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5.1 Bibliography
1. Introduction

The hybrid material presented here represents a milestone in the development of CAD/CAM materials. This newly-developed hybrid material combines the positive characteristics of proven all-ceramic materials with those of the composite materials used with CAD/CAM technology.

The hybrid ceramic is comprised of a structure-sintered ceramic matrix, the pores of which are filled with a polymer material. The mass percentage of the inorganic ceramic part is 86 wt%, while the mass percentage of the organic polymer part is 14 wt%. The combination of both of these materials provides considerable benefits for the user. For example, the tendency to brittle fracture is lower than in comparison with pure ceramics, and excellent CAD/CAM processing is also achieved.

VITA ENAMIC can be used for definitive single-tooth restorations. The restorations are fabricated using CAD/CAM technology.
1.1 VITA ENAMIC - material composition

The hybrid material is manufactured by first infiltrating a porous ceramic base structure with a monomer mixture and then curing (polymerization) is carried out. The composition of the ceramic corresponds to that of a fine-structure feldspar ceramic enriched with aluminum oxide.

**Composition of the ceramic part (86 wt% / 75 vol%)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Composition range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide</td>
<td>SiO₂</td>
<td>58 – 63%</td>
</tr>
<tr>
<td>Aluminum oxide</td>
<td>Al₂O₃</td>
<td>20 – 23%</td>
</tr>
<tr>
<td>Sodium oxide</td>
<td>Na₂O</td>
<td>9 – 11%</td>
</tr>
<tr>
<td>Potassium oxide</td>
<td>K₂O</td>
<td>4 – 6%</td>
</tr>
<tr>
<td>Boron trioxide</td>
<td>B₂O₃</td>
<td>0,5 – 2%</td>
</tr>
<tr>
<td>Zirconia</td>
<td>ZrO₂</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Calcium oxide</td>
<td>CaO</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>

**Composition of the polymer part (14 wt% / 25 vol%)**

**UDMA (urethane dimethacrylate)**

![UDMA molecule](image1)

**TEGDMA (triethylene glycol dimethacrylate)**

![TEGDMA molecule](image2)
### Summary of the physical/mechanical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>VITA ENAMIC</th>
<th>Standard value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static fracture load [N] (SD)</td>
<td>2766 (98)</td>
<td>None specified</td>
</tr>
<tr>
<td>Density [g/cm³]</td>
<td>2.1</td>
<td>None specified</td>
</tr>
<tr>
<td>Flexural strength [MPa]</td>
<td>150 - 160</td>
<td>ISO 10477: ≥ 50</td>
</tr>
<tr>
<td>Modulus of elasticity [GPa] (SD)</td>
<td>30 (2)</td>
<td>ISO 6872: ≥ 100</td>
</tr>
<tr>
<td>Abrasion [µm]</td>
<td>In the same range as Mark II, veneering ceramics</td>
<td>None specified</td>
</tr>
<tr>
<td>Extension in the case of fracture [%] (SD)</td>
<td>0.5 (0.05)</td>
<td>None specified</td>
</tr>
<tr>
<td>Weibull modulus</td>
<td>20</td>
<td>None specified</td>
</tr>
<tr>
<td>Hardness [GPa]</td>
<td>2.5</td>
<td>None specified</td>
</tr>
<tr>
<td>Fracture toughness [MPa√m]</td>
<td>1.5</td>
<td>None specified</td>
</tr>
<tr>
<td>Adhesion with veneering material [MPa]</td>
<td>Without silane: 12</td>
<td>ISO 10477: ≥ 5</td>
</tr>
<tr>
<td></td>
<td>With silane: 27</td>
<td></td>
</tr>
<tr>
<td>Shear strength, cementation [MPa]</td>
<td>RelyX Unicem: approx. 21, Variolink II: approx. 27, RelyX Ultimate: approx. 31</td>
<td>None specified</td>
</tr>
<tr>
<td>Shade stability</td>
<td>Excellent, ∆E &lt; 2</td>
<td>None specified</td>
</tr>
<tr>
<td>Machinability, edge stability</td>
<td>Excellent</td>
<td>None specified</td>
</tr>
<tr>
<td>Milling times, normal milling mode MC XL</td>
<td>Inlay: 7:56 min</td>
<td>None specified</td>
</tr>
<tr>
<td></td>
<td>Anterior crown: 7:10 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior crown: 9:07 min</td>
<td></td>
</tr>
<tr>
<td>Milling times, fast milling mode MC XL</td>
<td>Inlay: 4:40 min</td>
<td>None specified</td>
</tr>
<tr>
<td></td>
<td>Anterior crown: 4:19 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior crown: 5:13 min</td>
<td></td>
</tr>
<tr>
<td>Milling tool service life: posterior crowns</td>
<td>Normal: 148</td>
<td>None specified</td>
</tr>
<tr>
<td></td>
<td>Fast: 132</td>
<td></td>
</tr>
<tr>
<td>Biocompatibility</td>
<td>Confirmed</td>
<td>ISO 10993</td>
</tr>
<tr>
<td>Chemical solubility [µg/cm²]</td>
<td>0.0</td>
<td>ISO 6872: ≤ 100</td>
</tr>
<tr>
<td>Water absorption [µg/mm³]</td>
<td>5.7</td>
<td>ISO 10477: ≤ 40</td>
</tr>
<tr>
<td>Solubility in water [µg/mm³]</td>
<td>≤ 1.2</td>
<td>ISO 10477: ≤ 7.5</td>
</tr>
</tbody>
</table>
2. Physical/mechanical properties (in vitro)

2.1 Fracture load

2.1.1 Static fracture load

a) Materials and methods
In this study, standardized, prefabricated and filled resin dies were prepared with a convergence angle of 5° and a 90° shoulder with a width of 1 mm. The axio-occlusal and axio-gingival angles were rounded. VITA ENAMIC, IPS e.max CAD, Lava Ultimate and IPS Empress CAD were used to fabricate crowns with a uniform, biogeneric and fully anatomical crown geometry in Sirona’s MC XL system and Multilink Automix (Ivoclar Vivadent) was used for bonding the crowns. The bonded crowns were immersed in water at room temperature for 24 hours prior to the static fracture load tests. A tin foil was used to transfer the static load with a steel ball (diameter: 4.5 mm) to the central fossa of the crown. The load that led to failure of the crown was recorded for all samples. ANOVA and Tukey tests were carried out for statistical evaluation.

b) Source
Boston University, Goldman School of Dental Medicine, Department of Restorative Dentistry/Biomaterials, Prof. Dr. Russell Giordano, ([1], cf p. 27)

c) Result

![Fracture Load Chart]

Fracture Load [N]

<table>
<thead>
<tr>
<th>Material</th>
<th>Fracture Load [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td>2766 ± 98 N</td>
</tr>
<tr>
<td>IPS e.max CAD HT</td>
<td>2000 ± 78 N</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>2250 ± 87 N</td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td>2100 ± 72 N</td>
</tr>
</tbody>
</table>

d) Conclusion
In this test the average static fracture load of VITA ENAMIC is 2766 N (± 98 N), which is the highest average fracture load of the materials tested. Compared to the other materials in this test, VITA ENAMIC has the lowest standard deviation.
2.1.2 Fracture load after dynamic loading

a) Materials and methods
In this study, standardized, prefabricated and filled resin dies were prepared with a convergence angle of 5° and a 90° shoulder with a width of 1 mm. The axio-occlusal and axio-gingival angles were rounded. VITA ENAMIC, IPS e.max CAD, Lava Ultimate and IPS Empress CAD were used to fabricate crowns with a uniform, biogeneric and fully anatomical crown geometry in Sirona’s MC XL system and Multilink Automix (Ivoclar Vivadent) was used for bonding the crowns. The bonded crowns were immersed in water at room temperature for 24 hours prior to the dynamic load tests. The samples that were immersed in water were subjected to cyclic loads in a specially designed continuous loading machine (pneumatic). The load was transferred to the occlusal surface (three-point contact) using a hardened steel ball (diameter: 4.5 mm) that rested on a tin foil. Initially, the samples were subjected to dynamic loading in 150,000 cycles and a maximum load of 450 N and a minimum load of 0 N at room temperature and then subjected to static loading until fracturing occurred. ANOVA and Tukey tests were carried out for statistical evaluation.

b) Source
Boston University, Goldman School of Dental Medicine, Department of Restorative Dentistry/Biomaterials, Prof. Dr. Russell Giordano, ([1], cf p. 27)

c) Result

![Fracture load graph]

Fracture load [N]

VITA ENAMIC | IPS e.max CAD | Lava Ultimate | IPS Empress CAD

<table>
<thead>
<tr>
<th>Fracture load [N]</th>
<th>3000</th>
<th>2500</th>
<th>2000</th>
<th>1500</th>
<th>1000</th>
<th>500</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d) Conclusion
After dynamic loading, the average fracture load of the VITA ENAMIC crowns in this test was 2661 N (± 101 N), which is the highest average fracture load of the materials in this test. Compared to the other materials in this test, VITA ENAMIC has the lowest standard deviation.
2.1.3 Dynamic fracture load

Chewing simulator

a) Materials and method
14 VITA ENAMIC crowns were tested in the chewing simulator. Following etching, the crowns were cemented to composite dies (modulus of elasticity approx. 18 GPa) using Variolink II, embedded in Technovit 4000 ( Heraeus Kulzer) and immersed in warm water (37 °C) for 24 hours. Following accelerated aging, the crowns were subjected to a cyclic load in the chewing simulator: 198 N for 1.2 million cycles at a frequency of 1.6 Hz, with 3 mm steatite beads as the antagonist, TC 5 – 55 °C. Following the dynamic tests, static load was applied to the crowns until fracturing occurred.

In addition to VITA ENAMIC crowns with walls of normal thickness (approx. 1.5 mm occlusal, approx. 1.0 mm circumferential), crowns with walls of reduced thickness (approx. 1.0 mm occlusal, approx. 0.8 mm circumferential) were tested in the chewing simulator.

b) Source
Freiburg University Hospital, Division of Oral and Maxillofacial Surgery, Department of Prosthodontics, Prof. Petra Güß, ([2], cf p. 27)

c) Result
During dynamic masticatory load, none of the VITA ENAMIC crowns showed any defects.

d) Conclusion
The survival rate of VITA ENAMIC crowns with walls of normal and reduced thickness is 100%.
2.2 Modulus of elasticity

a) Materials and method
The modulus of elasticity was determined based on the stress-strain curves of the measurements of flexural strength.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

![Graph showing modulus of elasticity comparison between different materials and dentine.]

**Modulus of elasticity [GPa]**

Elastic ← → Rigid

IPS e.max CAD LT
IPS Empress CAD
Mark II
VITA ENAMIC
Lava Ultimate
CAD-Temp

**Dentine**

**Elastic**

**Rigid**

---

d) Conclusion
With an elasticity of 30 GPa, VITA ENAMIC is in the same range as human dentine. Up until now, no dental restorative material was in this elastic range.

Note: There are big differences concerning the modulus of elasticity of human dentine in literature.

Sources:

2.3 Abrasion

2.3.1 Two-body abrasive wear

2.3.1.1 Results: University of Zurich

a) Materials and method
Zurich chewing simulator, 1.2 million cycles, 1.7 Hz, load 49 N, 6000 thermal cycles, natural enamel as the antagonist

b) Source
University of Zurich, Center of Dental and Oral Medicine, Clinic for Preventive Dentistry, Periodontology and Cariology, Dept. of Computer-Aided Restorative Dentistry, Prof. W.H. Mörmann, ([4], cf. p. 27)

c) Result

![Graph showing abrasion results for VITA ENAMIC, Mark II, and ENAMEL.]

Material abrasion | Antagonist abrasion

---

\( \text{Abrasion (µm)} \)

\( \text{VITA ENAMIC} \) | \( \text{Mark II} \) | \( \text{ENAMEL} \)
---|---|---
\( 49 \) | \( 38.1 \) | \( 30.2 \)

\( a \) Material abrasion  \( b \) Antagonist abrasion

4. Conclusion
The abrasion level of VITA ENAMIC is 49 µm. The level of abrasion to the antagonist enamel caused by VITA ENAMIC is 30.2 µm. Mark II causes a slightly higher level of antagonist abrasion of 38.1 µm. As a control group, the abrasion of enamel to enamel was measured in the study. The goal with VITA ENAMIC was to further improve on the antagonist-friendly properties of Mark II without abandoning the ceramic behavior of the material.
2.3.1.2 Results: University of Regensburg

a) Materials and methods
- Pin-on-block wear test design in chewing simulator
- Steatite beads as the antagonist
- 50 N load force
- \(1.2 \times 10^6\) cycles, 1.6 Hz
- 600 thermal cycles, 5 – 55 °C
- Evaluation: measurement of substance loss

b) Source
University of Regensburg, Faculty of Medicine, Polyclinic for Dental Prosthetics, Prof. Martin Rosentritt, ([5], cf. p. 27)

c) Result

![Graph showing abrasion levels](image)

**Abrasion [µm]**

- **VITA ENAMIC**
- **IPS e.max CAD**
- **Paradigm MZ 100**

- Material abrasion
- Antagonist abrasion

**d) Conclusion**
With an abrasion level of approx. 120 µm, VITA ENAMIC is in the same range as ceramic. In this test, the composite material Paradigm MZ 100 demonstrates a significantly higher level of abrasion of approx. 185 µm.
2.3.2 Three-body abrasive wear

a) Materials and method
3-body abrasion testing in accordance with the ACTA (Academisch Centrum Tandheelkunde Amsterdam)

b) Source
University of Regensburg, Faculty of Medicine, Polyclinic for Dental Prosthetics, Prof. Martin Rosentritt, ([6], cf p. 27)

c) Result

\[
\begin{array}{l|c|c|c}
& Sinfony (reference) & Tetric Evo Ceram & VITA ENAMIC \\
\hline
\text{Wear after 50,000 cycles} & & & \\
\text{Wear after 100,000 cycles} & & & \\
\text{Wear after 150,000 cycles} & & & \\
\text{Wear after 200,000 cycles} & & & \\
\end{array}
\]

d) Conclusion
The level of wear increases for all three materials as the number of cycles increases. Comparatively speaking, the highest level of wear resistance was measured for VITA ENAMIC.
2.3.3 Toothbrush abrasion

2.3.3.1 Results: University of Zurich

a) Materials and method
Three polished samples were brushed for 25 minutes using Depurdent (Dr. Wild & Co. AG, Muttenz, Switzerland) toothpaste suspension (extremely abrasive) (PARO M39, Esro, Thalwil, Switzerland). The level of shine and the surface roughness after polishing and brushing were determined.

b) Source
University of Zurich, Center of Dental and Oral Medicine, Clinic for Preventive Dentistry, Periodontology and Cariology, Dept. of Computer-Aided Restorative Dentistry, Prof. W.H. Mörmann, ([4], cf. p. 27)

c) Result

Surface quality in terms of shine and roughness following toothbrush abrasion:

<table>
<thead>
<tr>
<th>Material</th>
<th>Level of shine</th>
<th>Surface roughness (Ra value, µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High-luster</td>
<td>Brushed</td>
</tr>
<tr>
<td>Enamel</td>
<td>53 (2,4)</td>
<td>0,012 (0,0008)</td>
</tr>
<tr>
<td>Mark II</td>
<td>52 (0,2)</td>
<td>0,009 (0,0005)</td>
</tr>
<tr>
<td>VITA ENAMIC</td>
<td>56 (0,4)</td>
<td>0,027 (0,0009)</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>56 (0,9)</td>
<td>0,025 (0,0003)</td>
</tr>
</tbody>
</table>

A level of shine of 56 could be achieved when polishing VITA ENAMIC, which, from a statistical point, is identical to or comparable with those of Lava Ultimate (56), Mark II (52) and enamel (53).

After the test with abrasive toothpaste, VITA ENAMIC retained a higher level of shine of 41 than enamel (25). Following toothbrush abrasion, the materials Mark II (0.013 µm), VITA ENAMIC (0.05 µm) and Lava Ultimate (0.05 µm) revealed lower surface roughness than enamel (0.187 µm).

d) Conclusion
The surface quality of VITA ENAMIC can be considered durable and of an excellent standard.
2.3.3.2 Results: VITA

a) Materials and method
The materials polished to a high-luster finish were brushed for 32 hours using the abrasive toothpaste Depurdent. The reduction in weight and the surface roughness following toothbrush abrasion were then measured.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

![Diagram showing reduction in weight and surface roughness following toothbrush abrasion for different materials.]

<table>
<thead>
<tr>
<th>Material</th>
<th>Reduction in weight [%]</th>
<th>Surface roughness Ra [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC MK II</td>
<td>9.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Paradigm MZ 100</td>
<td>11.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>15.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

d) Conclusion
In this test, VITA ENAMIC demonstrated resistance to abrasion that was clearly superior to that of the composites Lava Ultimate and Paradigm MZ 100.
2.4 Reliability/Weibull modulus

a) Materials and method
The Weibull modulus was determined based on the flexural strength of bending bars. The Weibull modulus describes the reliability of a material in a way that cannot be fully described based solely on flexural strength. Outliers due to material faults that reduce the level of reliability are included in the calculation for flexural strength and are qualified, however they do determine the reliability and the probability of survival of the material. The higher the Weibull modulus, the greater the reliability.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

![Weibull modulus graph]

<table>
<thead>
<tr>
<th>Material</th>
<th>Weibull modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td>25</td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td>15</td>
</tr>
<tr>
<td>IPS e.max CAD LT</td>
<td>10</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>5</td>
</tr>
</tbody>
</table>

d) Conclusion
Of the materials measured in this test, VITA ENAMIC offered the greatest reliability. A Weibull modulus of 20 was achieved. When evaluating the Weibull modulus, the flexural strength (in-house measurements of VITA R&D: VITA ENAMIC: 153.82 MPa (SD 7.56 MPa), Lava Ultimate: 188.42 MPa (SD 22.29 MPa), IPS Empress CAD: 157.82 MPa (SD 17.33 MPa), IPS e.max CAD LT: 344.05 MPa (SD 64.5 MPa)) should always also be taken into account.
2.5 Vickers hardness

a) Materials and methods
The materials embedded in epoxy (VITA ENAMIC, Mark II, IPS Empress CAD, IPS e.max CAD LT and Lava Ultimate) were polished to a high-luster finish. The polished specimens were clamped into position in the hardness tester. In each case, 5 indent impressions were made for each material with a load of 30 N. Once the maximum load (30 N) had been reached, this was maintained for 20 seconds before release. Hardness in GPa was calculated by measuring the diagonals of the indent. The bars in the diagram correspond to the average values obtained based on five measurements in each case.

b) Source
Internal study, VITA R&D, (3), cf. p. 27

c) Result

<table>
<thead>
<tr>
<th></th>
<th>Enamel</th>
<th>Dentine</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mark II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS e.max CAD LT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d) Conclusion
The level of hardness of VITA ENAMIC is approx. 2.5 GPa and is therefore between that of dentine (0.6 – 0.92 GPa, (1), (2)) and enamel (3 – 5.3 GPa; (3), (4)). The hardness levels of the three ceramics (Mark II, IPS Empress CAD and IPS e.max CAD) are significantly higher than that of enamel. With a hardness level of approx. 1 GPa, Lava Ultimate is in the same range as dentin.

Sources:


2.6 Etchability of the material

a) Materials and methods
Polished VITA ENAMIC samples were etched for 60 seconds using VITA CERAMICS ETCH (5% hydrofluoric acid gel). SEM images were then taken of the etched surface.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

The etching pattern is clearly recognizable. The light grey areas represent the polymer network structure, the dark grey areas show the ceramic network structure. Etching caused the surface of the ceramic to separate.

d) Conclusion
As a result of etching, a good retentive etching pattern can be generated as only the ceramic network structure is separated and the polymer structure and its large surface remain intact. Unlike with composites, the etched areas are clearly recognizable on the restoration.
2.7 Shear strength
2.7.1 Study with RelyX Unicem/Variolink II

a) Materials and methods
Test pairs were prepared, each comprising one plate (10 mm x 10 mm x 3 mm) with a central conical 6° bore hole and a cone preparation (6° conicity). Following pre-treatment and with a load of 2 kg applied, the cone preparations and plates were bonded using the luting agent in question. Depending on the method, the cones and bore holes were subjected to the following treatment after ultrasonic cleaning:
- Etched for 60 sec with VITA CERAMICS ETCH (5% hydrofluoric acid gel)
- Silanizing in accordance with the manufacturer’s instructions (either with VITASIL, VITA or Monobond Plus, Ivoclar Vivadent)
- Luting in accordance with the manufacturer’s instructions
- Immersion (2 weeks in water (37 °C))

Determination of compressive shear strength:
Each value (see diagram) is based on 5 test specimens (n=5). Once the test specimens had been bonded, they were tested using a universal testing machine. This involved applying a stamp to the cone preparation with a feed rate of 0.5 mm/min until ejection.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

![Shear strength diagram](image)

<table>
<thead>
<tr>
<th>Material/Glue System</th>
<th>Shear Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RelyX Unicem</td>
<td>30</td>
</tr>
<tr>
<td>RelyX Unicem (with accelerated aging)</td>
<td>25</td>
</tr>
<tr>
<td>Variolink II</td>
<td>20</td>
</tr>
<tr>
<td>Variolink II (with accelerated aging)</td>
<td>15</td>
</tr>
<tr>
<td>VITA ENAMIC</td>
<td>35</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>30</td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td>25</td>
</tr>
<tr>
<td>Paradigm MZ 100</td>
<td>20</td>
</tr>
</tbody>
</table>


d) Conclusion
Appropriate bonding of VITA ENAMIC is possible using adhesive systems such as RelyX Unicem (3M Espe, Seefeld, Germany) or Variolink II (Ivoclar Vivadent, Schaan, Liechtenstein) as tested. At approx. 20 MPa, VITA ENAMIC offers average shear strength values.
2.7.2 Study with RelyX Ultimate

a) Materials and methods

Plates were sawed out of VITA ENAMIC and Lava Ultimate blanks. To ensure an identical initial surface structure, all plates were ground using SiC paper (grit size 320). The prepared VITA ENAMIC plates were etched for 60 sec (VITA Ceramics Etch). The plates made from Lava Ultimate were sandblasted in accordance with the manufacturer’s instructions (50 µm Al₂O₃, 2 bar). Following etching or sandblasting, Scotchbond (3M ESPE) was applied to the plates for 20 sec in accordance with the manufacturer’s instructions. Then cylinders made of RelyX Ultimate were polymerized on the plates, sheared according to DIN EN ISO 10477 and the bond strength was determined. Single factor variance analysis was used for the statistical evaluation.

b) Source

Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

![Graph showing bond strength comparison between VITA ENAMIC and Lava Ultimate.]

\[\text{Bond strength [MPa]}\]

\[\begin{array}{c}
\text{VITA ENAMIC} \\
\text{Lava Ultimate}
\end{array}\]

\[\begin{array}{c}
50 \\
45 \\
40 \\
35 \\
30 \\
25 \\
20 \\
15 \\
10 \\
5 \\
0
\end{array}\]

\[\begin{array}{c}
\text{VITA ENAMIC} \\
\text{Lava Ultimate}
\end{array}\]

\[\begin{array}{c}
31.32 \text{ MPa (± 14.5 MPa)} \\
9.92 \text{ MPa (± 1.89 MPa)}
\end{array}\]

\[\begin{array}{c}
\text{VITA ENAMIC} \\
\text{Lava Ultimate}
\end{array}\]

\[\begin{array}{c}
\text{i.e. fractures within the material, were determined for VITA ENAMIC. This also}
\text{explains the higher degree of variation compared to Lava Ultimate.}
\end{array}\]

\[\begin{array}{c}
The bond strength of RelyX Ultimate on Lava Ultimate is 9.92 MPa (± 1.89 MPa) and
\text{mainly adhesive fractures, i.e. within the bonding zone, were found.}
\end{array}\]

\[\begin{array}{c}
\text{d) Conclusion}
\end{array}\]

Within the scope of this test setup, bonding of RelyX Ultimate to VITA ENAMIC can be considered very good (31.32 MPa (± 14.5 MPa)), since mainly cohesive fractures, i.e. fractures within the material, were determined for VITA ENAMIC. This also explains the higher degree of variation compared to Lava Ultimate. The bond strength of RelyX Ultimate on Lava Ultimate is 9.92 MPa (± 1.89 MPa) and mainly adhesive fractures, i.e. within the bonding zone, were found.
2.8 Discoloration tests

a) Materials and methods
The samples (n = 40) were prepared in accordance with the manufacturer’s instructions (Herculute XRV and Dentsply Bridge resin) or cut out of blocks (Mark II, VITA ENAMIC; Bühler Isomet saw). After polishing (Bühler Ecomet, final with 1µm diamond paste), the series of samples were stored in coffee or distilled water, subjected to thermocycling (2500 cycles, 5 °C - 55 °C) and one series was additionally subjected to accelerated aging in coffee (15 days, 37 °C) after thermocycling. Another group was exposed to UV irradiation for 15 days (ADA specification No. 80). The CIE L*a*b*-color coordinates before and after treatment were determined using a spectrophotometer (Color I5, X-rite) and the delta E values to determine the overall color deviation were calculated.

b) Source
Boston University, Goldman School of Dental Medicine, Department of Restorative Dentistry/Biomaterials, Prof. Russell Giordano, ([7], cf. p. 27)

c) Result

![Graph showing properties: color stability]

Properties: color stability

Properties: color stability

Water
Coffee
UV
Thermo
Thermo/Coffee

∆(Δ E) = 2 - 4 Clinically significant

d) Conclusion
No significant differences in color could be observed for Mark II and VITA ENAMIC for different types of treatment (ANOVA and Scheffe’s test). Significant changes in color were determined for the composite and the acrylic resin, in particular following UV irradiation and after thermocycling in combination with immersion in coffee (accelerated aging).
2.9 Machinability

a) Materials and method
Using the Sirona MC XL milling system, 30° wedges were milled from various materials in normal milling mode.

b) Source
Internal study, VITA R&D, [3], cf. p. 27

c) Result

![Image of VITA ENAMIC, IPS Empress CAD, and IPS e.max CAD materials]

![Image of VITA ENAMIC and IPS e.max CAD materials at 200x magnification]

VITA ENAMIC, 200 x magnification, source: VITA R&D
IPS e.max CAD, 200 x magnification, source: VITA R&D


d) Conclusion
VITA ENAMIC demonstrates marginal accuracy that is significantly more precise than that of conventional CAD/CAM ceramic restoration materials with fewer irregularities.
2.10 Edge stability

**a) Materials and methods**
Using the Sirona MC XL milling system, non-prep veneers were milled in normal milling mode from various materials with a wall thickness of approx. 0.2 mm. The manufacturer has not approved the use of IPS Empress CAD and IPS e.max CAD for a wall thickness of approx. 0.2 mm. Additionally, using the Sirona MC XL milling system, inlays were milled from various materials in normal milling mode (see SEM pictures).

**b) Source**
Internal study, VITA R&D, ([3], cf. p. 27)

**c) Result**

![Images showing VITA ENAMIC, IPS Empress CAD, and IPS e.max CAD](image1)

**d) Conclusion**
The exact edge stability of VITA ENAMIC is demonstrated by the non-prep veneers. The geometry in this case, with a wall thickness of approx. 0.2 mm, could only be milled fully using VITA ENAMIC. The milled inlay illustrates the high edge quality of VITA ENAMIC, which provides for extremely precise milling results.
2.11 Milling times

a) Materials and methods
The milling times for three types of restorations (inlay, anterior crown and posterior crown) were determined using four different CAD/CAM materials (VITA ENAMIC, Mark II, both from VITA Zahnfabrik, IPS e.max CAD from Ivoclar Vivadent and Lava Ultimate from 3M ESPE). The tests were performed using the Sirona MC XL milling system. 5 units were milled for each material and type of restoration. The milling times were taken from the log files.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result
Milling times (min:s) for the VITA ENAMIC, Mark II, IPS e.max CAD and Lava Ultimate materials. The times correspond to the average value determined on the basis of five measurements.

<table>
<thead>
<tr>
<th>Material</th>
<th>Normal</th>
<th>Fast</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td>7:56</td>
<td>4:40</td>
<td>9:07</td>
</tr>
<tr>
<td>Mark II</td>
<td>10:27</td>
<td>6:24</td>
<td>13:29</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>12:17</td>
<td>10:00</td>
<td>14:58</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>10:39</td>
<td>7:27</td>
<td>11:55</td>
</tr>
</tbody>
</table>

d) Conclusion
Compared to Mark II, Lava Ultimate and IPS e.max CAD, VITA ENAMIC restorations can be milled more quickly.
2.12 Service life of the milling tools

a) Materials and method
Using the Sirona MC XL milling system, one milling pair in each case was used to grind as many molar crowns as possible from a variety of CAD/CAM materials in normal milling mode and in fast milling mode. The lives of the milling tools indicate the results of a series of measurements.

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result

Number of molar crowns milled with a milling pair (MC XL Software 3.8x)

<table>
<thead>
<tr>
<th>Material</th>
<th>Normal milling</th>
<th>Fast milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA ENAMIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MK II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS e.max CAD HT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS e.max CAD LT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Normal milling: 148/132 milled crowns

d) Conclusion
VITA ENAMIC can be milled more cost-effectively than any other tooth-colored ceramic block material. The milling time for VITA ENAMIC restorations is by far the shortest [see 2.12], which also results in a long milling tool service life of approx. 148/132 milled crowns.

2.13 Polishing results

VITA ENAMIC can be easily polished to a high-luster finish when dry (extra-orally) and when wet (intra-orally) using the polishing instruments available from VITA. This was confirmed during the acceptance phase.

2.14 Biocompatibility

Tests regarding biocompatibility were carried out by North American Science Associates Inc. (NAMSA). VITA ENAMIC was deemed biocompatible.
2.15 Solubility in acid, absorption of water, solubility in water

a) Materials and method
Testing in accordance with DIN EN ISO 6872 and DIN EN ISO 10477

b) Source
Internal study, VITA R&D, ([3], cf. p. 27)

c) Result
No chemical solubility in accordance with ISO 6872. Absorption of water (5.7 µg/mm^2) and solubility in water (< 1.2 µg/mm^2) are within the reference values specified by ISO 10477.

d) Conclusion
The properties of VITA ENAMIC are intermediate between those of ceramics and composites.
3. In-vivo studies

a) Clinical study, Freiburg University Hospital, Division of Oral and Maxillofacial Surgery, Department of Prosthodontics, Prof. Petra Güß: VITA ENAMIC crowns
   Start date of study: November 2011
   Number of restorations fitted: 71

b) Clinical study, Freiburg University Hospital, Division of Oral and Maxillofacial Surgery, Department of Prosthodontics, Prof. Petra Güß: VITA ENAMIC inlays, onlays, partial crowns, “table tops”
   Start date of study: November 2011
   Number of restorations fitted: 100

c) Acceptance phase: VITA ENAMIC crowns, implant crowns, partial crowns, inlays, onlays, veneers
   various users in a practice setting
   number of restorations fitted: approx. 594
   As of December 2012

4. Publications

Publications on VITA ENAMIC:

Al-Harbi A, Ardu S, Bortolotto T, Krejci I.
Stain intensity of CAD/CAM Materials versus direct composites.
IADR 2012 Poster Abstract, Iguacu Falls, Brazil

Coldea A, Swain MV, Thiel N.
Mechanical properties of polymer-infiltrated-ceramic-network materials.
Dent Mater. 2013 Apr; 29(4):419-426

Coldea A, Swain MV, Thiel N.
In-vitro strength degradation of dental ceramics and novel PICN material by sharp indentation.

He LH, Swain M.
A novel polymer infiltrated ceramic dental material.

He LH, Purton D, Swain M.
A novel polymer infiltrated ceramic for dental simulation.

Mörmann W, Stawarczyk B, Ender A, Sener B, Attin T, Mehl A.
Wear characteristics of current aesthetic dental restorative CAD/CAM materials: Two-body wear, gloss retention, roughness and Martens hardness.
5. Appendix

5.1 Bibliography

1. Giordano R.
   Development of Novel All-Ceramic Restorations and Wear, Strength, and Fatigue of Restorative Materials
   Research Report, Period 09/2012 – 06/2013 to VITA Zahnfabrik, July 22, 2013
   Principal Investigator: Russell Giordano, D.M.D., D.M.Sc., Director of Biomaterials
   Boston University, Goldman School of Graduate Dentistry, Department of Biomaterials, Boston MA, U.S.A.

2. Bilkhair A, Güß P.
   Fatigue behavior and damage modes of a monolithic CAD/CAM hybrid ceramic (VITA ENAMIC) material compared to CAD/CAM all-ceramic posterior crown restorations.
   Publication forthcoming.

3. Internal studies, VITA R&D:
   VITA Zahnfabrik H. Rauter GmbH & Co. KG
   Research and Development Division, Inorganic Chemistry
   Spitalgasse 3, 79713 Bad Säckingen
   Dr. Enno Bojemüller, Project Manager ENAMIC, R&D - Inorganic Chemistry, Bad Säckingen
   Dipl.-Ing. Andrea Coldea, Material Development, R&D Inorganic Chemistry, Bad Säckingen
   Dr. Norbert Thiel, Head of R&D - Inorganic Chemistry, Bad Säckingen
   Date of issue: 11.13

   Wear characteristics of current aesthetic dental restorative CAD/CAM materials: Two-body wear, gloss retention, roughness and Martens hardness.

5. Rosentritt M.
   Pin-on-block wear test of different dental materials.
   Report Number: 133. Author: Priv.-Doz. Dr.-Ing. Martin Rosentritt, Head of Research Division, University Clinic, Regensburg, Polyclinic for Dental Prosthetics, Prof. Martin Rosentritt

6. Rosentritt M.
   Untersuchung zum 3-Medienverschleiß verschiedener Polymer/ Keramikwerkstoffe. [3-body wear study of various polymers/ceramic materials.]
   Report Number: 130. Author: Priv.-Doz. Dr.-Ing. Martin Rosentritt, Head of Research Division, University Clinic, Regensburg, Polyclinic for Dental Prosthetics, Regensburg

7. Giordano R.
   Wear and color stability testing. Research Report to VITA Zahnfabrik,
   Principal Investigator: Russell Giordano, D.M.D., D.M.Sc., Director of Biomaterials
   Boston University, Goldman School of Graduate Dentistry, Department of Biomaterials, Boston MA, U.S.A.
With the unique VITA SYSTEM 3D-MASTER, all natural tooth shades can be systematically determined and perfectly reproduced.

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Date of issue of this information: 11.13

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