Scientific Studies on

# VarseoSmile Crown plus

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Partners in Progress

BEGO

# Scientific Studies on VarseoSmile Crown plus

VarseoSmile Crown plus is the world's first hybrid material for 3D printing of permanent single crowns, inlays, onlays and veneers.

Scientific studies by renowned universities and institutes prove the excellent material properties.

The summary of the study results includes the following aspects:

- **Stability & Strength**
  - Breaking Load and Abrasion Resistance (10-year Chewing Simulation)
  - Abrasion and Surface Roughness (5-year Toothbrushing Simulation)
  - Long-term Cementation Stability, Decementation Behavior, and Marginal Gap Formation (5-year Chewing Simulation)
  - Bonding Strength with Luting Composite
  - Breaking Load of Metal Framework Crown with Veneer Shell (5-year Chewing Simulation)
- **Aesthetics & Individualization**
  - Adhesion of Sealants
  - Bonding Strength with Veneering Composites
  - Effects of Additional UV Light Curing Processes
- **Biocompatibility**
  - Solubility
  - Cytotoxicity

## VarseoSmile Crown plus – Technical data

| | |
|---|---|
| Shades | A1, A2, A3, B1, B3, C2, D3 |
| Density | approx. 1.4–1.5 $g/cm^3$ |
| Viscosity | 2,500–6,000 mPa*s |
| Flexural strength | 116–150 MPa* |
| Modulus of elasticity | 4,090 MPa |
| Hardness | ≥ 90 Shore D |
| Water solubility | < 1 $\mu g/mm^3$ |
| Water uptake | < 12 $\mu g/mm^3$ |
| Layer thickness | 50 µm |
| Wavelength | 385 nm and 405 nm |

## VarseoSmile Crown plus – Chemical composition

Esterification products of 4.4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid. Silanized dental glass, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide.
Total content of inorganic fillers (particle size 0.7 µm) is 30–50 % by mass.

BEGO
Compatibility Overview 3D Printing System Components:
https://www.bego.com/3d-printing/compatibility-overview

Your Free 3D Printed Sample Made of VarseoSmile Crown plus – **Order now:**
www.bego.com/sampleprint


* See study on effects of additional UV light curing processes

# Breaking Load and Abrasion Resistance

## 10-year Chewing Simulation

**Objective**

In this study, the long-term (10-year) performance of 3D printed crowns made of VarseoSmile Crown plus was studied, with a focus on the breaking load and abrasion behaviour.

**Materials and Methods**

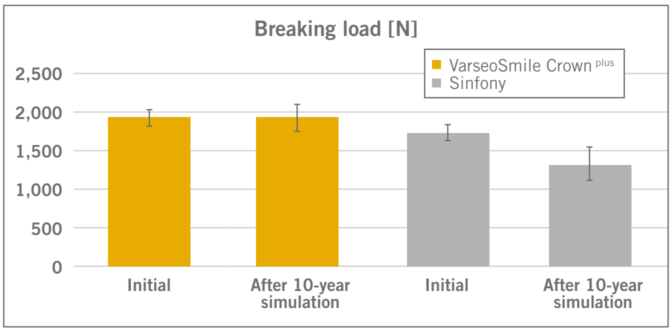
3D printed crowns made of VarseoSmile Crown plus, and crowns made of the manually-layered material Sinfony* were tested under the same conditions for comparison purposes. Sinfony was chosen as the comparison material since it is a hybrid material with a long track record, that has demonstrated the highest abrasion resistance to date in scientific studies [1]. The crowns were affixed onto milled stumps made of Trinia* (the elasticity of the stump material conforms to the 18.8 GPa of natural dentin) using Variolink Esthetic DC*.
The breaking load for both materials was determined using a series of 8 crowns in each case, measuring both before and after a simulated in-vivo 10-year masticatory load (2.4 million chewing cycles at a load of 50 N and a lateral motion of 0.7 mm with simultaneous thermocycling of 12,000 cycles of between 5 and 55 °C). Steatite, a magnesium silicate with properties similar to enamel, was used as antagonist material. Measurement of the breaking load was performed via a compression test in a universal testing machine. For this purpose, the respective test specimen was placed in the testing device and loaded with a test die (ball ø 6 mm) onto the middle of the crown, until breakage. The abrasion following the lateral motion was determined by comparing the digital 3D scans of the occlusal surfaces both before and after the chewing simulation.

**Results**

The breaking loads for the VarseoSmile Crown plus crowns exhibited an initial average value of 1,936 N before the chewing simulation. This average value did not change after the chewing simulation. Thus, no detectable material fatigue took place. With an average breaking load of 1,740 N, the comparison product Sinfony exhibited a lower maximum value before the chewing simulation, as compared to VarseoSmile Crown plus. After the simulation, this value decreased to 1,337 N due to material fatigue.
The material wear was measured on the basis of the change in height profile of the crowns, and totalled 0.275 mm after simulation of the 10-year in-vivo masticatory load for the crowns made of VarseoSmile Crown plus. It is thus about 7 % lower than the material wear of 0.296 mm for the Sinfony crowns.

**Conclusion**

The study under consideration demonstrates that crowns made of VarseoSmile Crown plus achieve breaking loads more than two times higher than the maximum average human masticatory forces of 720 N [2] and almost four times as high as the maximum average masticatory force of approx. 490 N [3], both initially and after a 10-year chewing simulation.
In terms of abrasion resistance, VarseoSmile Crown plus demonstrated less material loss (higher resistance to wear) after the chewing simulation than the material Sinfony.
Restorations are thus preserved for a long period of time and there is a very low risk that a crown could fracture in the patient's mouth.




**Breaking loads for crowns made of VarseoSmile Crown plus (BEGO) and Sinfony (3M), before and after a 10-year chewing simulation**

**Source**
The above information is based on a scientific study on breaking load and abrasion resistance of VarseoSmile Crown plus conducted by:
Eva Jerman, M.Sc., Marlis Eichberger, Lisa Schönhoff, B.Sc., Dr. Marcel Reymus, Prof. Dr. Dipl.-Ing. (FH) Bogna Stawarczyk, M.Sc. (2020): Fracture load and two-body wear of 3D printed and conventionally fabricated crowns: artificial aging of 10 in-vivo years, Department of Prosthetic Dentistry, University Hospital, LMU Munich, Germany

[1] Bogna Stawarczyk, Roger Egli, Malgorzata Roos, Mutlu Özcan, Christoph H.F. Hämmerle (2011): The impact of in vitro aging on the mechanical and optical properties of indirect veneering composite resin, in: Journal of Prosthetic Dentistry, Vol. 106, Nr. 6, P. 386 – 398
[2] Charles H. Gibbs, Kenneth J. Anusavice, Henry M. Young, Jack S. Jones, Josephine F. Esquivel-Upshaw (2002): Maximum clenching force of patients with moderate loss of posterior tooth support: A pilot study, in: Journal of Prosthetic Dentistry, Vol. 88, Nr. 5, P. 498 – 502
[3] Körber K., Ludwig K., Maximale Kaukraft als Berechnungsfaktor zahntechnischer Konstruktionen. Dent-Labor 1983; 1: 55-60

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# Abrasion and Surface Roughness

## 5-year Toothbrushing Simulation

**Objective**

In this study the loss of mass and the surface roughness on VarseoSmile Crown plus arising from brushing teeth with an electric toothbrush was tested.

**Materials and Methods**

This study examined samples made of VarseoSmile Crown plus as well as samples made of Sinfony* material. Here, Sinfony was chosen as the comparison material because it is a material that has proven itself in the market for many years, and is used for permanent crown restorations and cured via light.
Discs with a diameter of 15 mm and a height of 3 mm were manufactured for test purposes. In the case of VarseoSmile Crown plus this was done through 3D printing, and in the case of Sinfony it was done by filling a form and allowing it to cure on both sides with a light-curing device, in accordance with manufacturer's specifications in both cases. Next, one surface of the disc was polished.
The toothbrushing simulation was performed on the polished surfaces in a toothbrushing simulation machine. This test used the electric toothbrush Oral-B Vitality Sensitive Clean* and "elmex cavity-protection toothpaste"*. In the process, the rotational movement of the brushes was overlaid with a lateral movement of the brushes of 5 mm and a speed of 10 mm/s. The pressing force of the toothbrush on the sample was set at 1.5 N.
The toothbrushing simulation was based on the assumption of a brushing time of 4 minutes per day for all teeth, resulting in a total annual brushing time of about 15 minutes per tooth surface. The toothbrushing simulation was stopped after 15:12 min (1-year simulation), 45:37 min (3-year simulation) and 76:02 min (5-year simulation). Each time, the loss of mass of the samples and the roughness of the sample surface was determined.

**Results**

The calculated loss of mass, resulting from the toothbrushing simulation, was significantly higher for the samples made of Sinfony material than for those made of VarseoSmile Crown plus, for all three toothbrushing durations. Thus, the mean loss of mass for VarseoSmile Crown plus was 0.08 mg for the 1-year simulation, 0.32 mg for the 3-year simulation, and 0.56 mg for the 5-year simulation. In contrast, the mean loss of mass for Sinfony was almost double for all of these toothbrushing durations (1-year simulation: 0.24 mg; 3-year simulation: 0.76 mg and 5-year simulation: 0.99 mg).
On the other hand, the resulting surface roughnesses for VarseoSmile Crown plus and for Sinfony were almost equal, and for both materials they were independent of the time at which the toothbrushing simulation was stopped and the roughness measured. The mean roughness (R) ascertained for VarseoSmile Crown plus after the 1-year simulation was $R_a$: 0.09 µm, after the 3-year simulation $R_a$: 0.10 µm and after the 5-year simulation 0.11 µm. The roughness value for Sinfony after the 1-year simulation was $R_a$: 0.09 µm, after the 3-year simulation it was 0.10 µm and after the 5-year simulation it was 0.10 µm.

**Conclusion**

Through the toothbrushing simulation it was possible to demonstrate that crowns made of Sinfony experience significantly greater loss of mass than those made of VarseoSmile Crown plus. Restorations made of VarseoSmile Crown plus are thus preserved for a long time and the existing tooth substance is protected in the best possible manner. Moreover, the roughness values provide evidence that there is no significant increase in roughness resulting from toothbrushing duration, in the case of both materials. Since the roughness values always remained clearly below the clinically significant threshold of $R_a$: 0.2 µm, an increased accumulation of plaque on the surface of the tooth-restoration is not to be expected.


**Toothbrush simulator ZM.3.4**

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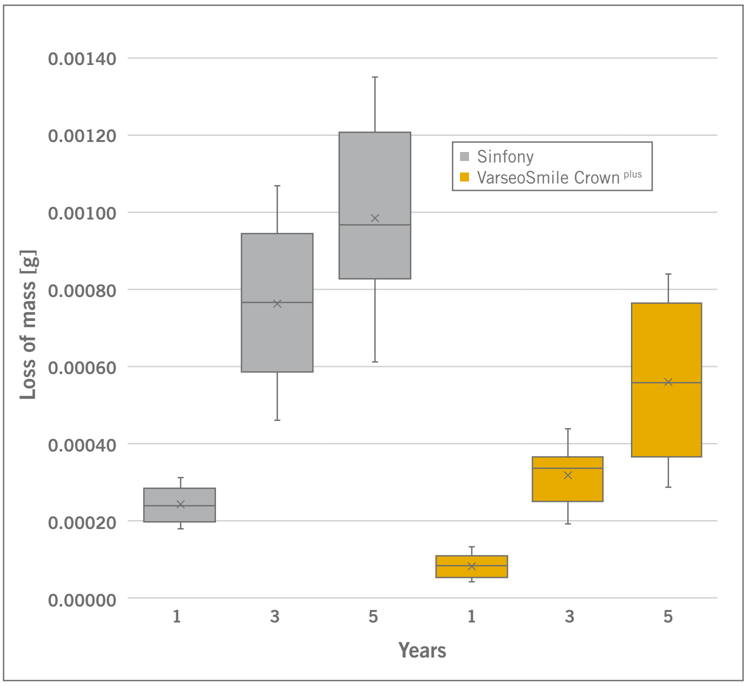


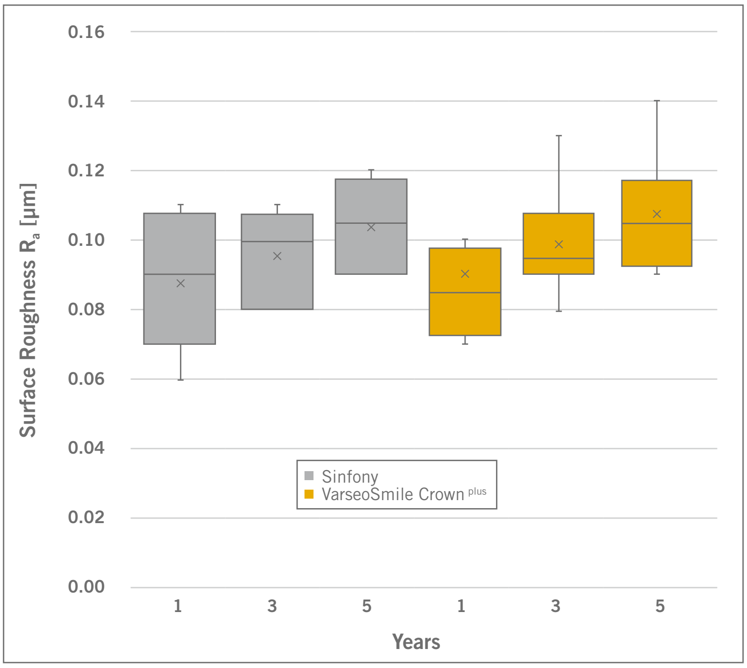


**Boxplot/distribution of the measured values of loss of mass and surface roughness**

**Source**
The above information is based on a scientific study of the toothbrush abrasion of VarseoSmile Crown plus conducted by Niclas Albrecht, SD Mechatronik GmbH, Germany

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# Long-term Cementation Stability, Decementation Behavior, and Marginal Gap Formation

## 5-year Chewing Simulation

**Objective**

This study intended to provide information, under conditions resembling application, on

- the long-term stability of the cementation,
- the decementation behavior and
- the tendency toward microleakage (marginal gap formation)

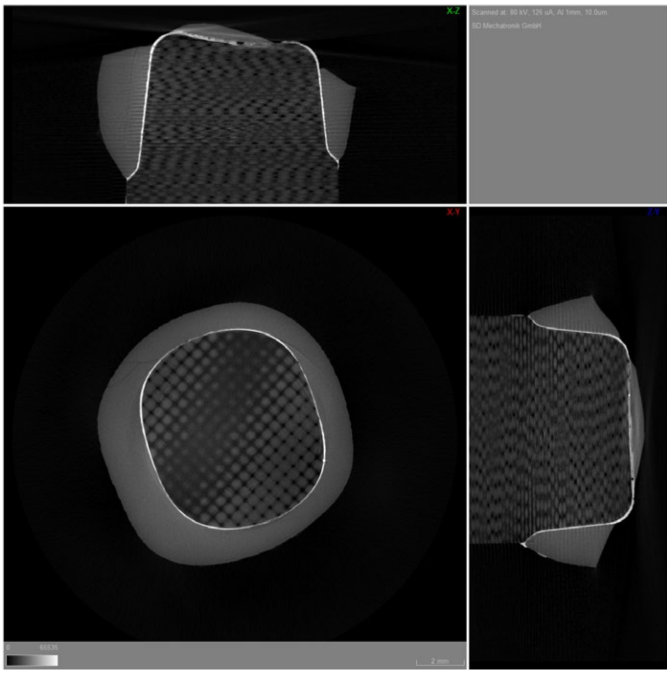
of VarseoSmile Crown plus crowns under masticatory loads.

**Materials and Methods**

The 3D printed crowns made of VarseoSmile Crown plus were cemented, i.e. adhesively affixed, to milled Trinia* stumps (the elasticity modulus of the stump material of 18.8 GPa is comparable to that of natural dentin) using Variolink Esthetic DC*. There was no pre-treatment in which the inner surfaces were sandblasted.

This study design, based on clinical use, was subject to both a chewing simulation at 50 N load with 1.2 million chewing cycles (1.2 Hz) and 10,000 thermocycles (5 °C / 55 °C) (corresponding to approx. 5 years in the mouth) and to a staircase simulation (significantly elevated requirements through gradual increase of the load force (with 50 – 80 – 120 N load), with 400,000 chewing cycles and 10,000 thermocycles (5 °C / 55 °C) each time.

After the simulation, the cemented crowns were removed from the stumps. The force required to do so was measured and the damage profile was analyzed. In addition, the marginal gaps were inspected using microcomputer tomography (µCT). The validity of the results was conclusively verified using a computer-based finite element analysis (FEA).



**µCT image: No washout of adhesive in the crown margin area**

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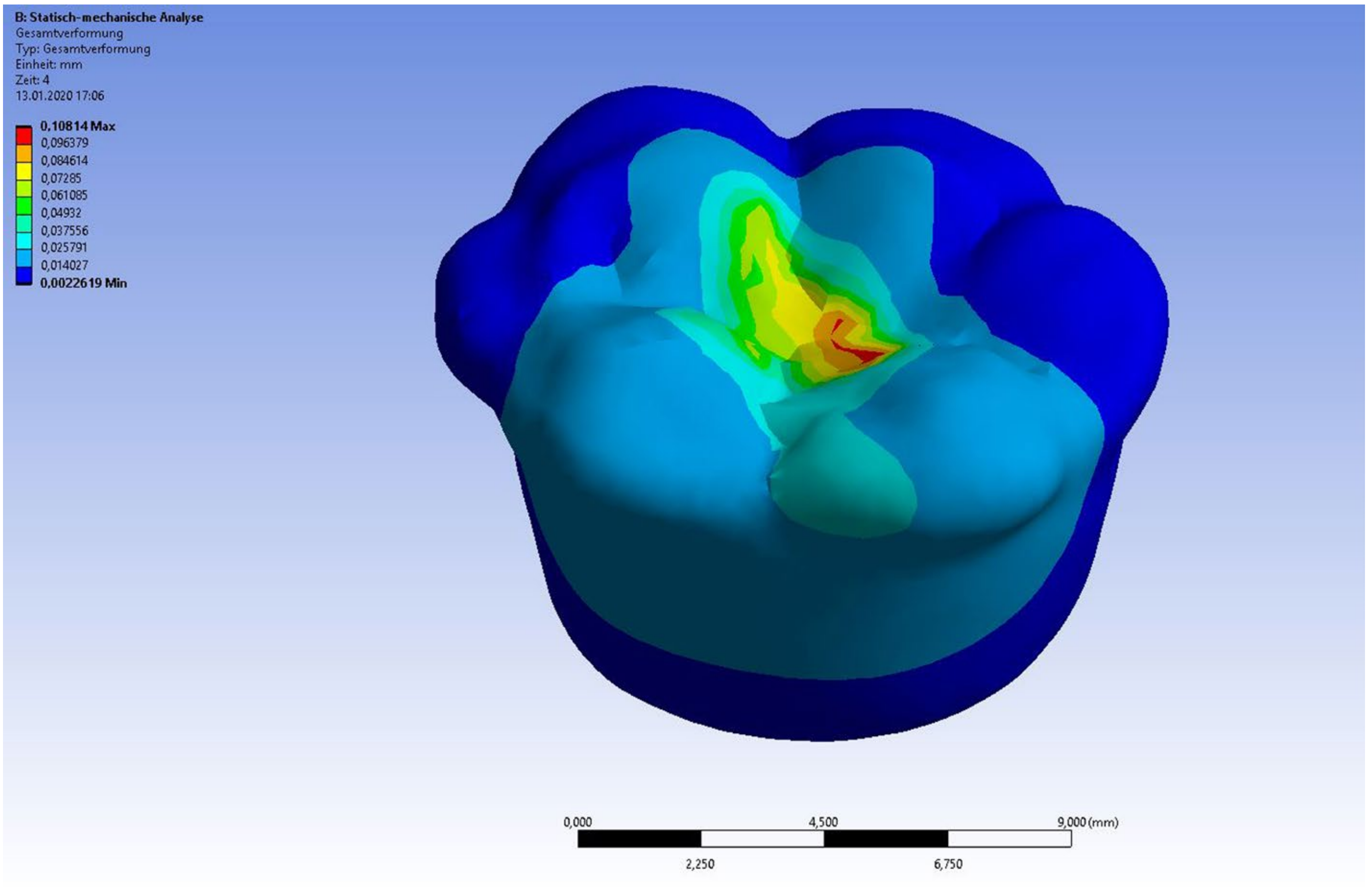
**Results**

The values ascertained for all BEGO VarseoSmile Crown plus crowns fell within a very high range, which speaks in favor of a long clinical retention time.

- On average, the force of withdrawal without conducting a chewing simulation was approx. 800 N, and after a chewing simulation it was approx. 1000 N. These high values were determined after the chewing simulation at 50 N and after the staircase chewing simulation, demonstrating that the forces of withdrawal themselves fell within a high range and even increased with the duration of wear. From a clinical perspective, the application of such high forces could result in extraction of the tooth due to failure of the adhesive bond.
- The examined crowns displayed a resistance to fracture that was greater than the physiological masticatory forces.
- A decementation was not detected throughout the entire test sequence.
- Neither a lifting of the crown margins or washout of the luting composite from the marginal gap could be observed. The µCT showed that the marginal gap did not increase, the bonding area was not damaged, and the crowns did not shift due to mechanical load, in any of the tested cases.
- The FEA analysis demonstrated that no clinically relevant tensions or deformations were detectable or to be expected in the crown margin area, for crowns made of VarseoSmile Crown plus. This result promises a stable, durable margin closure.

**Conclusion**

The present studies provide evidence that 3D printed crowns made of VarseoSmile Crown plus do not exhibit a tendency toward decementation, i.e. a loss of composite material or marginal gap formation, when using commercially available, dual-curing luting composites (e.g. Variolink Esthetic DC*).




**FEA analysis with visualization of the very minor deformation load in the crown margin area**

**Source**

The above information is based on a scientific study of the decementation behavior of VarseoSmile Crown plus, conducted by:
Prof. Dr. Jan-Frederik Güth, ZT Josef Schweiger, M.Sc., Dipl. Ing. Dr. Kurt-Jürgen Erdelt; Polyclinic for Dental Prosthetics, Medical Center of the University of Munich, Germany

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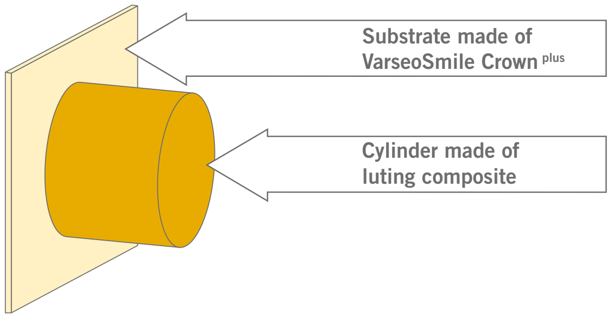
# Bonding Strength with Luting Composite




**Objective**

The aim of this study was to test the bonding strength between 3D printed test specimens made of VarseoSmile Crown plus and a luting agent following different surface treatments. As when the study was conducted there was no suitable testing standard for 3D printed plastics, it was performed in accordance with DIN EN ISO 10477:2018. The test specimens were artificially aged with thermal cycling before the shearing test (5000 × 5 °C – 55 °C).

**Materials and Methods**

The following three test groups were examined using five test specimens in each group, each consisting of a substrate made of printed VarseoSmile Crown plus and a cylinder made of luting composite applied to the substrate:

1. The substrate was cleaned with ethanol in an ultrasonic bath and blasted with glass beads (the procedure is described in the instructions for use for the VarseoSmile Crown plus)
2. The substrate was cleaned with ethanol in an ultrasonic bath
3. The substrate was cleaned with ethanol in an ultrasonic bath and blasted with glass beads. The surface was then polished

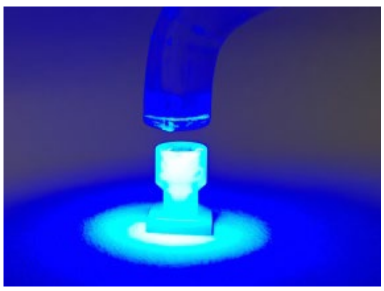
The test groups are outlined in the overview below.

| | | | | |
|---|---|---|---|---|
| **Test group 1** | 3 min + 2 min ethanol ultrasonic bath | Blasting with Perlablast Micro | 2 × 1,500 flashes with BEGO Otoflash without $N_2$ atmosphere | – |
| **Test group 2** | 3 min + 2 min ethanol ultrasonic bath | – | 2 × 1,500 flashes with BEGO Otoflash without $N_2$ atmosphere | – |
| **Test group 3** | 3 min + 2 min ethanol ultrasonic bath | Blasting with Perlablast Micro | 2 × 1,500 flashes with BEGO Otoflash without $N_2$ atmosphere | Pre-polishing: Pumice stone High gloss polishing: Universal polishing paste/Opal L |

**Test groups to measure the bonding strength between 3D printed test specimens made of VarseoSmile Crown plus and a luting agent**

The substrates were conditioned as set out above for the different test groups. The surface was then initially cleaned with a cleaning solution (Ivoclean*). The primer Monobond Plus* was then applied and the surface dried with oil-free compressed air.
An acrylic cylinder (internal diameter 2.9 mm, height 10 mm) was placed on the surface treated in this manner and filled with Variolink Esthetic DC* luting composite. The composite was cured from four sides for 10 seconds on each and once from above for 20 seconds with an LED lamp.
The test specimen produced in this way was stored in an incubator for 24 hours at 36° C (Hera Cell 150*) and then exposed to 5000 thermocycles (from 5 °C to 55 °C).

In the subsequent shearing test in accordance with DIN EN ISO 10477:2018 the cylinder made of Variolink Esthetic DC* was sheared off the substrate made of VarseoSmile Crown plus in a universal testing machine with the aid of a punch. The force required to do so was measured and the shear bond strength was thus calculated. The fracture pattern analysis was also carried out on the sheared test specimens.



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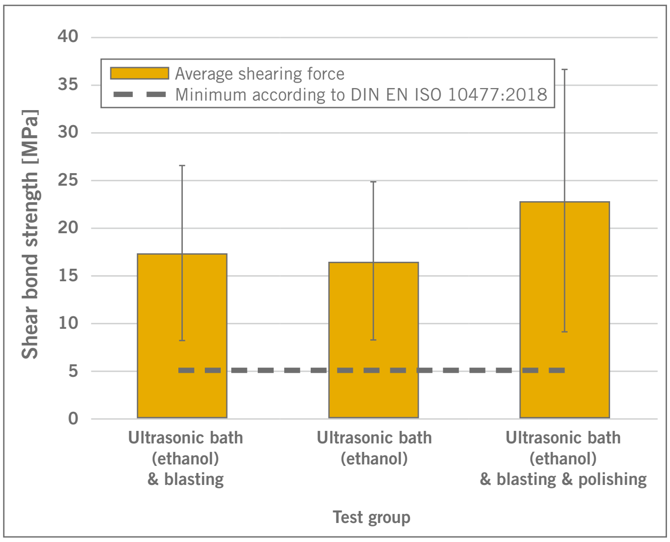
## Results

The results of the bonding strength are shown in the overview below. All test groups meet the criteria of DIN EN ISO 10477:2018, requiring a minimum bonding strength of 5 MPa.

### Results of the shear bond test according to DIN EN ISO 10477:2018

| Test groups | Mean ± standard deviation [MPa] | 95 % CI [MPa] | Min/Median/Max [MPa] |
|---|---|---|---|
| Ultrasonic bath (ethanol) & blasting | 17.2 ± 9.1 | 5.7; 28.6 | 6.7/14.1/30.0 |
| Ultrasonic bath (ethanol) | 16.5 ± 8.4 | 5.9; 27.0 | 7.2/21.6/23.7 |
| Ultrasonic bath (ethanol) & blasting & polishing | 22.8 ± 13.7 | 5.7; 39.9 | 0.0/27.4/35.4 |

The fracture type was examined in addition to the measured shear bond strength. An adhesive fracture is a fracture in the bonding zone between the substrate and the luting agent. A cohesive fracture is when something breaks out of the substrate or the luting agent. An adhesive fracture pattern was only observed in one test specimen in the group "ultrasonic bath (ethanol)" and "ultrasonic bath (ethanol) & blasting & polishing". All other test specimens thus had cohesive fracture patterns.




Mean shear bond strengths of the test groups

### Frequency of fracture types resulting from shearing test

| Test group | Adhesive [number of test specimens] | Cohesive – fracture runs through the bonding composite [number of test specimens] | Cohesive – fracture pattern in the substrate [number of test specimens] |
|---|---|---|---|
| Ultrasonic bath (ethanol) & blasting | 0 | 0 | 5 |
| Ultrasonic bath (ethanol) | 1 | 0 | 4 |
| Ultrasonic bath (ethanol) & blasting and polishing | 1 | 0 | 4 |

## Conclusion

All test groups significantly exceed the minimum requirement of 5 MPa defined in the DIN EN ISO 10477:2018 standard.
The cohesive fracture type is the most commonly observed. This type of fracture indicates that the bond is higher than the strength of the substrate or the bonding composite. An adhesive fracture pattern indicating failure of the adhesive bond was only observed in one of five test specimens in the groups "Ultrasonic bath (ethanol)" and "Ultrasonic bath (ethanol) & blasting & polishing".
In conclusion, the results show that VarseoSmile Crown plus has a very high bonding strength with luting composite, irrespective of the test groups selected here.

**Source & Literature**

The above information is based on a study on the bonding strength between VarseoSmile Crown plus and luting composite, performed by Material Research at the Polyclinic for Prosthetic Dentistry, University Hospital Munich, Germany

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# Breaking Load of Metal Framework Crown with Veneer Shell

## 5-year Chewing Simulation

**Objective**

This study was designed to investigate the long-term stability of crowns made of a metal framework and a veneer shell made of printed VarseoSmile Crown plus in relation to the breaking load.

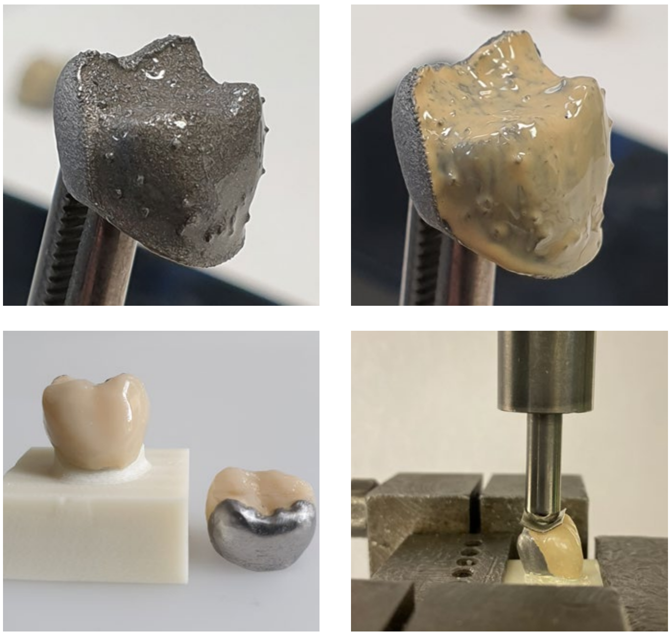
**Materials and Methods**

BEGO manufactured 16 framework of Wirobond® C+ by Selective Laser Melting (SLM) and printed 16 veneers of VarseoSmile Crown plus (with a wall thickness of 0.5 mm).
The frameworks and veneer shells were bonded at the University Hospital of Munich. This involved conditioning the framework exterior in the following layers following corundum blasting (250 µm Al2O3 at 3 bar):

1. Metal primer (Alloy primer*)
2. Pre opaquer (VITA VM LC PRE OPAQUE*)
3. Paste opaquer (VITA VM LC OPAQUE PASTE*)

The inside of the veneer shells was corundum blasted with 50 µm Al2O3 and coated in modelling liquid VITA VM LC MODELLING LIQUID. It was then adhered to the framework with the veneering composite VITA VM LC BASE DENTINE* and cured for 360 seconds (bre. Lux PowerUnit 2*). A glaze, VITA ENAMIC GLAZE*, was then applied to the bonded veneer shell.
To secure the veneered metal framework (crown) to the stump (fiberglass reinforced composite TRINIA*), the contact surfaces were blasted with corundum at 110 µm Al2O3 at 2 bar and cleaned in an ultrasonic bath. The stump and crown were then bonded together with a bonding cement.

All test specimens created in this way were stored in distilled water in an incubator (HERA Cell 150, Kulzer) for 24 hours at 37 °C. The initial fracture strength was determined in eight of the test specimens (i.e. the breaking load before artificial aging). Another eight test specimens underwent a chewing simulation of 1.2 million chewing cycles at 50 N and a lateral movement of 0.7 mm with an additional 6000 thermocycles between 5 °C and 55 °C (Chewing Simulator CS-4.8). Steatite balls with a diameter of 6 mm were used as an antagonist material.



**Production of the veneered framework, bonding to the stump and testing the breaking load**

The breaking load of the test specimens was measured in a compression test in a universal testing machine (RetroLine). A ball (ø 6 mm) was used as a test punch and was positioned in the middle of the crown. Tinfoil (thickness: 0.3 mm) was placed between the punch and the crown to ensure that the force was evenly distributed and to avoid localized stress peaks. The test specimens were each prestressed with 10 N. The load was then increased until a fracture occurred. The maximum load was registered (testXpert*).

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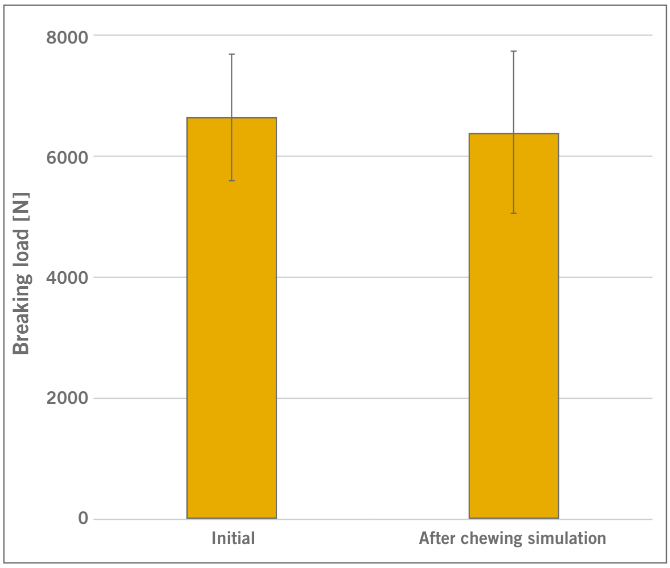
**Results**

In the test specimens not subjected to prior chewing simulation (initial), the mean breaking load was 6658 N. The mean measured breaking load in the test specimens previously subjected to the chewing simulation was 6396 N.

**Conclusion**

This test confirms that crowns made of a metal framework and a veneer shell made of VarseoSmile Crown plus have breaking loads far above the clinically expected loads both without and after 5-year chewing simulation. Furthermore, it demonstrated that there is no substantial reduction in breaking load after artificial aging. Metal crowns with veneer shells made of the 3D printed material VarseoSmile Crown plus are therefore suitable for permanent restorations.




**Breaking loads (mean and standard deviation) without and after 5-year chewing simulation**

**Source**
The above information is based on a study on the breaking load of metal framework crowns with veneers made of VarseoSmile Crown plus and was carried out by Material Research at the Polyclinic for Prosthetic Dentistry, University Hospital Munich, Germany

# Adhesion of Sealants

**Objective**
It should be possible to customize the shade of restoration surfaces made of VarseoSmile Crown plus. To minimise abrasion of the color and/or to smooth the surfaces and thus seal them, special sealants may be used. These are designed to achieve good bonding to the restoration material and not to chip. Veneers that blow or crack can not only compromise the ascetics, but also exacerbate material loss.
To demonstrate the durability of sealants on restorations made of VarseoSmile Crown plus, the restoration material was pretreated and conditioned in different ways and coated with standard sealants.

The coated restoration material was subjected to a three media aberration test with an ACTA (Academic Center for Dentistry Amsterdam) device.

**Materials and Methods**
Sixty test specimens made of VarseoSmile Crown plus were manufactured with the Varseo XS 3D printer as set out in the instructions for use.

**VarseoSmile Crown plus test groups (12 test specimens per group)**

| | | | | | |
|---|---|---|---|---|---|
| **Surface treatment** | Blasting | Blasting | Diamond grinder | Blasting | – |
| **Pretreatment** | VITA* ADVAC primer | – | Ceramic Primer II & GC Composite Primer | Ceramic Primer II & GC Composite Primer | Ceramic Primer II & GC Composite Primer |
| **Characterization** | VITA ENAMIC STAIN | VITA ENAMIC STAIN | GC OPTI-GLAZE Color | GC OPTI-GLAZE Color | GC OPTI-GLAZE Color |
| **Seal** | VITA GLAZE | VITA GLAZE | GC OPTI-GLAZE Clear | GC OPTI-GLAZE Clear | GC OPTI-GLAZE Clear |

**Abrasion test ACTA device**

**Diagram of the test implementation and the materials used – the test involved a total of five groups overall (n = 12 in each group)**

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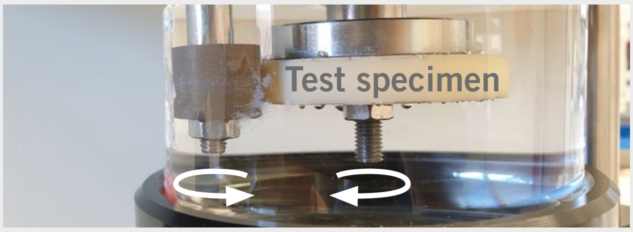
The test specimens were secured to five metal wheels with 12 wells in each using veneer composite (Ceramage). The exterior of the VarseoSmile Crown plus segments were conditioned with two standard primers. When conditioning with VITA* ADIVA C-Primer the surfaces were also blasted with corundum. Another group was only blasted with corundum (50 µm corundum, 1 bar) without applying the VITA ADIVA C-Primer. The sealant VITA ENAMIC Stain was then applied to the appropriately prepared surfaces in accordance with the manufacturer's instructions. The surfaces were then coated with VITA Glaze and polymerized according to the manufacturer's instructions. In the groups in which the sealant GC OPTIGLAZE Color was used the surfaces of the test specimens were removed with a diamond burr before the Ceramic Primer II and GC Composite Primer were applied; in another test group the surfaces were blasted with corundum and in the third group the surfaces were left untreated. GC OPTIGLAZE Color was then applied and the surfaces were sealed with GC OPTIGLAZE Clear.

The metal wheels were clamped into a three media ACTA device. An antagonistic steel wheel with an adjustable force (15 N[1]) running in the opposite direction was used to press a millet slurry (millet-water mixture) onto the rotating metal sample wheels holding the test specimens conditioned as described above.
The surfaces of the test specimen were microscopically tested after approximately 1,000 rotations. The test specimens were each subjected to a total of 160,000 rotations.

Test specimen: a metal holder inside the wheel. The individual segments of the "tyre" consist of the VarseoSmile Crown plus with a sealed surface.

Test device for abrasion: there is a closed glass vessel in the lower half containing the test specimen immersed in a fluid with an abrasion agent.



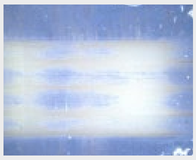
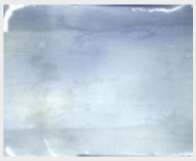

The test specimen is secured to a pivot in the aforementioned glass vessel. To the left, there is an axis that rotates in the opposite direction. The abrasion material is then pressed against the test specimen with an adjustable pressure. This results in abrasion, which is assessed with a microscope after a defined number of rotations.

**Description of the ACTA test device**

[1] Stawarczyk B, Dinse L, Eichberger M, Jungbauer R, Liebermann A. Flexural strength, fracture toughness, three-body wear, and Martens parameters of pressable lithium-X-silicate ceramics. Dent Mater 2020;36(3):420–430.
* This symbol is a commercial designation/registered trademark of a company which is not part of the BEGO company group.

## Results

**Microscopic images and assessment of the sealed and artificially aged VarseoSmile Crown plus test specimen after the test**

| Group | Description | Surface after loading | Assessment |
|---|---|---|---|
| 1 | Blasted, VITA* ADIVA C-Prime, VITA ENAMIC Stain, VITA Glaze |  | Uniform abrasion marks without chipping or fracture of the sealant |
| 2 | Blasted, VITA ENAMIC Stain, VITA Glaze |  | Uniform abrasion marks without chipping or fracture of the sealant |
| 3 | Diamond burr, Ceramic Primer II, GC Composite Primer, GC Optiglaze Color, GC Optiglace Clear |  | Uniform abrasion marks without chipping or fracture of the sealant |
| 4 | Blasted, Ceramic Primer II, GC Composite Primer, GC Optiglaze Color, GC Optiglace Clear |  | Uniform abrasion marks without chipping or fracture of the sealant |
| 5 | Ceramic Primer II, GC Composite Primer, GC Optiglaze Color, GC Optiglace Clear |  | Uniform abrasion marks without chipping or fracture of the sealant |

**Microscopic images and assessment of the sealed and artificially aged VarseoSmile Crown plus test specimen after the test**

The results show that the two standard sealants formed a tight bond with the 3D printed test specimens made of VarseoSmile Crown plus irrespective of how the surfaces were previously treated. The sealant material did not break out or chip during the abrasion tests and surface abrasion was evenly distributed.

### Conclusion

Since the sealant did not chip, the bond between the VarseoSmile Crown plus and the two commercially available sealants tested here is considered favorable. The application of a sealant to color-customized VarseoSmile Crown plus is thus an option that is recommended.

**Source**
The above information is based on a study on the adhesion of sealants on VarseoSmile Crown plus and was carried out by Material Research at the Polyclinic for Prosthetic Dentistry, University Hospital Munich, Germany

* This symbol is a commercial designation/registered trademark of a company which is not part of the BEGO company group.

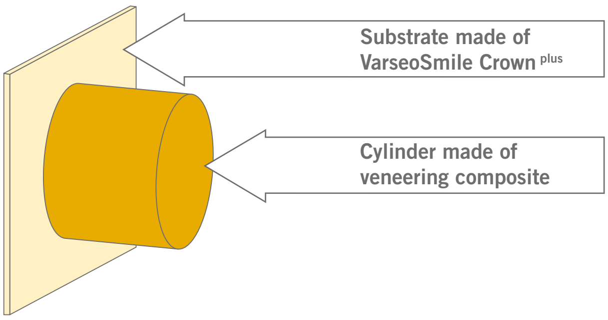
# Bonding Strength with Veneering Composites

**Objective**

VarseoSmile Crown plus is a ceramic filled hybrid material designed for 3D printing dental models, including the production of permanent crowns. These are often veneered with veneering composites for aesthetic reasons. This study was designed to verify the bonding strength with veneer composites and the bonding agents designed for this purpose. To achieve this, the shear bond strength was tested in accordance with DIN EN ISO 10477:2018 on test specimens made of VarseoSmile Crown plus, VITA* VM LC and VITA VM LC flow.

**Materials and Methods**

Test specimens were produced in accordance with DIN EN ISO 10477:2018. Substrates for a total of six test groups, each containing 5 test specimens measuring 11 mm × 1 mm × 2 mm were manufactured of VarseoSmile Crown plus in accordance with the instructions for use. After corundum blasting at 3 bar with 110 µm aluminum oxide (Korox® 110) as specified in the instructions for use of the veneer composite, the surfaces of four series were coated with the VITA VM LC Modeling Liquid. After an exposure time of 50 seconds, a cylinder of VITA VM LC flow or Vita VM LC on the center of the substrates made of VarseoSmile Crown plus was polymerized with the aid of a metal ring. Two further series with VITA VM LC were also produced, but in these cases without applying the VITA VM LC Modelling Liquid beforehand.
This resulted in four test groups made of VarseoSmile Crown plus substrates with VITA VM LC (two with and two without VITA VM LC Modelling Liquid) and two test groups composed of VarseoSmile Crown plus substrates with VITA VM LC flow. One test group from the resulting three identical test group pairs was immersed in water for 24 hours at 37 °C, while another was exposed to 25,000 thermocycles between 5 °C and 55 °C:




**Manufactured test groups consisting of five test specimens each with storage conditions**

| Series | Base | Veneer | Primer | Storage conditions |
|---|---|---|---|---|
| 1 | VarseoSmile Crown plus | VITA VM LC flow | VITA VM LC Modelling Liquid | 24 h / 37 °C |
| 2 | VarseoSmile Crown plus | VITA VM LC flow | VITA VM LC Modelling Liquid | 25,000 thermocycles |
| 3 | VarseoSmile Crown plus | VITA VM LC | VITA VM LC Modelling Liquid | 24 h / 37 °C |
| 4 | VarseoSmile Crown plus | VITA VM LC | VITA VM LC Modelling Liquid | 25,000 thermocycles |
| 5 | VarseoSmile Crown plus | VITA VM LC | without | 24 h / 37 °C |
| 6 | VarseoSmile Crown plus | VITA VM LC | without | 25,000 thermocycles |

The test conditions were stricter than those specified in DIN EN ISO 10477:2018. The number of thermocycles was increased from 5000 to 25000 to accommodate the more challenging demands placed on permanent restorations.

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The test specimen was then clamped into a holder of a universal test machine and the bonding composite cylinders were sheared off. The force required to shear off the cylinder was recorded and the fracture surfaces were then analyzed.

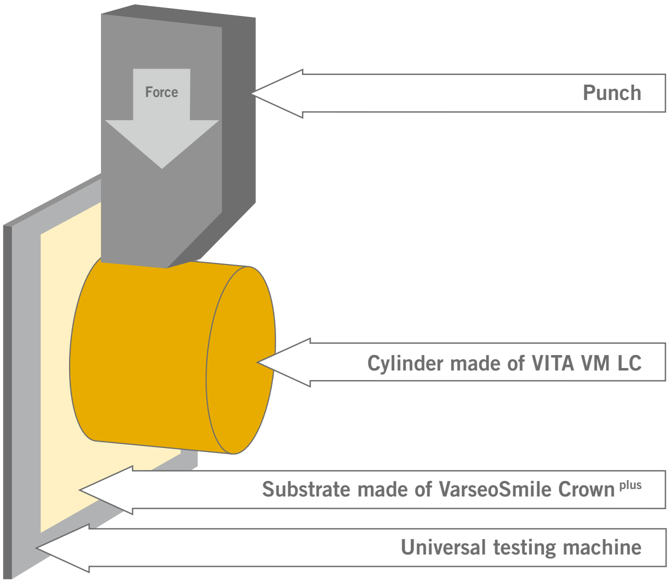
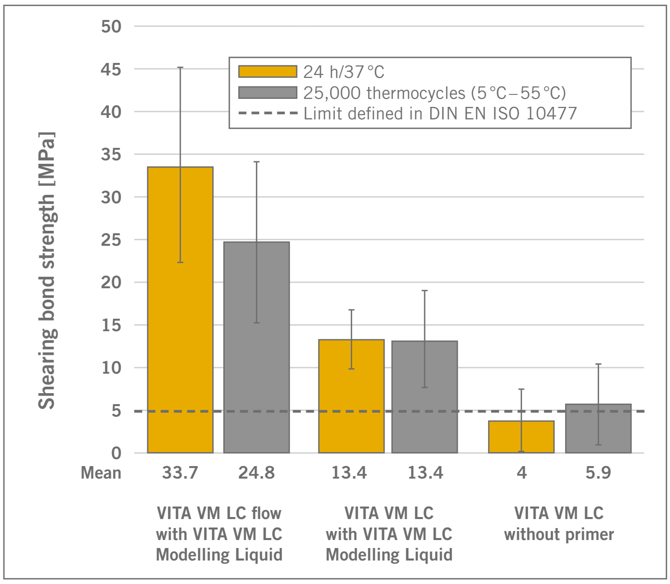



Diagram of the test procedure and the test method

**Results**

The threshold of the shear bond strength is defined as 5 MPa in DIN EN ISO 22674:2016. This limit is significantly exceeded when using both veneer composites in combination with the VarseoSmile Crown plus, working with the VITA VM LC Modelling Liquid. Bonding without the use of a primer does not meet the requirements of the standard. The low viscosity veneering composite VITA VM LC flow has a significantly higher shear bond strength than the more viscous flowing material VITA VM LC. However, the latter easily meets the standard when working with the VITA VM LC Modelling Liquid. This also initially applies to the test series exposed to cyclic temperature changes.

The analysis of the fracture surfaces showed that the use of the VITA VM LC Modelling Liquid generally resulted in a cohesive fracture, i.e. the actual material of the test specimen fractured. Without VITA VM LC Modelling Liquid, adhesive fractures occurred in nearly all cases, i.e. the test specimens failed at the composite zone.




Results of the tests for shear bond strength based on DIN EN ISO 10477

**Conclusion**

The studies show that use of VITA VM LC Modelling Liquid achieves very high bonding strength between the VarseoSmile Crown plus and the low viscosity veneer composite VITA VM LC flow even when the test conditions are stricter than those set out in DIN EN ISO 10477:2018.
While bonding to the highly viscous composite is less effective, it remains stable after artificial aging and the fracture pattern is cohesive, just as with composite with a low viscosity.
Veneering without the use of the VITA VM LC modelling liquid is not recommended.

**Source**

The above information is based on a scientific study of the bonding strength of VarseoSmile Crown plus to VITA VM LC and VITA VM LC flow conducted by University Hospital Jena, Dental, Oral and Maxillo-facial Center, Polyclinic for Dental Prosthetics and Material Research

# Effects of Additional UV Light Curing Processing

**Objective**

This study explored the effects of additional UV light curing processes on the mechanical properties, the dental fit and the color of 3D printed restorations made of VarseoSmile Crown plus.

3D printed restorations made of VarseoSmile Crown plus already have a similar appearance to natural teeth, even without customization. Nonetheless, treatment downstream of the production process, e.g. with stains or veneering composites, is common, especially for anterior restorations. This requires additional UV curing cycles.

Other examples of downstream processing are the addition and repair of already printed restorations with VarseoSmile Crown plus and the cementation of restorations on titanium abutments or metal frameworks, each of which also requires additional UV curing cycles.

**Materials and Methods**

A consultation of experienced dental technicians showed that in rare cases up to 10 additional curing cycles may be needed as a result of the aforementioned supplementary treatments. Although it is not expected that restorations made of VarseoSmile Crown plus will be exposed to more than 10 additional curing cycles, in this study test groups were reviewed after 10 and after 20 additional curing cycles to ensure that the worst-case scenario was covered.

Test specimens were printed using a Varseo XS printer to investigate the effects of additional curing cycles on the mechanical properties, fit and color of VarseoSmile Crown plus restorations. The test specimens were cleaned for two plus three minutes in ethanol (96 %) and subsequently cured with the BEGO Otoflash light curing device. The Heraeus HiLite Power* was used for the additional curing cycles. This light curing device with its high intensity white light spectrum was selected to achieve a maximum effect on the test specimen.

**Mechanical properties**

Two test groups, each with five test specimens, were prepared in accordance with DIN EN ISO 10477:2018 to investigate the mechanical properties. One test group was exposed to 10 and the other to 20 additional UV curing cycles (1 cycle = 2 × 90 s). The mechanical properties were evaluated by measuring the flexural strength in a 3-point flexure test. In at least four of the five samples the flexural strength must be ≥ 100 MPa in accordance with DIN EN ISO 4049:2019 and ≥ 50 MPa in accordance with DIN EN ISO 10477: 2018.

**Dental fit**

Dental fit was tested with six test specimens in the form of 7-unit bridges, of which three had to undergo 10 and another three had to undergo 20 additional curing cycles. Although VarseoSmile Crown plus is not indicated for 7-unit bridges, this restoration was used in the study as changes in dental fit are comparatively easy to notice in this type of bridge. The test was carried out by trained dental technicians who assessed the dental fit of the test specimens following additional UV curing compared to a reference sample that was manufactured according to the instructions for use (IFU) without additional UV curing.

**Color deviation**

The 7-unit bridges were also used to test the color deviation according to DIN EN ISO 10477:2018. The assessment was carried out by three observers using a lightbox and a reference sample which had not been subjected to additional curing.

**Test specimens manufactured for the study**

| Test specimen | Curing cycles | Tests |
|---|---|---|
| 5 × test specimens according to ISO 10477 | 10 additional curing cycles (HiLite Power*) | • Material properties<br>• Fit<br>• Shade deviation |
| 3 × 7-unit bridges as test specimens | | |
| 5 × test specimens according to ISO 10477 | 20 additional curing cycles (HiLite Power*) | |
| 3 × 7-unit bridges as test specimens | | |
| 1 × 7-unit bridge as test specimen | No additional curing cycles | Reference for fit & color deviation |

* This symbol is a commercial designation/registered trademark of a company which is not part of the BEGO company group.

## Results

- **Material properties**
  The results of the 3-point flexural test carried out to investigate the material properties are shown below:

**Results of the 3-point flexural test**

| Test group | Flexural strength [MPa] | Mean [MPa] | Standard deviation [MPa] |
|---|---|---|---|
| 10 cycles | 145 | 150 | 4.29 |
| | 154 | | |
| | 150 | | |
| | 145 | | |
| | 153 | | |
| 20 cycles | 157 | 153 | 6.43 |
| | 158 | | |
| | 142 | | |
| | 152 | | |
| | 154 | | |

- **Fit**
  The evaluation of the fit test yielded no difference between the objects before and after the additional curing.
- **Color deviation**
  The results of the color deviation test are presented below for the color components red, yellow and black/white and for brightness.

**Results of the color deviation test (more: ↗; less: ↘; the same:→)**

| | Tester 1 | Tester 2 | Tester 3 |
|---|---|---|---|
| Corresponds to the reference sample | No | No | No |
| Brightness | ↗ | ↗ | ↗ |
| Red | ↗ | ↗ | ↗ |
| Yellow | ↗ | ↗ | ↗ |
| White | ↘ | ↘ | ↘ |

## Conclusion

- **Mechanical properties**
  The test specimens meet the requirements of the standards DIN EN ISO 4049:2019 and DIN EN ISO 10477:2018 after 10 and after 20 additional UV curing cycles in terms of the flexural strength. The measured values actually exceed the flexural strength of VarseoSmile Crown plus without additional curing cycles. This is an average of 116 MPa (manufactured according to the IFU with Varseo XS and BEGO Otoflash). The individual results of both test groups are within a relatively small range which indicates that the additional UV light curing did not have a negative impact on the mechanical properties of the samples.
- **Dental fit**
  The effects on dimensional stability were negligible, as no impairment of dental fit was observed.
- **Color deviation**
  The additional UV light exposure did have an influence on the color of the test specimens. The established color change was, however, assessed only as a slight deviation and thus complies with the standard DIN EN ISO 10477:2018.
  Overall, it can be concluded that UV light curing cycles, which are usually performed during customization and/or supplementation or other procedures in addition to the regular printing workflow, do not impair the properties of restorations made of VarseoSmile Crown plus.

**Source**
The information provided above is based on a study on the effects of additional UV curing cycles on VarseoSmile Crown plus carried out by BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG

# Solubility

**Objective**
In this study, the solubility of 3D printed restorations made of VarseoSmile Crown plus were tested, since the dimensions, color, and in very unfavorable circumstances even the mechanical properties of composite restorations may be affected by the extraction (= leaching) of components.
Solubility is of great importance in the evaluation of biocompatibility. When substances formed from processes of dissolution with saliva are released into the oral cavity, undesired biological reactions (allergic or toxic) may be triggered. The extent of such reactions depends on the type and quantity of the released substances, amongst other things.

**Materials and Methods**
The solubility of composites is determined through extraction tests. To this end, test specimens made of VarseoSmile Crown plus, which were manufactured under serial conditions, were stored in a solvent for one and three days. Different polar solvents (water and ethanol) were used in order to simulate various saliva compositions.
The eluates (= solutions) obtained in this manner were analyzed via gas chromatography - mass spectrometry (GC-MS) for composite constituents that entered the solution. GC-MS is an analysis method with extremely low detection limits for organic substances.

**Results**
In these studies for the VarseoSmile Crown plus, none of the components were found to have dissolved, irrespective of which solvent was used. Thus, there is only an exceedingly low risk of undesired biological reactions.

**Conclusion**
Under the study conditions selected, VarseoSmile Crown plus yielded no substances in the detectable area. Therefore, the risk of conceivable risk to patients, e.g. through allergies, can be classified as exceedingly low.

**Source**
The above information is based on a scientific study of the solubility of VarseoSmile Crown plus, conducted by:
International Advising Centre for the Compatibility of Dental Materials (BZVZ) of the Ludwig-Maximilians-Universität München, Germany

* This symbol is a commercial designation / registered trademark of a company that is not part of the BEGO company group.

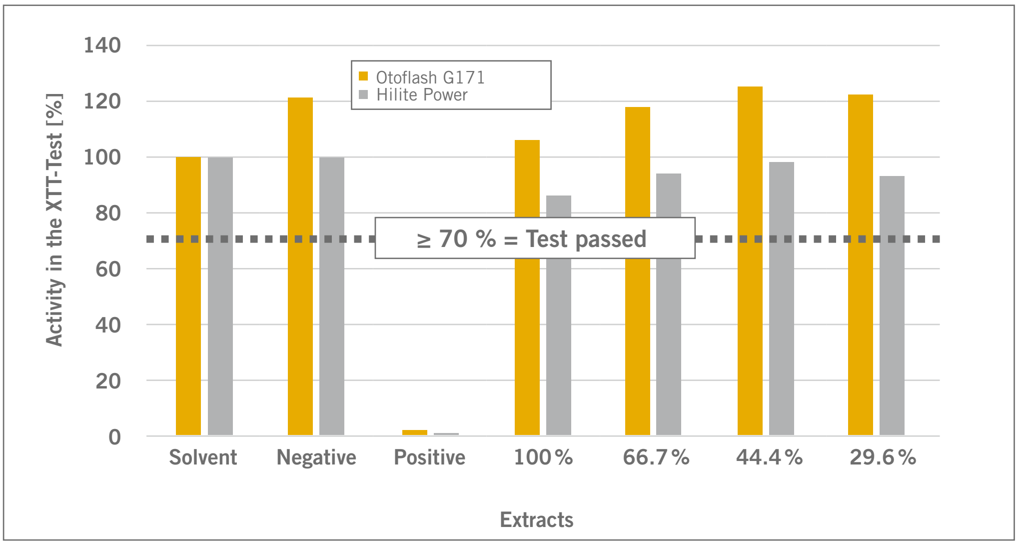
# Cytotoxicity

**Objective**
The objective of the study was the testing of cytotoxicity (= cell toxicity) of 3D printed restorations made of VarseoSmile Crown plus in accordance with DIN EN ISO 10993-5, which is fundamentally intended for the determination of the biocompatibility of materials.

**Materials and methods**
For this test, extracts of the pertinent samples, which were produced as per manufacturer specifications, were compared with the pure dissolver (solvent) and with positive and negative control samples.
To prepare the extracts, the test specimens were extracted in a solvent for 24 hours. These extracts were then diluted to obtain four different concentrations (100% (undiluted), 66.7%, 44.4%, 29.6%).
In order to ensure the validity of the test, the pure solvent (without contact to the test specimens) as well as one negative (polypropylene) and one positive sample (latex) were also tested. The pure solvent was used as reference. For the negative probe, a substance that in accordance with DIN EN ISO 10993-5 demonstrates no evidence of cytotoxicity was used. In contrast to this, a cytotoxic material was used for the positive probe.
The extracts of the control samples and the different extract concentrations of the test specimens were added to cell cultures and after 68 h to 72 h the cell activity, which is determined through enzymatic reactions, was measured. The activity of mitochondrial dehydrogenases (an enzyme) was measured as a gage of cell activity.
Certain "markers", i.e. substances that react to certain enzymes and form colored complexes, were used for detection purposes. Cell activity was determined through color intensity and the XTT method (XTT = sodium-3'-[-(1-phenylamino carbonyl)-3,4-tetrazolium]-to(4-methoxy-6-nitro)benzenesulfonic acid hydrate) was applied as standard. With cell activity falling below 70%, the test is considered as not passed. The closer the cell activity is to that of the solvent control, the better.

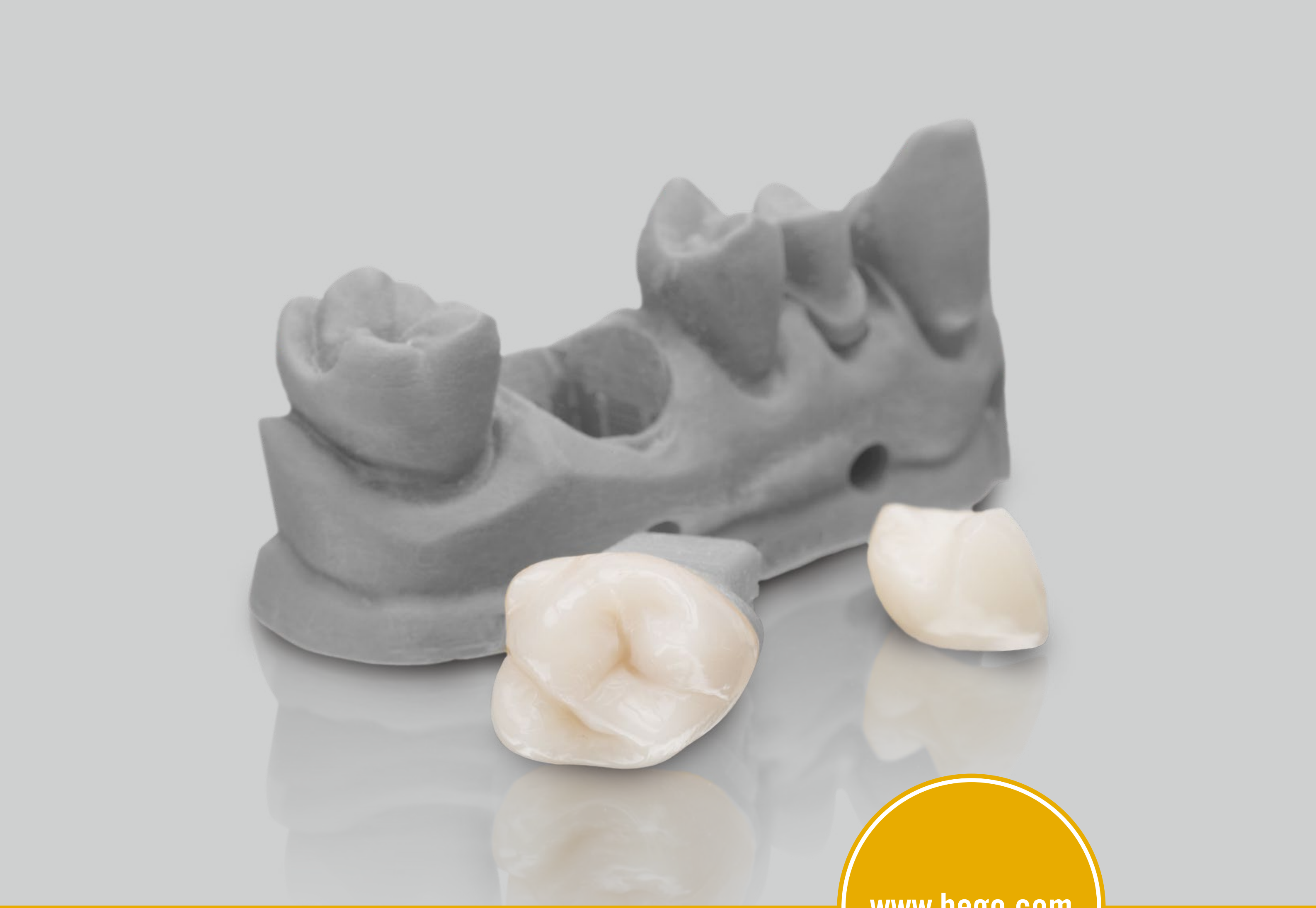
**Results**
The results of VarseoSmile Crown plus in the XTT test yielded, for all tested concentrations, including for the undiluted extract (100%), cell activities (determined through mitochondrial dehydrogenase activity) that were markedly higher than 70%. Thus, the test is considered as passed.

**Conclusion**
VarseoSmile Crown plus showed no cytotoxic properties in the XTT test. Thus, the results of the extraction measurement are confirmed. VarseoSmile Crown plus therefore constitutes a very well tolerated material.




**Mitochondrial dehydrogenase activity of VarseoSmile Crown plus and of the dissolver (solvent), negative and positive samples in the XTT test, results for test specimens that were polymerized with either the Otoflash G171 or Hilite Power light-curing devices**

**Source**
The above information is based on a scientific study of the cytotoxicity of VarseoSmile Crown plus, conducted by:
Eurofins BioPharma Product Testing Munich GmbH, Germany



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product information:

BEGO compatibility
overview of 3D printing
system components:

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3D sample print:

Other BEGO
3D printing materials:

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