have proven to be a great tool in dentistry, both chairside and in dental laboratories. Until recently, computer-aided manufacturing (CAM) has mostly relied on computer numerical controlled (CNC) milling machines – with AM, dental models can now be manufactured at high speed and reasonably low cost with unprecedented level of accuracy. The range of applications for dental models in dentistry is wide:

- crowns and bridges
- veneers
- inlays / onlays / overlays
- clear aligners
- bitesplints
- surgical drill guides
- individual impression trays
- denture bases
- partial frameworks

Forward AM, the brand of BASF 3D Printing Solutions, has one of the broadest portfolios of high-performance 3D printing materials, ranging from polymer powders, plastic and metal filaments to photopolymers.

Focusing on the latter material, the corresponding 3D printing technology DLP (Digital Light Processing, also known under the term VAT polymerization) is ideally suited for dentistry as it allows the manufacturing of parts with highly accurate details – crucial for applications such as crowns, bridges or inlays.

Forward AM offers a suite of materials vital for applications mentioned above in the Ultracur3D® Dental Line - three advanced reactive urethane photopolymers specifically developed for key dental-technical applications.

The Ultracur3D® DM and DMD resins by Forward AM are highly wear-resistant, enabling high-precision detailing, and rapid as well as cost-effective 3D printing of bespoke dental models and molds, which can be used for on-site production of aligners in laboratories and dental practices. With its high rigidity, Ultracur3D® DM 2505 is the ideal solution for 3D modeling and molding for dental applications. This resin's very high print accuracy and detailing can bring the cost-per-part down for dental prosthetics manufacturers and clinics by reducing post-processing and fitting time, thereby accelerating their customer-base growth. Topping it off, no cleaning chemicals are required, as printed parts can be washed with water.

Objective

Something all dental applications produced via a dental model have in common: the accuracy requirements are very high because the perfect fit to the patient's teeth is essential. Thus, this paper's objective is to calibrate Forward AM's resin Ultracur3D® DM 2505 on the 3D dental printer Organical® 3D Print X1S from Organical CAD/CAM in order to provide the end user with validated process parameters. For this purpose, exposure times are determined by means of a defined calibration matrix to avoid over- as well as underexposure. The dimensional accuracy with regards to shrinkage behaviour as well as the different model manufacturing processes, such as hollow and solid printing, are also taken into account.

Experimental Setup

Hardware:

- Organical® 3D Print X1S LCD printing system (Organical CAD/CAM GmbH, Berlin)

- Organical® Wash & Cure for cleaning and light curing (Organical CAD/CAM GmbH, Berlin)

- Shining® 3D Autoscan DS EX Pro S for digitalization of the 3D printing objects (Shining 3D Tech Co., Ltd., Wenyan, Xiaoshan, Hangzhou, Zhejiang Province)

- Detaching tool

- Electronic calliper (Hch. Perschmann GmbH, Braunschweig)

Software:

- Exocad® CAD Software (exocad GmbH, Darmstadt)

- Chitu Box V1.8.1 Slicing Software (Shenzhen CBD Technology Co., Ltd., Shenzhen)

- GOM® 2017 for comparison analysis (GOM GmbH, Braunschweig)

Consumables:

- Ultracur3D® DM 2505 Resin (BASF 3D Printing Solutions GmbH, Heidelberg)

- Isopropanol 99% cleaning medium (Höffer Chemie GmbH, Kleinblittersdorf)

Safety Equipment:

- Personal protective equipment (glasses, mask and gloves)

Figure 1: The resin, 3D printer and curing station applied for the study: Ultracur3D® DM 2505 resin, Organical® 3D Print X1S and Organical® Wash & Cure (Sources: Forward AM, Organical CAD/CAM)

Determination of Print Settings

First, a calibration matrix is developed using defined objects to determine possible deviation values from the X- and Y-axis that come to light during the printing process with Ultracur3D® DM 2505. A defined object (Figure 2 at a)) on the calibration matrix forms a measurement cross with a leg length of 50 mm in the X (=2) and Y (=1) axes. The measurement is carried out with an electronic calliper. In addition, special geometries (e.g. „columns", „comb with strands", „numbers") are arranged on the calibration matrix, which enable a quantitative check for overexposure and underexposure (Figure 2 to b)).

Figure 2: The calibration matrix (Source: Organical CAD/CAM)

If deviations are found in the measurement cross of the calibration matrix, these must be adjusted by changing the machine parameters in the slicing software so that the specified value of 50 mm is reached in both dimensions (Figure 3).
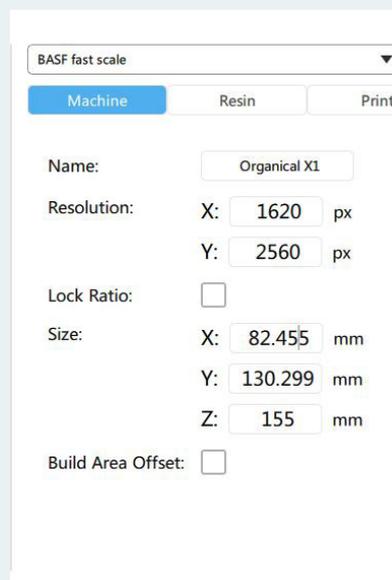

Figure 3: Screenshot Chitu Box V1.8.1 Slicing Software with machine parameters (Source: Organical CAD/CAM)

The exposure time must be reduced for overexposures and increased for underexposures so that the special geometries are printed with dimensional stability (Figures 4a and b). Not all resins are suitable for printing the finest details and can reproduce the very thin „pillars" attached to the matrix (Figure 4b). To successfully reproduce these „pillars", the material must be hard/strong enough. Reason for this: The „pillars" have to withstand the separation forces during the detachment process from the FEP film.

The „comb" of the calibration matrix cannot be completely represented with its thin, individual strands if the exposure is too short. In case of overexposure, the strands are not printed separately but literally stick together (Figure 4a).

The „8" of the calibration matrix meets with a peak, made of a raised and a recessed geometry. If both peaks do not touch, there is an underexposure. If the point of contact is too thick, the object is printed overexposed (Figure 4a).
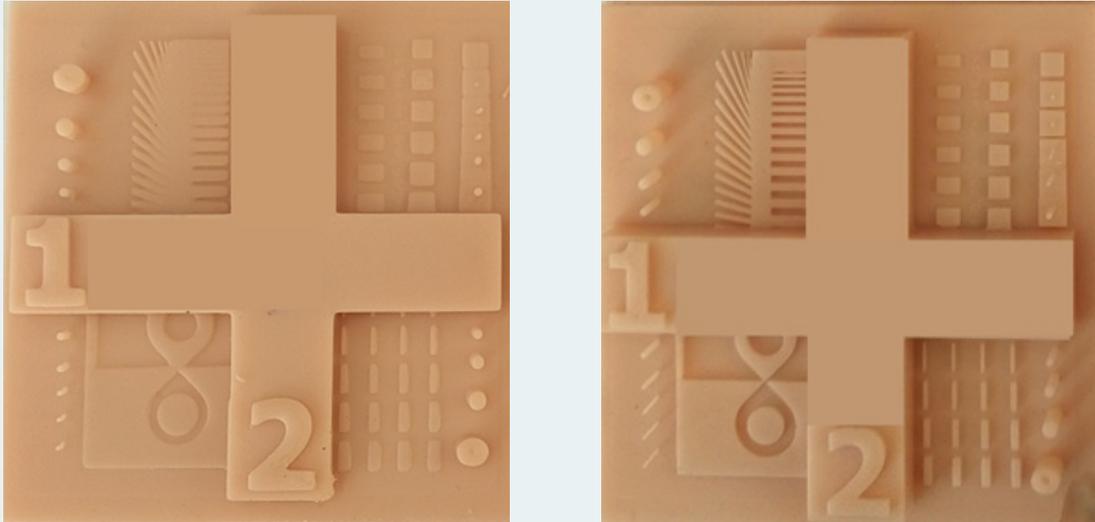

Figure 4a and 4b: Printed calibration matrix with visualized measure data (a) with visible over exposure and (b) with correctly adjusted exposure time (Source: Organical CAD/CAM)

Consequently, a correctly set exposure time has an effect on the material properties, detail accuracy and dimensional stability.

Figure 5: Material specific setting of various parameters such as exposure time in the Chitu Box V1.8.1 Slicing Software. (Source: Organical CAD/CAM)

For 3D printing of models with intricate details, especially deep fissures, a low viscosity resin is needed, which can easily escape such depressions or cavities. If the resin remains in these depressions and/or cavities, it can be very difficult to clean the printed object without leaving any residue. This can also lead to lost details during post-curing.

The test set-up for determining the print settings also corresponds to the following scheme for printing 3D models.

Test Setup

First, two different types of models are created CAD-based. This is done with the help of the Exocad-based add-on module Model Creator.

The first model is created as a hollow model (Figure 6) with a wall thickness of 3.0 mm. The base contains so-called „drain holes", which prevent a suction cup effect and enable the unhindered drainage of uncured resin from the inside of the model. In addition, they are used for cleaning from the inside with isopropanol. The model is provided with a stabilisation aid at the end, the transversal connector, which counteracts uncontrolled contraction of the model due to the post-curing process by light polymerisation.
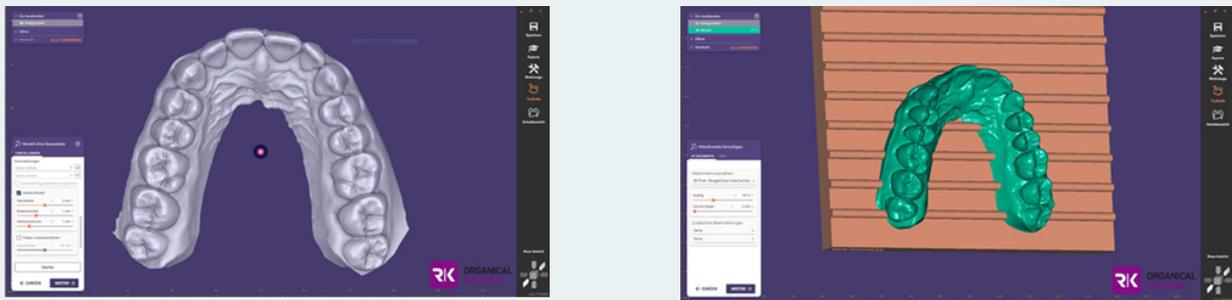

Figure 6: Creating the hollow model with exocad® Model Creator.

„Suction bells" are enclosed hollow volumes or cavities in a model. When printing hollow models, air is trapped between the printed object and the resin tank when the design platform lowers the cavity against the bottom of the resin tank during printing. The resulting suction effect can cause separation of printed layers or structural defects, deformation or misprints when subsequently lifted from the resin tank.
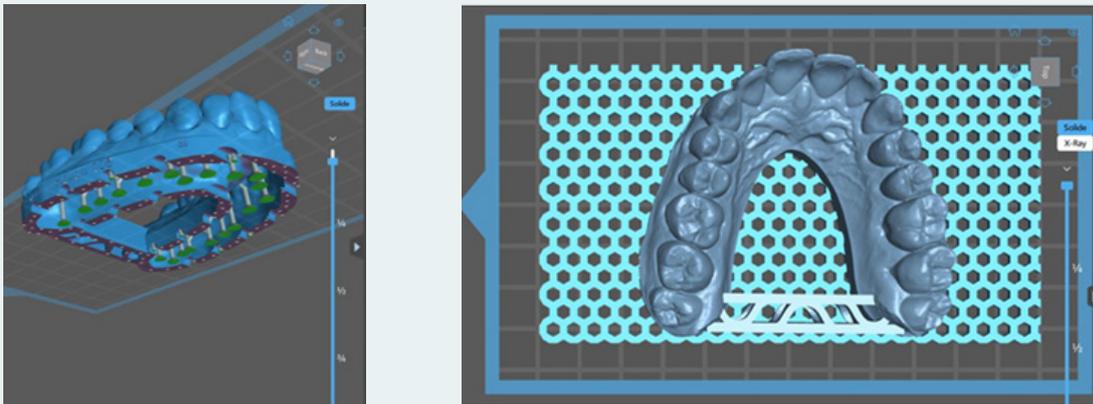
If models have internal or enclosed cavities, drain or vent holes are needed to reduce the suction effect during printing. If possible, the positioning of these vent holes should help relieve the pressure from the very first layer. Cleaning the hollow models through the drainage holes and drying the interior with compressed air before light curing is more time-consuming per se.

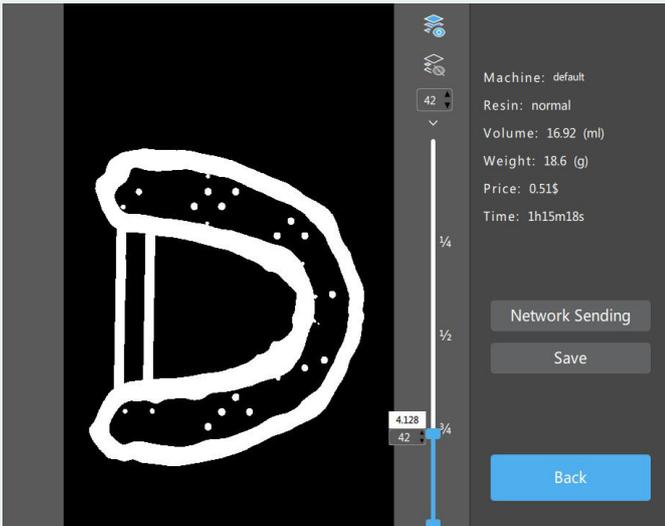The second model is created solid and also equipped with a transversal connector (Figure 7).

Figure 7: Solid created model with the exocad® Model Creator. (Source: Chitu Box Software, Organical CAD/CAM)

Both models are sliced in the Chitu Box V1.8.1 slicing software with the previously determined pressure settings in the layer thick-nesses 50 µm and 100 µm. In order to ensure an easier removal of the models from the build platform of the 3D printing system as well as a better distribution of the removal force, the models are placed with the base on a support plate with a grid structure (Figure 8b). The model plane is aligned horizontally to the build platform. While support structures can be dispensed with for the solid models, this must be taken into account for the hollow-printed models to support overhangs and „islands" inside the cons-truction space (Figure 8a).

Figures 8a and b: Placed and aligned models in the Chitu Box V1.8.1 slicing software. (a) Hollow printed model with first placed supports and drain holes. (b) Solid model including support plate with grid structure (Source: Chitu Box Software, Organical CAD/CAM)
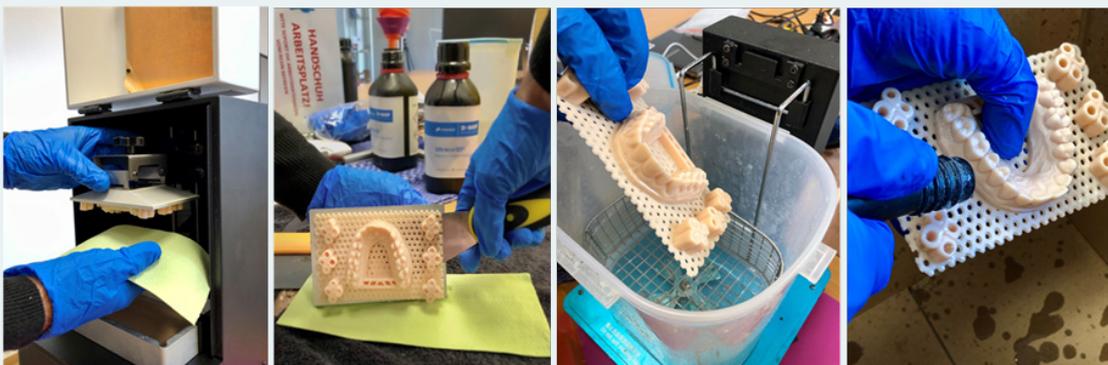
Printing Process and Finishing

Care must be taken to store and use Ultracur3D® DM 2505 resin at 23°C room temperature for consistent quality printing. In addition, the resin must be shaken before each printing process to mix the micro and macro fillers evenly. The film of the resin tank should be intact and printable. The build platform must be degreased with Isopropanol 99% in advance. It must not show any residues of previous printing processes. The system is levelled.

The resin is filled into the resin tank according to the volume requirement determined in the slicing software (Figure 9).

Figure 9: Determining the volume requirement in the Chitu Box V1.8.1 Slicing Software. (Source: Organical CAD/CAM)

The 3D data set is transferred to the 3D printing system via USB stick or data transfer cable, the 3D print object is selected and the print job is started in the closed 3D printing room.

After the printing process is completed, the building platform with the 3D print object attached to it is removed (Figure 10a) and post-processing begins. For this purpose, the model is carefully detached with the help of a detaching instrument (Figure 10b) and placed in the Organical® Wash & Cure System for 1 minute for the first pre-rinse with isopropanol 99% (Figure 10c). In this way, the coarse, uncured resin residues adhering to the model are removed in the flow bath. Important: Compared to other dental model materials, the resin Ultracur3D® DM 2505 is water washable. This means that you can also pre-clean with clear water after the printing process and thus reduce the consumption of isopropanol. The used water must of course be disposed of properly. If it is necessary, the model can then be cleaned as usual with a common cleaning agent. The model is then removed from the cleaning bath. Larger residues are removed with the help of compressed air (Figure 10d).

Figures 10a-d: Post-processing after 3D printing (Source: Organical CAD/CAM)

Afterwards, the models are again placed in the still unsaturated (!) isopropanol cleaning bath for another 3 minutes for final cleaning (Figure 10e). The model is removed again and completely dried by supplying compressed air (Figure 10f). Now the model is re-exposed in the Organical® Wash & Cure system for a period of 4 minutes (Figure 10g).

Figures 10e-g: Post-processing after 3D printing (Source: Organical CAD/CAM)

Determination deviations between target and actual object

In order to determine deviations in production in the 3D printing process from the original data (CAD files), to visualize them and to be able to analyze them quickly and precisely, a target-actual comparison is created. This also serves to minimize position and shape tolerances in the production process and to optimize the 3D printing process with regards to correct print settings.

For the upcoming measurement, each - as previously described - printed model is digitized with the Shining 3D® Autoscan DS EX Pro S without any further scan spray or scan wax (Figure 11).

Figure 11: Scan of the printed models with the Shining 3D® Autoscan DS EX Pro S (Source: Organical CAD/CAM)

This data set is then compared with the original data set in GOM 2017. The measurement data obtained during 3D digitization is transferred to a common object coordinate system, where it is transformed and aligned with the original data. Using the latest software, the deviation of each of the several hundred thousand measuring points recorded per square centimetre from the target contour can be calculated and visualised in colour as well as numerically.

In order to achieve this, a new project has to be created in the GOM Inspect software and import the original STL model as a CAD body. The CAD body (nominal object) is displayed in blue and the mesh (actual object) in grey. Both files must be aligned and placed on top of each other (Figures 12a-b).
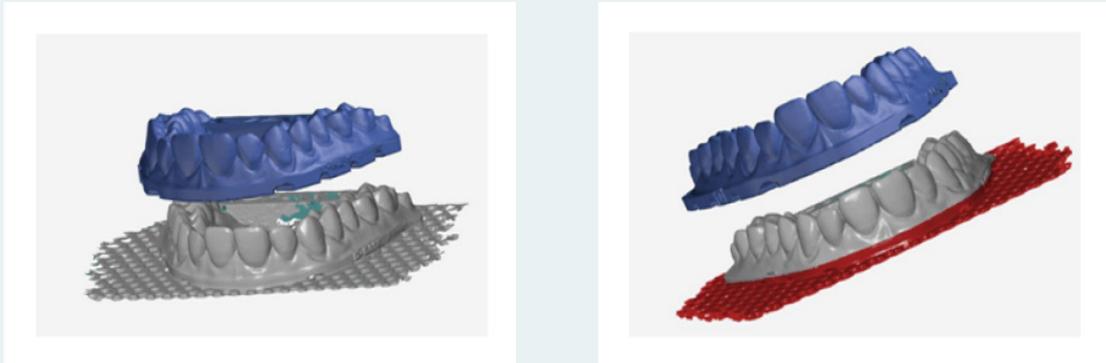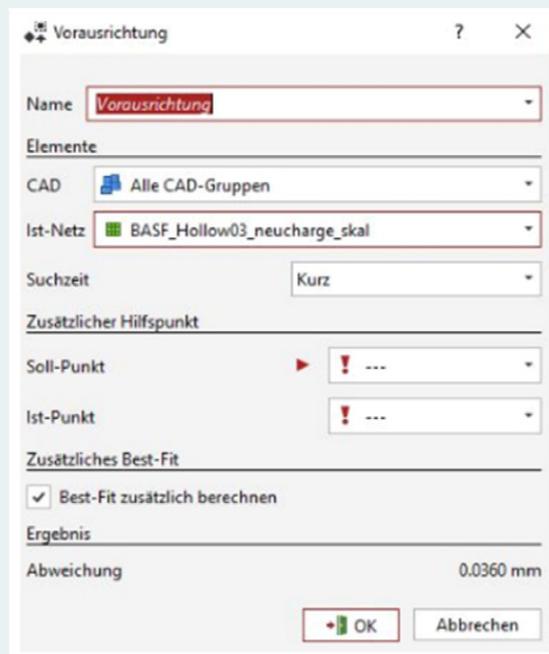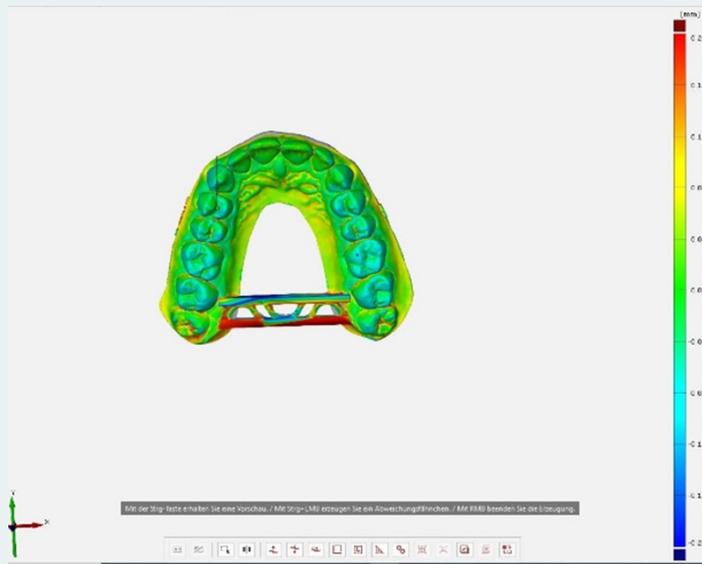

Figure 12a-b: Alignment and cropping of original STL model as CAD body and printed object in GOM Inspect software (Source: Organical CAD/CAM)

To improve the alignment, the files are cropped in such a way that, if possible, only identical areas are present in both files (Figure 12b). This makes it easier for the software to assign both files to each other. For an initial alignment, activate the Global Best Fit function (Figure 12c), which automatically carries out an initial pre-alignment and then also calculates a best fit.

Figures 12c-d: (c) Setting the default values plus (d) colour scale in the GOM Inspect software (Source: Organical CAD/CAM)

In order to compare the different evaluations easily, +0.2 and -0.2 mm are used as standard settings in this case. A colour scale on the right edge of the image shows the positive deviation of the models from each other in yellow up to a maximum of red and the negative deviation in turquoise up to a maximum of blue. In the middle area, where the deviation is within the previously agreed on acceptable tolerance range of ±50 µm, green is used (Figure 12d). Then a surface comparison is carried out on CAD, which takes the original STL file as the starting point for the measurement. A minimum and maximum deviation for the visual colour representation of the models to each other is specified for this.

For better analysis, point deviation flags are added to the object. These show the numerical value of the deviations at a freely defined point. For the sake of clarity, the deviation flags are placed at the edge of the image and connected to the selected measuring point (Figure 13).
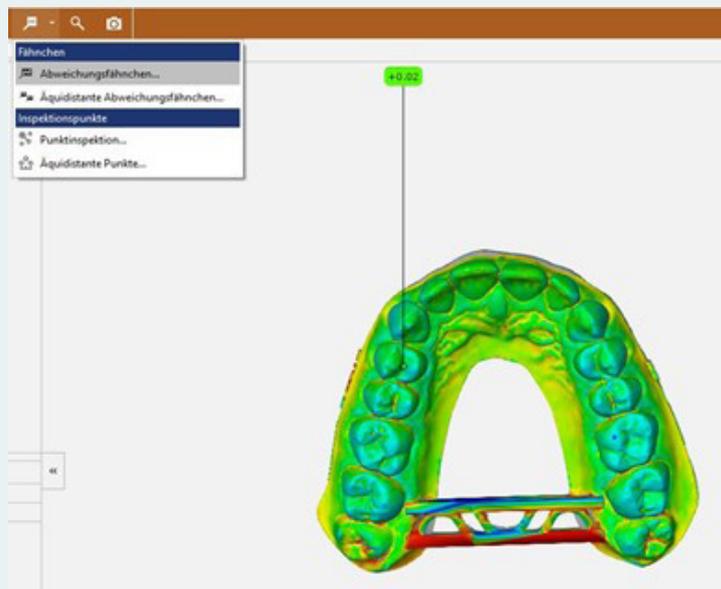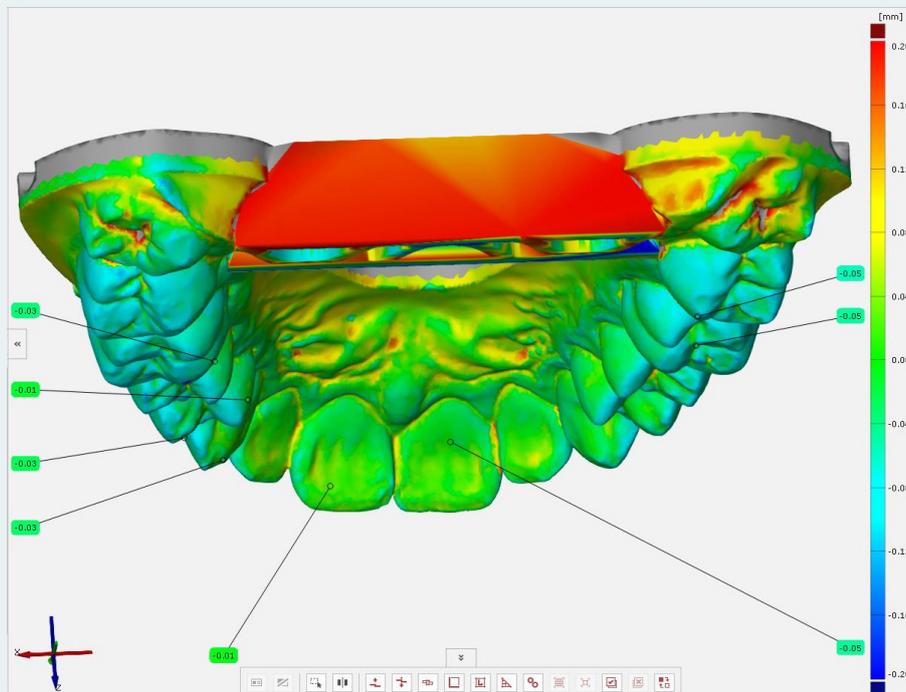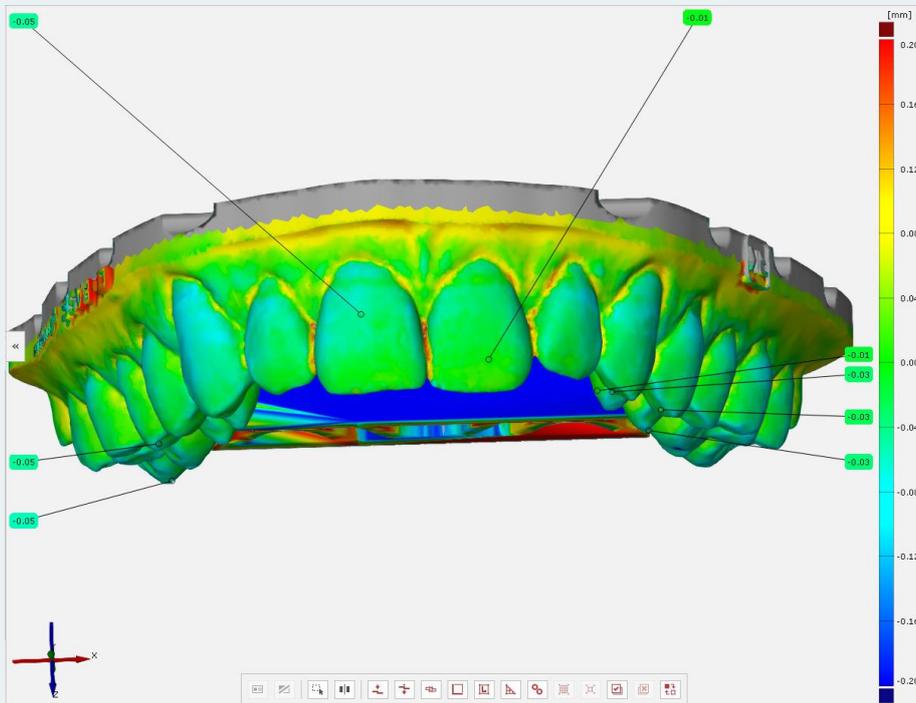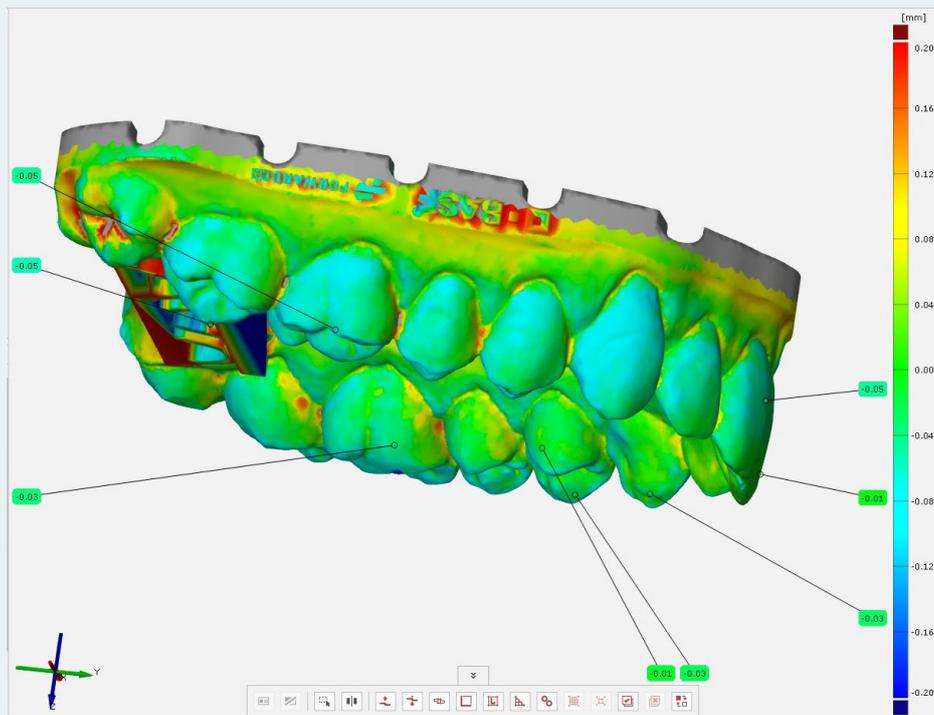

Figure 13: Point deviation flags (values in mm) in the GOM Inspect software. (Source: Organical CAD/CAM)

Individual pages with different perspectives on the model still have to be created. The different perspectives are particularly helpful in the evaluation, as it is easier to see in which direction and on which axis defined deviations are moving. To do this, the model is aligned from above, in front, behind on the left and on the right and saved in the desired position via a screen-shot. Finally, a report is created that consists of the different viewing directions on the model, the deviation flags and the colour scale (Figure 14a-e). This can be exported as a PDF file.

Figures 14a-c: Test report in the GOM Inspect Software from different views of the model, the deviation flags and the colour scale.
(Source: Organical CAD/CAM)

Conclusion

A best possible calibration of the 3D resin Ultracur3D® DM 2505 from Forward AM has been done on the 3D dental printer Organical® 3D Print X1S of the company Organical CAD/CAM. For a reliable use in the dental field, the end user can choose from validated process parameters, as well as a coordinated work-flow, which guarantees consistently stable quality of the 3D printing objects based on Ultracur3D® DM 2505 when all specifications are adhered to. The determined deviations lie within a fully acceptable tolerance area. In combination with the „Organical® 3D Print X1S" the 3D resin Ultracur3D® DM 2505 is therefore ideal for the printing of dental models of all kinds. The resin Ultracur3D® DM 2505 is characterized by high dimensional stability and edge sharpness. At the same time, the 3D print objects can be cleaned particularly efficiently. In principle, it is possible to clean with water. In this test set-up, the focus is on conventional cleaning with isopropanol 99%. With Ultracur3D® DM 2505, Forward AM enables the dental sector to produce highly precise dental applications with Additive Manufacturing.

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