# Scientific Manual

## Spectra ST Composites


Dentsply Sirona

Research

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# 1 Introduction

Dentsply Sirona shows an ongoing commitment to the development of superior dental materials which use innovative technologies. A major milestone was achieved by introducing **SphereTEC®**, Dentsply Sirona's advanced granulated filler technology, to the new composite restoratives **Spectra ST**, **Spectra ST Effects** and **Spectra ST flow**[1]. Spectra ST composite is indicated for anterior and posterior direct restorations as well as for the fabrication of inlays, partial crowns and veneers. As with the clinically well-established predecessor TPH Spectra® composite, two different viscosities are available. Thanks to their pronounced chameleon effect, only five universal CLOUD shades are needed to match the color of the surrounding tooth structure. Spectra ST flow composite is also indicated for direct restorations except occlusal stress bearing class II cavities. Based on the patented SphereTEC® filler technology, all Spectra ST composites provide unprecedented handling properties, fast and easy polishing and outstanding gloss for composite restorations with natural esthetics.

## 1.1 Classification

Contemporary dental composites may be classified according to their **consistency** ('flowable', 'universal' or 'packable'), chemistry of the **resin matrix** (methacrylate-, acid-modified methacrylate-, inorganic polycondensate- or epoxide based) or constitution of the **filler system** (by filler-size: nanofills to macrofills and mixtures thereof, so called 'hybrids').

Regarding its **consistency**, the high viscosity version (HV) of Spectra ST and Spectra ST Effects composites offer an intermediate consistency, comparable to e.g. Filtek Supreme™ Ultra/XTE (Figure 1, Figure 2). While the low viscosity version (LV) of Spectra ST composite contains a slightly lower filler content than HV without affecting the physical properties, Spectra ST flow composite has a reduced filler content to offer higher flow characteristics, comparable to e.g. Filtek Supreme™ Ultra/XTE flowable.

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[1] Depending on the market, Spectra ST, Spectra ST Effects and Spectra ST flow are available as either TPH Spectra® ST and TPH Spectra® ST flow, Ceram.x Spectra™ ST and Ceram.x Spectra™ ST flow, or Neo Spectra™ ST and Neo Spectra™ ST flow.

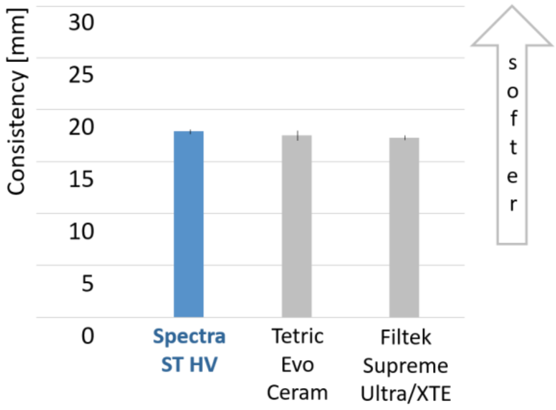


**Figure 1** Consistencies of dental composites in mm diameter at **room temperature** (data for the propagation of a cylindrical sample of initially 7 mm diameter at 23°C and under a weight of 575 g for 120 s).

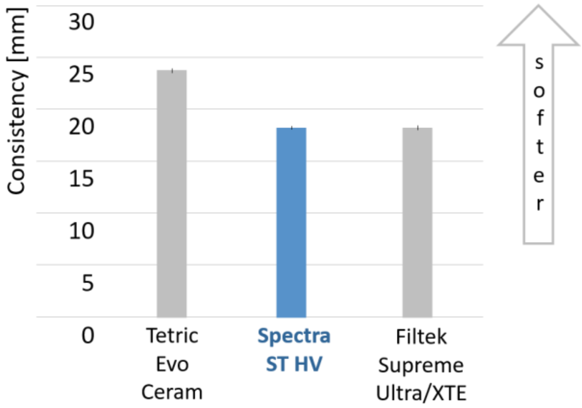


**Figure 2** Consistencies of dental composites in mm diameter at **body temperature** (data for the propagation of a cylindrical sample with initially 7 mm diameter at 37°C and under a weight of 575 g for 120 s).

Regarding their **resin matrix**, Spectra ST composites are based on a slightly modified version of the original TPH Spectra® composite resin matrix. By incorporating an optimized photo initiator system, the result is a durable, low-leaching methacrylate resin matrix.

The **filler system** of Spectra ST composites is a blend of spherical, pre-polymerized SphereTEC® fillers ($d_{3,50}$≈15 µm), non-agglomerated barium glass and ytterbium fluoride. Furthermore, the resin matrix contains highly dispersed, methacrylic polysiloxane nano-particles, which are chemically similar to glass or ceramics. Depending on the shade, the filler load ranges from 78-80 weight-% or 60-62 volume-% for the HV version and 76-78 weight-% or 57-60 volume-% for the LV version, respectively. The total filler of Spectra ST flow composite is 62.5 weight-% and 40 volume-%, respectively. In conclusion, Spectra ST composites can be classified as nano-hybrid composites with pre-polymerized fillers.

## 1.2 SphereTEC® Filler Technology

In general, high filler load supports mechanical strength and reduces polymerization shrinkage of a composite. Maximum filler loads can be achieved by combining particles of different size categories, so that large particles form a pre-packed grid and smaller ones can occupy the space in between (Figure 3). This approach is widely used in dental composites and, depending on the size of combined filler particles, different types of hybrid composites are produced.

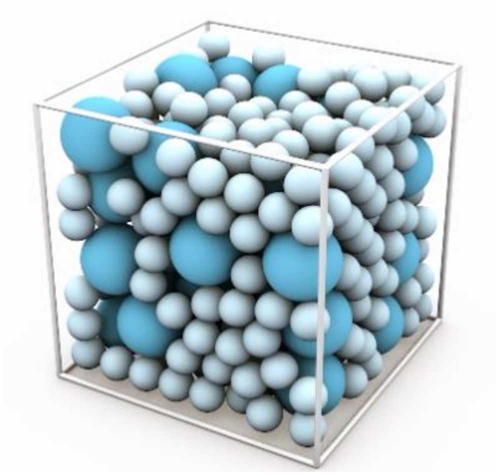

**Figure 3** Simulated, random packing of spherical particles with two different sizes.

More specifically, **large fillers > 10 µm** facilitate high filler loads due to their lower surface area and corresponding lower energy to wet the particles with resin. Yet, at the same time, they impair esthetical properties like a materials' gloss by being torn out under mechanical strain, leaving significant surface defects.
On the other hand, smaller, i.e. **sub-micron particles** are favorable to obtain superior esthetics and polishability, but are more difficult to wet, limiting the maximum possible filler load.

To overcome the described technical conflict, Spectra ST composites are equipped with SphereTEC® filler, the latest development in the field of composite filler technology. SphereTEC® labels the process of manufacturing µm-scaled, well-defined superstructures, essentially built from sub-micron particles. Hence, when combined with isolated sub-micron particles, SphereTEC® fillers allow the maximization of filler load in a composite by using primary particles of < 1 µm only.

SphereTEC® fillers are produced via spray-granulation. The process roughly contains three steps (Figure 4). First, by atomization at specific pressure and temperature, small droplets of barium-glass filler particles are produced, surrounded by activated resin and solvent. Dictated by surface tension in the gaseous phase, the droplets then form spherical shapes of a well-defined size distribution and the solvent is evaporated. Finally, by travelling through hot processing zones, the resin is cured and completed, and solid SphereTEC® fillers are collected.

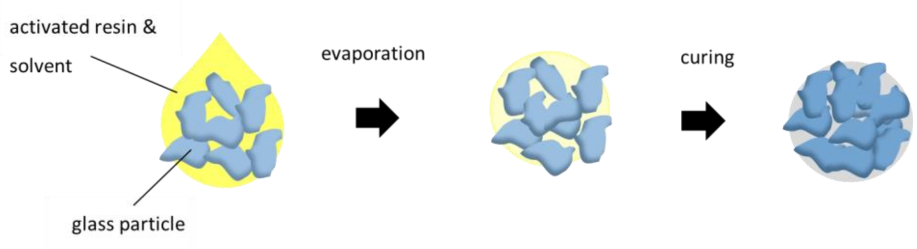


**Figure 4** Schematic of the SphereTEC® filler manufacturing process. From left to right: 1. Atomization of a slurry comprising finely dispersed barium glass, activated resin and solvent; 2. Forming spherical shapes and evaporation of solvent; 3. Curing to obtain pre-polymerized, spherical fillers.

SphereTEC® fillers are virtually perfectly spherical (see Figure 5) and have a distinct, microstructured surface (see Figure 6), which distinguishes them from other pre-polymerized fillers.

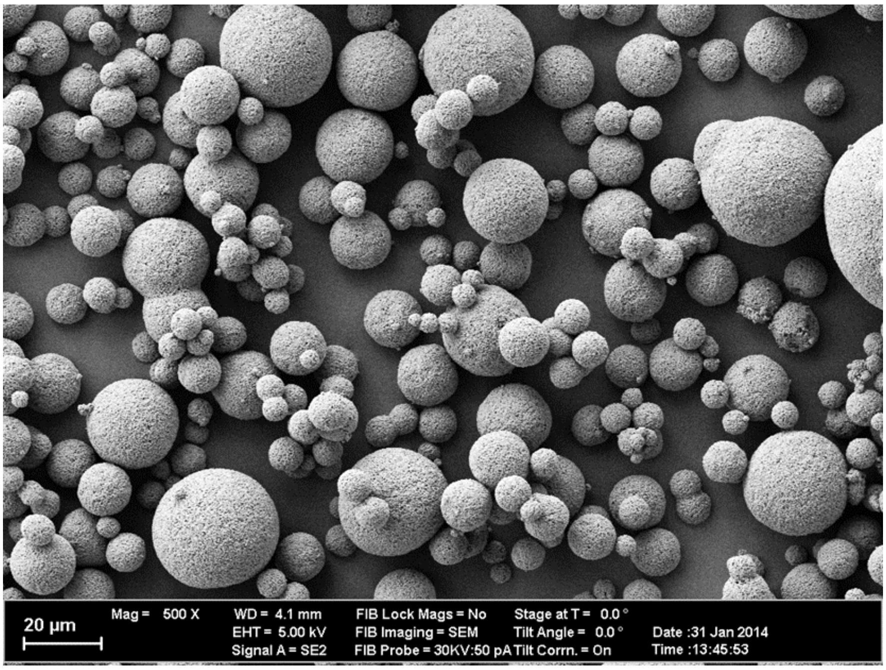


**Figure 5** Typical SEM-pictures of SphereTEC® fillers (Hagner M 2014).

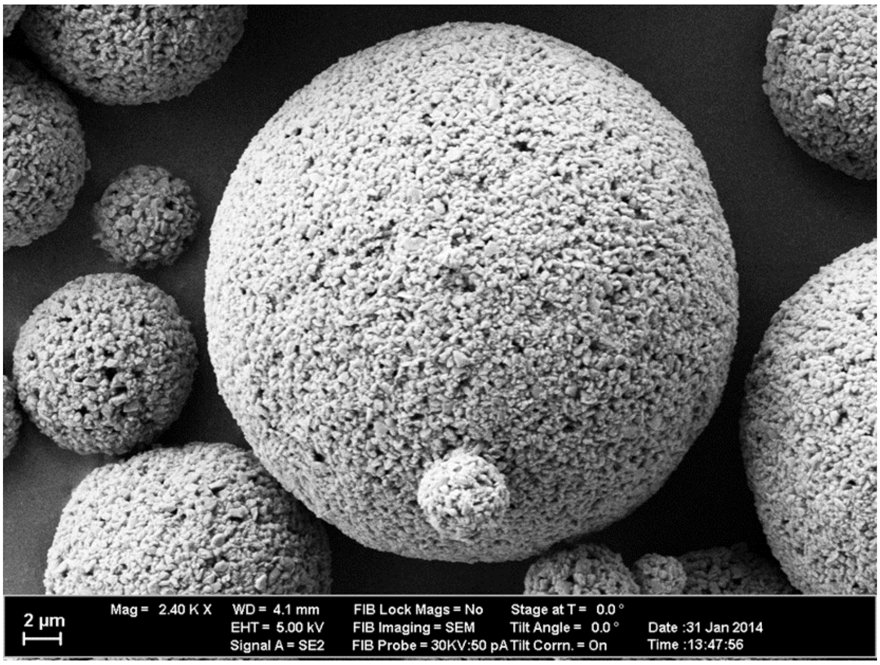


**Figure 6** Typical SEM-pictures showing the microstructured surface of a SphereTEC® filler (Hagner M 2014).

When used in Spectra ST composites, they are thoroughly impregnated with resin, fully blended in the overall composition, and not distinguishable from other parts of the filler system, i.e. isolated submicron glass particles (Figure 7).

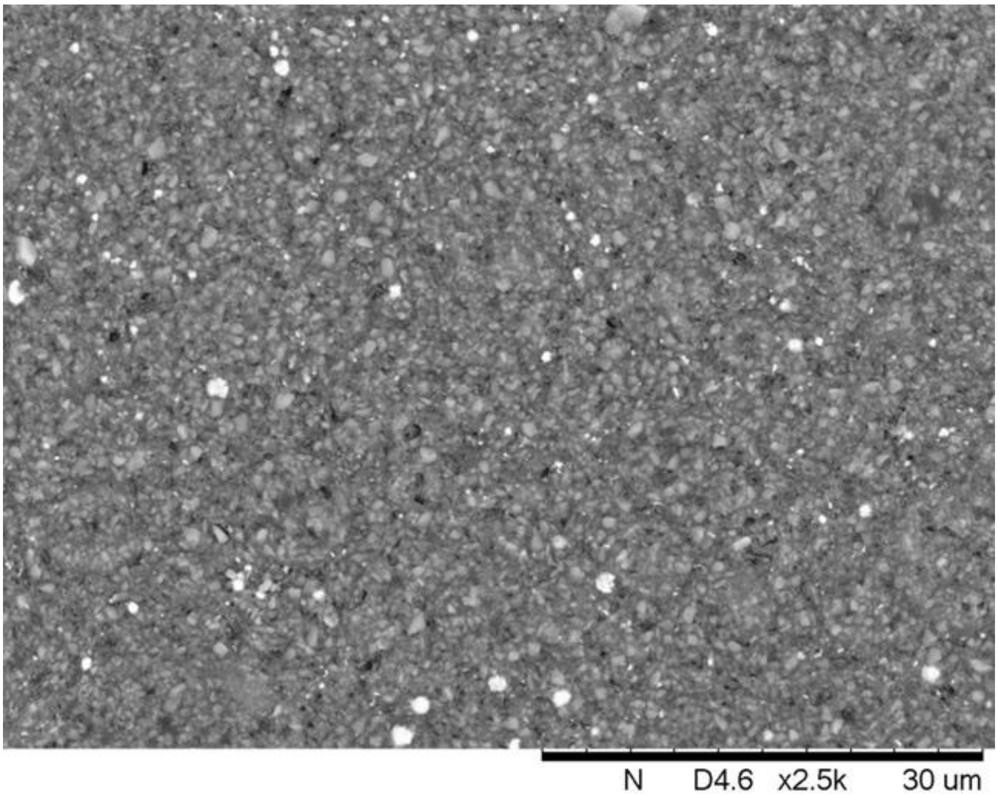


**Figure 7** SEM picture of an abraded (see also Figure 33) surface of Spectra ST composite with homogenously embedded SphereTEC® filler particles (Latta MA 2015).

Due to their specific morphology, SphereTEC® fillers lend unique features to the new composite materials (see also chapter 2.1 to 2.3).

Most notably, they reduce the intrinsic friction of Spectra ST and Spectra ST Effects composites when under shear stress. This is achieved by inhibited interlocking of the filler particles as SphereTEC® fillers have a relatively smooth, concave surface facilitating easy application from the Compule® Tips as well as excellent sculptability by hand instruments.

At the same time, when left unagitated, the combination of SphereTEC® fillers with irregularly shaped, sub-micron particles leads to the distinct slump-resistance of Spectra ST composites.

Because of the low active surface < 2 m²/g and its distinct microstructure, SphereTEC® fillers also reduce the amount of resin needed in a composite and thus minimize the stickiness to metal instruments.

Finally, in vitro data on finishing and polishing shows that SphereTEC® fillers, although ~15 µm in size, facilitate high gloss of Spectra ST composites. Upon polishing SphereTEC® fillers, embedded sub-micron primary fillers are removed layer-by-layer providing a smooth surface (see chapter 3.3.1).

## 1.3 Rheology of Spectra ST and Spectra ST Effects Composites

The above described novel SphereTEC® filler technology leads to favorable thixotropic properties of the Spectra ST composites during placement and sculpting. Thixotropy describes a time-dependent shear thinning and recovery. Generally speaking, viscoelastic materials, like dental composites, show both viscous (fluid-like) and elastic (solid-like) properties when undergoing deformation. The portion of each characteristic can be determined by dynamical mechanical analysis and expressed by the loss modulus G'' for viscous portions, the storage modulus G' for elastic portions and the phase angle tan δ for the ratio of viscous to elastic portions: $\tan\delta = \frac{loss\ modulus\ G''}{storage\ modulus\ G'}$.

Figure 8 shows the δ-values over three states of low- to high- to low shear stresses for Spectra ST and Spectra ST Effects composites, Filtek Supreme Ultra/XTE and Tetric EvoCeram. As can be seen, Spectra ST material not only displays the lowest δ for low shear stresses but also the fastest recovery after the stress has been reduced. Translated into the clinical context, Spectra ST and Spectra ST Effects can be easily extruded from the Compule® Tip, adapted to the cavities' walls and sculpted with the hand instruments (high shear stress → high δ >45°) but remains slump-resistant when left unagitated (low/no shear stress → low δ <<45°). This unique property is a direct result of the novel SphereTEC® filler system and was validated by handling tests (see also chapter 2).

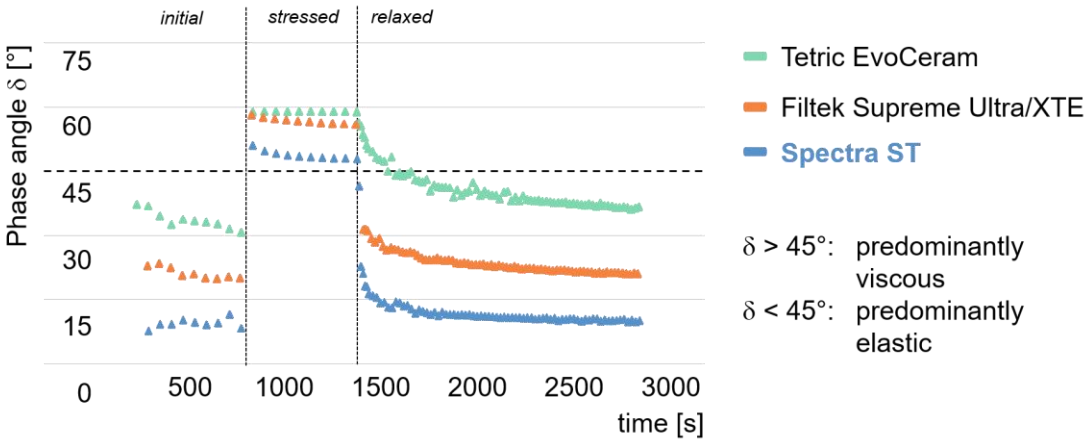


**Figure 8** Phase angles of dental composites under step-wise change from low ('initial': τ= 2·10$^{-3}$ %rel. deflection, ω= 1 Hz) to high ('stressed': τ= 10 %rel. deflection, ω= 1 Hz) to low shear stresses ('relaxed': τ= 2·10$^{-3}$ %rel. deflection, ω= 1 Hz) at 30 °C.

# 2 Handling Properties

When choosing a composite product, clinicians not only focus on performance regarding esthetic properties, long-time marginal quality or resistance to fracture and wear. Equally important features for selecting a composite restorative are handling properties in terms of

- Viscosity of choice
- Secure adaptation of the composite paste to cavity floor, walls and margins
- Easy shaping of the uncured composite into the desired anatomical form
- Fast finishing and polishing procedure to achieve surface luster

With this in mind, the handling properties of Spectra ST composites were validated in large-scale user evaluations by general dental practitioners (GDPs).

## 2.1 User evaluation in daily practice throughout the US

131 GDPs, 97 of them customers of the previous composite TPH Spectra®, 34 of them using another universal hybrid composite, applied Spectra ST composite for routine treatment placing at least 10 restorations each. In total, more than 2.200 restorations were placed during the test.

With the previous composite TPH Spectra®, two viscosities were also available. Thus, users of this material were provided with their preferred viscosity (LV or HV). All other GDPs received both viscosities of Spectra ST composite. Handling properties of Spectra ST composite was rated in comparison to the composite of choice of each GDP and the findings were reported by means of questionnaires.

### 2.1.1 Viscosity

Clinicians have a personal preference regarding viscosity, which in some cases might even depend on the clinical situation (e.g. posterior class II compared to class IV). Typically, a composite is chosen that fits best this personal preference. Overall the majority (56 %) of the answering GDPs described Spectra ST composite as offering a better viscosity compared to their current choice of composite. Details are given in Figure 9.

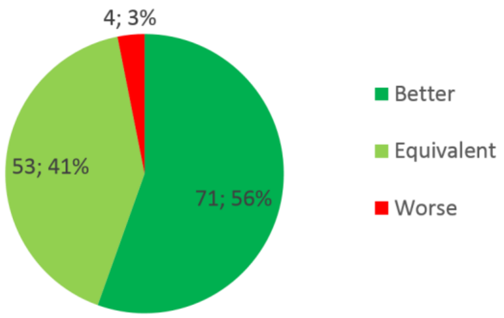


**Figure 9** Overall rating of the viscosity comparing Spectra ST composite to the current choice of composite.

### 2.1.2 Stickiness and adaptability

Market research showed that stickiness to hand instruments is regarded as the key challenge during direct filling therapy. To secure adaptation of the composite paste to cavity floor, walls and margins while manipulating the composite with hand instruments, stickiness needs to be as low as possible without losing the composite's ability to adapt to the cavity. Spectra ST material was found to be less sticky to hand instruments compared to the control composites by 66 % of the GDPs. Furthermore, adaptation of Spectra ST composite was not found to be compromised by the vast majority of answering GDPs and rated being better (45 %) or equal (52 %) compared to their current choice of composite. Details are given by Figure 10.


**Figure 10** Rating of stickiness of Spectra ST composite to hand instruments (left) and adaptability (right) in comparison to the current choice of composite.

### 2.1.3 Sculpting and slump resistance

Easy shaping of the uncured composite into the desired anatomical form and a low slump resistance before curing enables efficient filling therapy. The sculptability of Spectra ST composite was rated as being better to the control composites by 63 %. Furthermore, slump resistance was also positively rated with 43 % rating it as being better. Details are shown in Figure 11.


**Figure 11** Rating of sculptability of Spectra ST composite (left) and its slump resistance (right) in comparison to the current choice of composite.

### 2.1.4 Polishing

Regarding filler sizes, Spectra ST composites can be regarded as a nano-hybrid composite with pre-polymerized fillers. In vitro laboratory studies under controlled conditions (see chapter 3) had shown fast finishing with Enhance® finishers and polishing to high luster with Enhance® PoGo polishers. Within this user evaluation a huge variety of polishing systems had been used by the participating GDPs. The majority of answering dentists did not find a relevant difference. However, about a third rated Spectra ST composite as being better regarding speed (35 %) or quality (43 %) of polish. Figure 12 shows the detailed results.

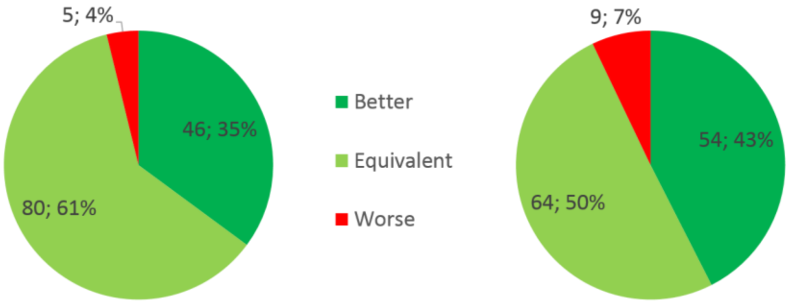


**Figure 12** Speed (left) and quality (right) of polish for Spectra ST composite using a variety of finishing and polishing systems in a clinical setting in comparison to the current choice of composite.

### 2.1.5 Overall handling properties

In summary, the handling properties of Spectra ST composite were found to be better compared to their current choice of composite by 68 % of the participating GDPs (Figure 13).

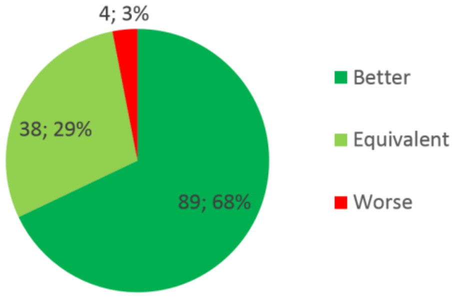


**Figure 13** Rating of the overall handling properties of Spectra ST composite in comparison to current choice of composite.

### 2.1.6 Interest in purchase

Overall, important properties determining the handling of a composite were rated being better compared to currently available composites by the majority of participating dentists. Against this background, it does not come as a surprise that 95 % of the participating dentists showed an interest in purchasing Spectra ST composite. This result indicates a very high level of customer acceptance and satisfaction with its handling properties and immediate clinical results.

## 2.2 User evaluation in daily practice in Germany

60 GDPs, 24 of them customers of the previous composite Ceram•X® mono+ in Germany, 36 of them using another universal hybrid composite, placed at least 20 restorations with Spectra ST composite, each. In total, more than 1.900 restorations were placed and served as basis for the rating of the handling properties of the composite by means of questionnaires.

### 2.2.1 Viscosity

61 % of the answering GDPs described Spectra ST composite as offering a better viscosity compared to their current choice of composite (Figure 14).

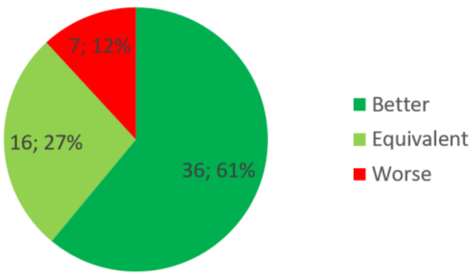


**Figure 14** Overall rating of the viscosity comparing Spectra ST composite to the current choice of composite.

### 2.2.2 Stickiness and adaptability

Spectra ST composite was found to be less sticky to hand instruments and to have a better adaptation to the cavity compared to the control composites by 70 % of the GDPs (Figure 15).


**Figure 15** Rating of stickiness of Spectra ST composite to hand instruments (left) and adaptability (right) in comparison to the current choice of composite.

### 2.2.3 Sculpting

The sculptability of Spectra ST composite was rated as being better to the control composites by 57 % (Figure 16).

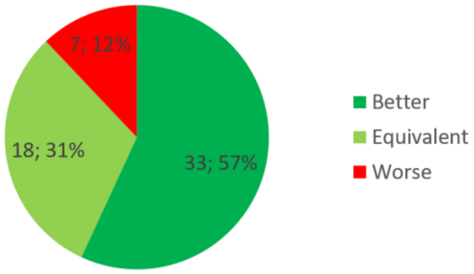


**Figure 16** Rating of sculptability of Spectra ST composite in comparison to the current choice of composite.

### 2.2.4 Polishing

Similar to the US user evaluation a huge variety of polishing systems had been used by the GDPs. The majority of answering dentists rated Spectra ST composite as being better regarding speed (60 %) or quality (70 %) of polish. Figure 17 shows the detailed results.


**Figure 17** Speed (left) and quality (right) of polish for Spectra ST composite using a variety of finishing and polishing systems in a clinical setting in comparison to the current choice of composite.

### 2.2.5 Overall handling properties

In summary, the handling properties of Spectra ST composite were found to be better compared to their current choice of composite by 70 % of the participating GDPs (Figure 18).

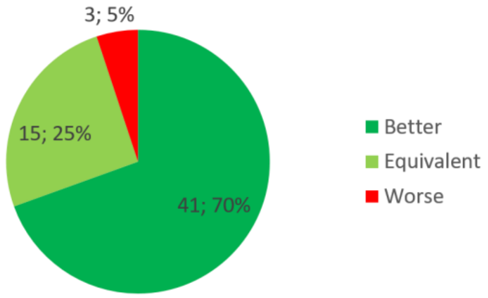


**Figure 18** Rating of the overall handling properties of Spectra ST composite in comparison to the current choice of composite.

### 2.2.6 Interest in purchase

The results indicate a very high level of customer acceptance and satisfaction with the handling properties of Spectra ST composite. Against this background, it does not come as a surprise that 92 % of the participating dentists showed an interest in purchasing Spectra ST composite.

## 2.3 Three-month results in daily practice in Germany

36 GDPs tested Spectra ST flow composite during routine use in over 4.000 procedures, mostly for anterior and posterior fillings (88 %) but also for pit and fissure sealings and composite repairs. In total, 2.895 patients were treated in this user evaluation.

### 2.3.1 Overall handling properties

All the participating dentists reported very good (67 %) or good (33 %) overall handling of Spectra ST flow in comparison to their currently used flowable composite (Figure 19). In particular, Spectra ST flow composite was primarily found to adapt easily to cavity surfaces (94 %) due to its precise control of flowability (78 %) and to offer fast and easy polishing (72 %).

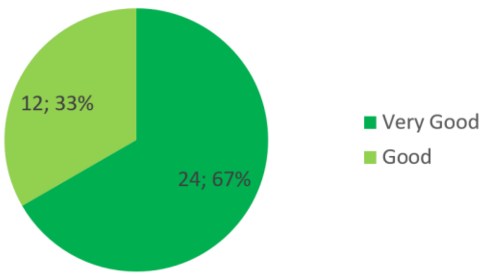


**Figure 19** Rating of the overall handling properties of Spectra ST flow composite.

### 2.3.2 Interest in purchase

The three-month results indicate a very high user acceptance of Spectra ST flow composite with the emphasis on flow behavior combining very good adaptation with slump resistance. It is noteworthy that that 97 % of the participating dentists considered purchasing the Spectra ST flow composite.

## 2.4 Universal CLOUD Shades

Spectra ST and Spectra ST flow are single translucency composites suitable for routine restorations of anterior and posterior teeth. The special features of the shade system are:

- Five universal CLOUD shades of moderate translucency allow restorations of all teeth within the shade range of the VITA® classical shade system (A1-D4).
- Universal CLOUD shades are named A1, A2, A3, A3.5, and A4 - equivalent to the most common tooth shades and familiar in appearance to every dentist.
- Shades are described as universal CLOUD shades to reflect that each of them matches different VITA® shades, which form a 3D data cloud within the coordinates of the L*a*b* color system.

The recipe for shade selection is given by Figure 20.

| Universal CLOUD shade | A1 | A2 | A3 | A3.5 | A4 |
|---|---|---|---|---|---|
| Vita shades | A1, B1, C1 | A2, B2, D2 | A3, D3, C2, D4 | A3.5, B3, B4, C3 | A4, C4 |

**Figure 20** The new universal CLOUD shade concept is designed to achieve shade match with the full range of VITA® shades.

Universal CLOUD shades cover more than one VITA® shade, because the shade of Spectra ST composite restorations is influenced by the color of the surrounding tooth structure. This phenomenon is called *chameleon effect.* The distinct chameleon effect of Spectra ST and Spectra ST flow composites enables each of the five universal CLOUD shades to match several VITA® shades.

In addition to the five universal CLOUD shades, a further shade is especially designed for restoration of bleached teeth. This shade (BW) is lighter than B1, the lightest VITA®

shade, thus, being beyond the VITA® shade range and not considered to be part of the universal CLOUD shade concept.

Along with the package comes a self-adhesive recipe label (Figure 21), ideal for fixation to the rear side of the VITA® shade guide, providing a quick survey over the VITA® dedicated universal CLOUD shades.

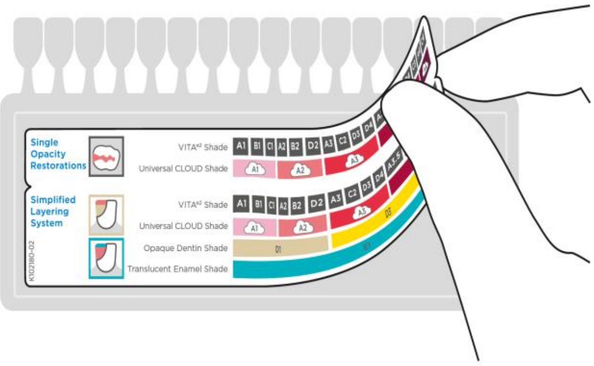


**Figure 21** i-shade label for VITA® reference to universal CLOUD shades.

## 2.5 Spectra ST Effects

For clinical situations with high esthetic demands, Spectra ST and Spectra ST flow composites are complemented by two additional opacities; opaque dentin (shades D1, D3) and translucent enamel (shade E1), named Spectra ST Effects in the HV version of Spectra ST and also available in flowable form with Spectra ST flow. The universal CLOUD shades and Spectra ST Effects are shade/opacity variations of the same formula. When curing recommendations are followed the material data shown above are applicable for the whole shade range. Unlike other composite layering systems, the combination of a universal CLOUD shade and dentin shade prevents the graying-darkening often seen in Class III, IV, incisal fractures, and large posterior restorations. The universal CLOUD shades are slightly more opaque than the enamel shades typically used in other layering techniques, and thus less sensitive to the inescapable variations of layer thickness and color of the previously applied dentin layer. The simplified layering system also includes a translucent enamel shade, however, it is intended for use on the facial incisal third area only in order to emulate incisal effects, like halo and mamelons. Feedback from users described the simplified layering system as being a technique which is particularly easy to use and leads to reliable esthetics in a timely manner (Figure 22).

**Figure 22** Large Class IV viewed from the palatal aspect. Simplified layering system using maximum three shades (beige, dentin shade; rose, universal CLOUD shade; blue, optional enamel shade on the incisal edge).

## 2.6 Shade selection

For shade selection, two tools and methods can be used as follows:

### 2.6.1 The Spectra ST shade guide

The Spectra ST shade guide consists of composite shade tabs, which are manufactured based on Spectra ST composite. For shade selection, remove individual tabs from the shade guide holder. Use the shade tabs of the Spectra ST shade guide to select the universal CLOUD shade closest to the shade of the area to be restored.

### 2.6.2 The VITA® classical shade guide in combination with the i-shade label

The i-shade label facilitates shade selection by assigning one of the universal CLOUD shades to each of the 16 VITA® shades. To make sure that the i-shade label is available at chairside, we recommend sticking it on the rear side of the VITA® classical shade guide. Select the VITA® classical reference tooth, the central part of which best matches the area of the tooth to be restored. Use the i-shade label (Figure 21) to determine the universal CLOUD shade of Spectra ST or Spectra ST flow composite matching the selected VITA® shade, and the accompanying Spectra ST Effects shade when applicable.

## 2.7 Light-curing

Each increment of Spectra ST, Spectra ST Effects, and Spectra ST flow is light-cured with a suitable curing light such as SmartLite® PS or SmartLite® Focus.
Spectra ST, Spectra ST Effects, and Spectra ST flow must be used with a compatible curing light. The curing light must be able to cure materials containing camphorquinone (CQ) initiator and the peak of its spectrum has to be in the range of 440-480 nm. A curing time table for Spectra ST, Spectra ST Effects and Spectra ST flow appears on all outer packages to facilitate sufficient light curing (Table 1).

| Shade | mW/cm² | sec | mm |
|---|---|---|---|
| A1-A4, BW | ≥ 550 | 20 | 2 |
| | ≥ 800 | 10 | |
| D1, D3 | ≥ 550 | 40 | 2 |
| | ≥ 800 | 30 | |
| E1 | ≥ 550 | 10 | 2 |

**Table 1** Curing times for 2 mm increments of Spectra ST (A1-A4, BW), Spectra ST Effects (D1, D3, E1), and Spectra ST flow (A1-E1). Check minimum light irradiance.

## 2.8 Instructions for Use

The up-to-date version can be found on www.dentsplysirona.com.

# 3 Material properties and in vitro studies

Developing a new filler technology and formulating a new composite requires a number of in vitro investigations to ensure sufficient performance in the intended indications. Primarily, mechanical strength and wear resistance need to be tested to support the use in permanent stress bearing posterior restorations. Polishability is an important factor when the material is used for restorations with high esthetic demand. And finally, composites are an integral part of adhesive dentistry, so that the interaction with an adhesive in different kinds of cavity classes should be looked at as well.
Following properties have been investigated and results from in vitro studies are reported in this chapter:

- Mechanical strength
- Wear resistance
- Surface quality and shade stability
- Marginal integrity

## 3.1 Mechanical strength

Lohbauer U and Belli R, University of Erlangen (Germany)

### 3.1.1 Flexural strength

15 specimens (2 x 2 x 25 mm) were made following ISO 4049 and stored in distilled water at 37°C for 14 days. Flexural strength was tested with a crosshead speed of 1 mm/min in a four-point bending test as shown in Figure 23 with 10 and 20 mm distance between the upper and lower support, respectively. Four-point bending allows challenging a larger portion of the bending beam compared to three-point bending described in the ISO 4049. Therefore, the resulting values are typically lower.

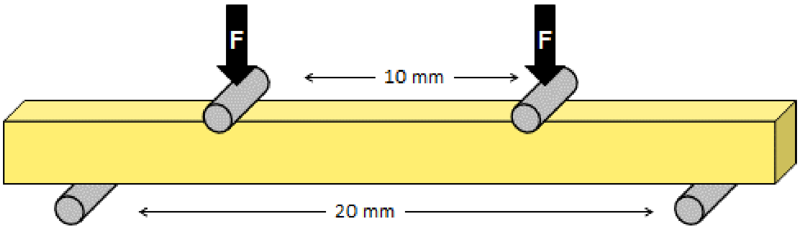


**Figure 23** 4-point bending test for flexural strength.

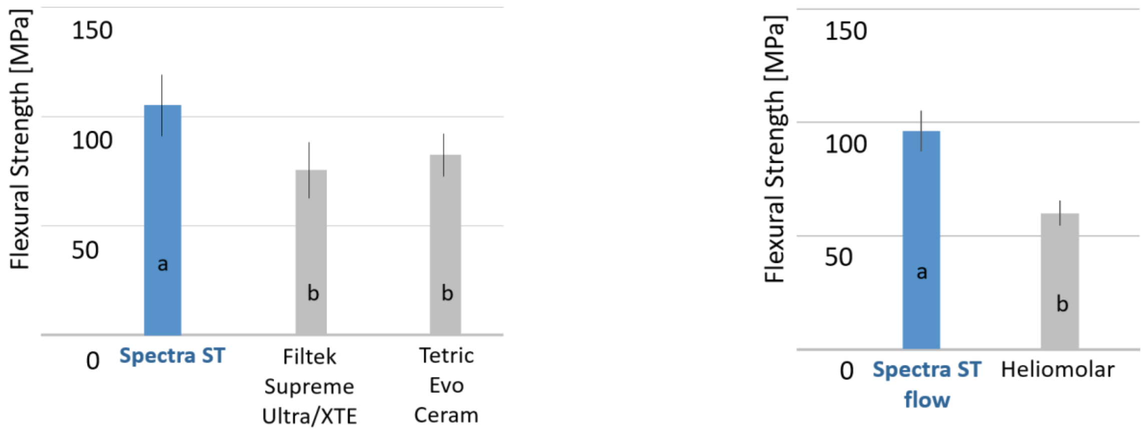


**Figure 24** Flexural strength of Spectra ST (left; Lohbauer U and Belli R, 2015) and Spectra ST flow (right; Lohbauer U 2018) in four-point bending after two weeks of water storage. Different letters indicate significant differences.

The results showed significantly higher flexural strength for Spectra ST and Spectra ST flow composites than for the other composites. Mean flexural strength of Spectra ST composite surpasses 100 MPa – the threshold for indirect restorations according to ISO 4049 – even under four-point bending as shown in Figure 24.

### 3.1.2 Flexural fatigue strength

While flexural strength represents the strength at maximum load, fatigue tests are needed to determine the behavior under subcritical loads and may allow a better prognosis of the long-term behavior of a material. Flexural fatigue strength was measured using 25 specimens per group in a stair-case approach starting at a level of 50% of the flexural strength and 10.000 cycles at a frequency of 0.5 Hz in water at 37°C.

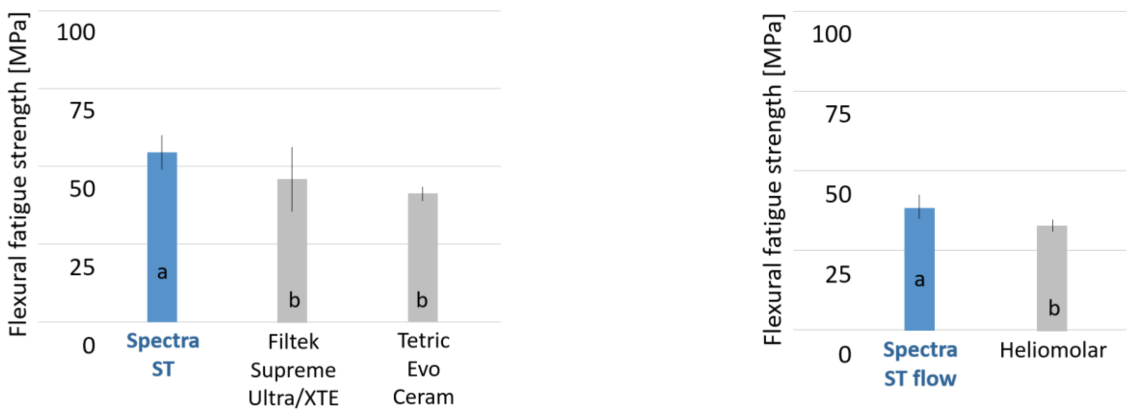


**Figure 25** Flexural fatigue strength of Spectra ST (left; Lohbauer U and Belli R, 2015) and Spectra ST flow (right; Lohbauer U 2018). Different letters indicate significant differences.

Spectra ST composite showed a high flexural fatigue strength which supports its use in permanent stress bearing restorations in posterior teeth (see Figure 25).

### 3.1.3 Fracture toughness

Fracture toughness ($K_{Ic}$) describes the resistance to catastrophic failure of an existing crack in a material. Following ISO 13856 15 specimens were prepared in a mold with an integrated V-shaped notch as shown in Figure 26 and stored dry at 37°C for 14 days.

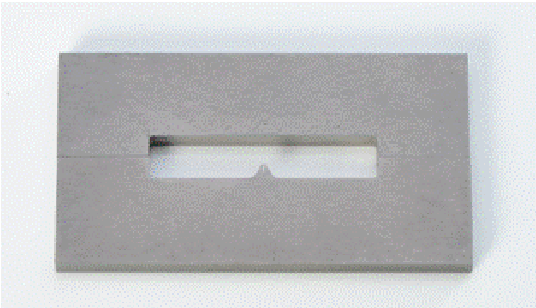

**Figure 26** Mold with integrated V-shaped notch (Lohbauer U).

The notch was further sharpened using razor blades in a device allowing controlled movement parallel to the specimen as shown in Figure 27.

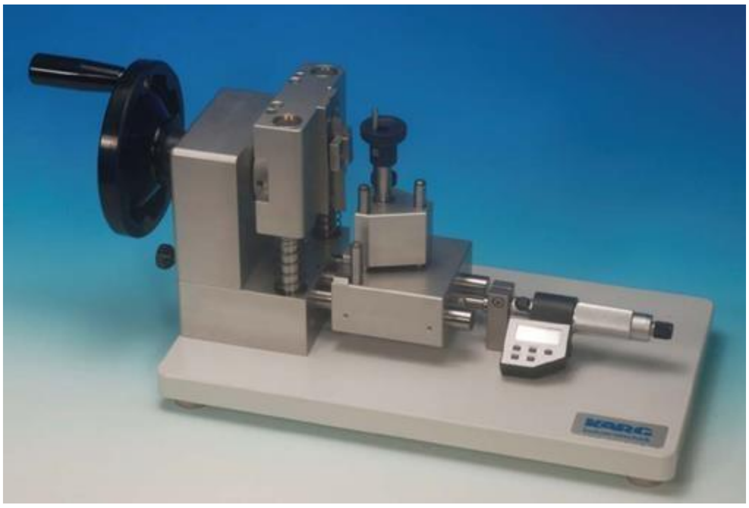

**Figure 27** Notching device for parallel movement of the razor blade (Lohbauer U).

Specimens were loaded at a crosshead speed of 10 mm/min in a three-point bending test with an additional extensometer to precisely record strain during testing (see Figure 28).

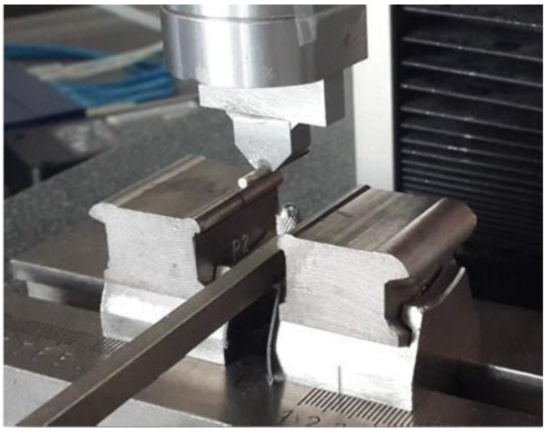

**Figure 28** Three-point test set-up with extensometer (Lohbauer U).

To calculate fracture toughness the precise size of the crack-specimen size ratio is needed and was determined under a light microscope.

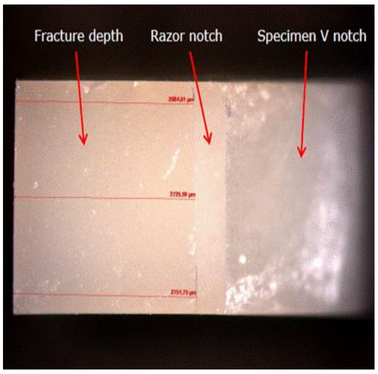


**Figure 29** Determination of crack length (Lohbauer U).

Figure 29 shows a microscopic view on a cracked specimen with a clearly visible distinction between the "fracture depth", the "specimen V notch" originating from the mold, and the "razor notch" from sharpening with the razor blade, respectively.

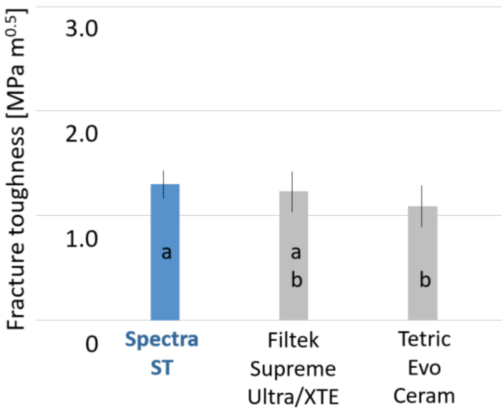


**Figure 30** Fracture toughness after 14 days dry storage at 37°C (Lohbauer U and Belli R, 2015).

Spectra ST composite shows a good fracture toughness comparable to other control materials as shown in Figure 30.

## 3.2 Wear resistance

Wear resistance is a key property for restorative materials used in stress bearing posterior restorations. To investigate different aspects of wear a variety of different methods have been employed for testing the wear resistance of Spectra ST material.

### 3.2.1 ACTA wear

Kleverlaan CJ and Werner A, University of Amsterdam (The Netherlands)
The three body wear simulator (see Figure 31) developed at ACTA (Academic Centre for Dentistry Amsterdam) and described by DeGee et al. in 1994 uses a spring loaded antagonist wheel which abrades the materials to be tested with a slip of 15% in a suspension of rice and millet seeds. As the spring load is constant during the wear run, this method rather simulates abrasion processes as in grinding a bolus than forces and impulses from chewing.

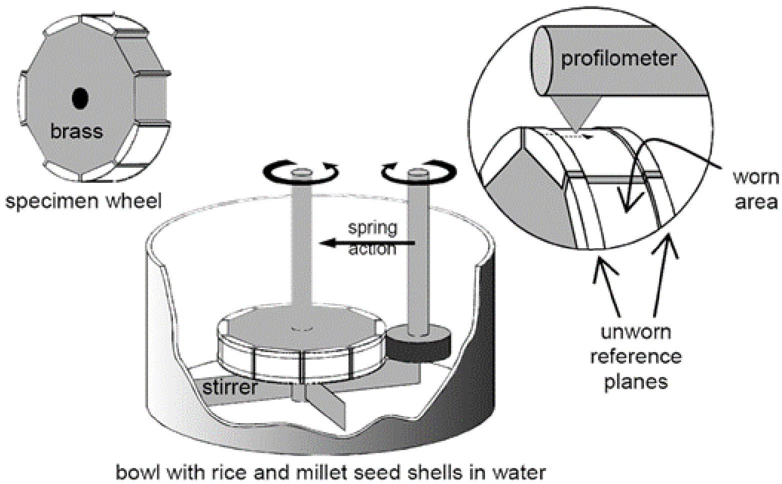


**Figure 31** Three body wear simulator developed at ACTA.

Results from 1 day up to 2 months are shown in Figure 32.

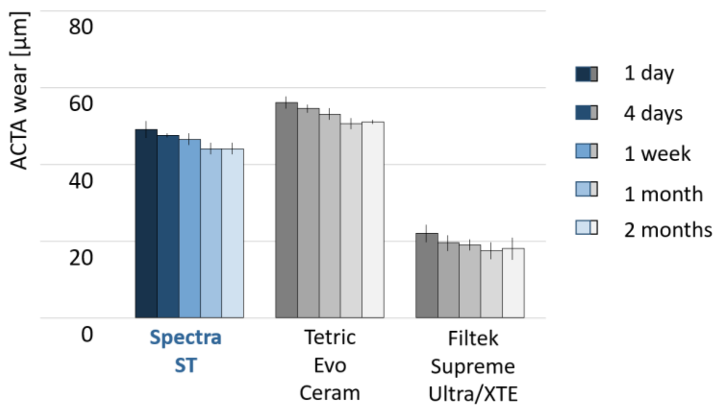


**Figure 32** ACTA wear up to 2 months (Kleverlaan CJ and Werner A, 2015).

Spectra ST material showed good resistance to abrasive wear (Figure 32).

### 3.2.2 Leinfelder wear

Latta MA, Creighton University Omaha, NE (United States)

Wear in the oral cavity is a multifactorial process. Besides abrasion during grinding movements different wear patterns are generated during forceful occlusal contacts. Furthermore, localized wear in the occlusal contact area (OCA) might be different from generalized wear induced by chewing the food bolus without direct contact to the antagonist. Therefore, the so called "Leinfelder Wear Machine" allows testing both situations – localized and generalized wear.

In the generalized wear mode a steel piston is pressed through slurry of acrylic glass (PMMA) beads onto the specimen without touching it while rotating 30°. Parameters for the experiment and typical wear pattern are shown in Figure 33.

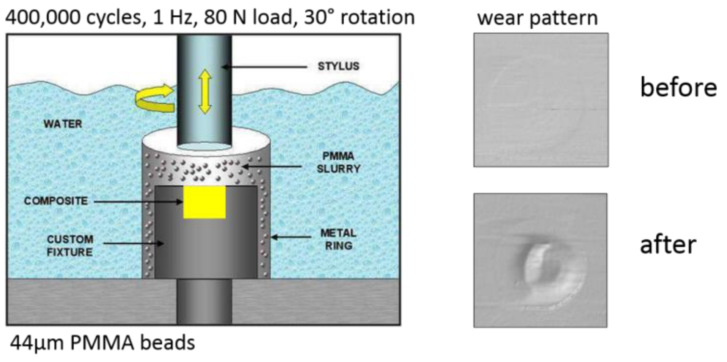


**Figure 33** Generalized wear mode and typical wear pattern (Latta MA).

Figure 34 shows the volume loss of the total surface under generalized wear.

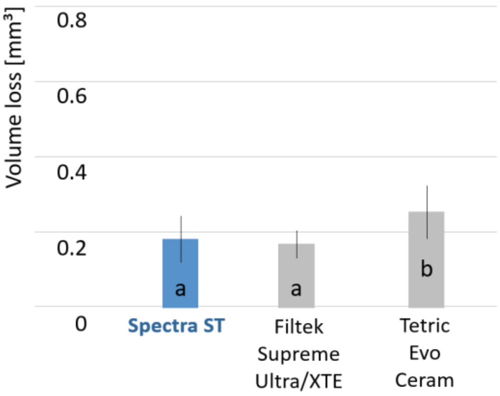


**Figure 34** Volume loss under generalized wear (Latta MA, 2015).

Spectra ST material showed very good resistance to generalized wear as shown in Figure 34.

To simulate wear in the occlusal contact area the stylus is modified as shown in Figure 35. The resulting wear pattern differs significantly from the generalized wear test (see Figure 33).

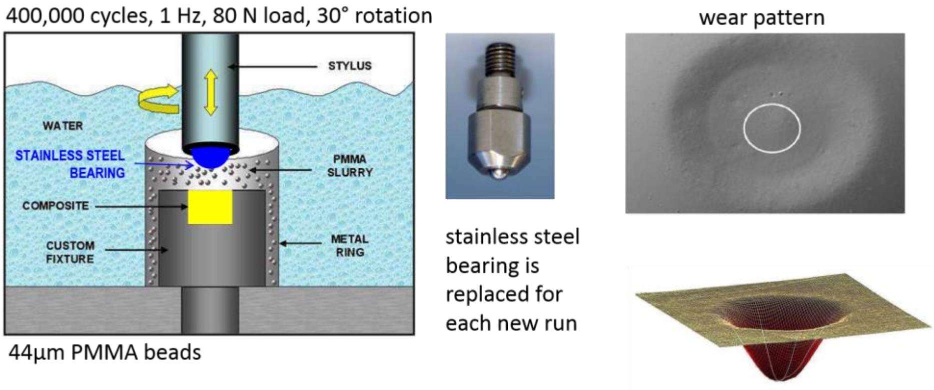


**Figure 35** Localized wear mode and typical wear pattern (Latta MA).

Under the harsh conditions of localized wear Spectra ST material showed very high resistance to loss of height resulting in a low depth of the wear facet as shown in Figure 36.

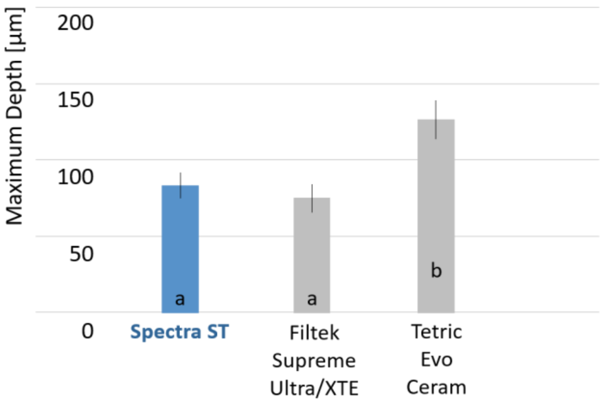


**Figure 36** Maximum depth of wear facet under localized wear (Latta, 2015).

Spectra ST composite is made with new filler technology SphereTEC® as explained in chapter 1.2. For composites comprised of different filler fractions (size, type, etc.), a key question is whether wear generates a rough or smooth surface and whether any disintegration of larger particles takes place.

Figure 37 to Figure 39 show pictures from surfaces after generalized wear using a Scanning Electron Microscope (SEM).

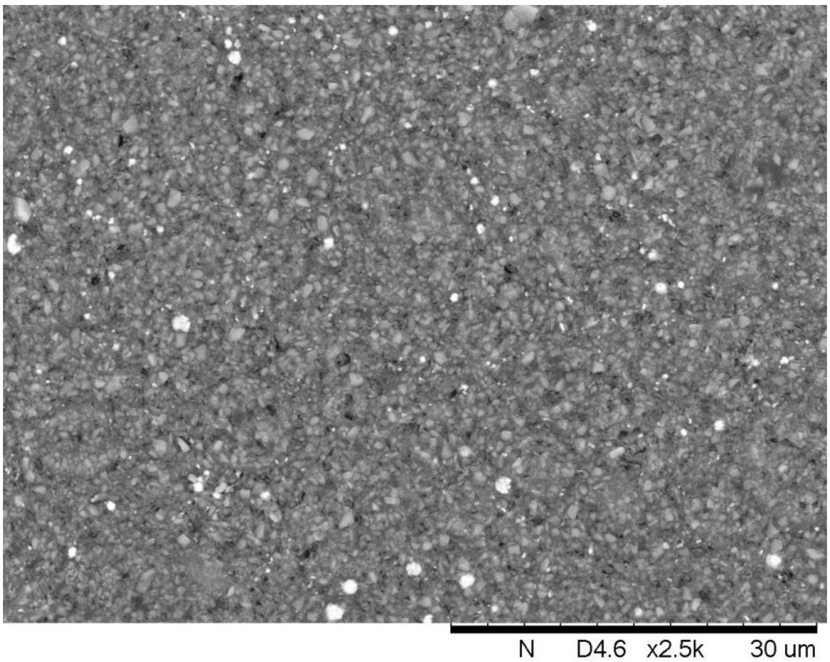


**Figure 37** SEM (2.500x) of Spectra ST composite after generalized wear (Latta MA, 2015).

The abraded surface of Spectra ST composite (Figure 37) is homogeneous and the granulated SphereTEC® fillers can hardly be distinguished from the surrounding structure.

Figure 38 shows the abraded surface of Filtek® Supreme Ultra/XTE. The clusters are clearly visible with no sign of disintegration.

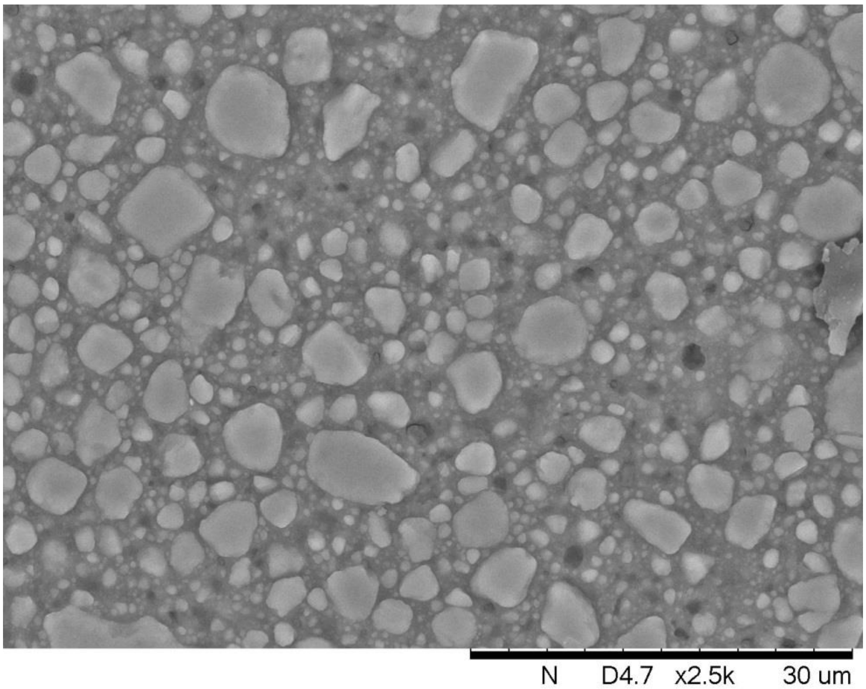


**Figure 38** SEM (2.500x) of Filtek® Supreme Ultra/XTE after generalized wear (Latta MA, 2015).

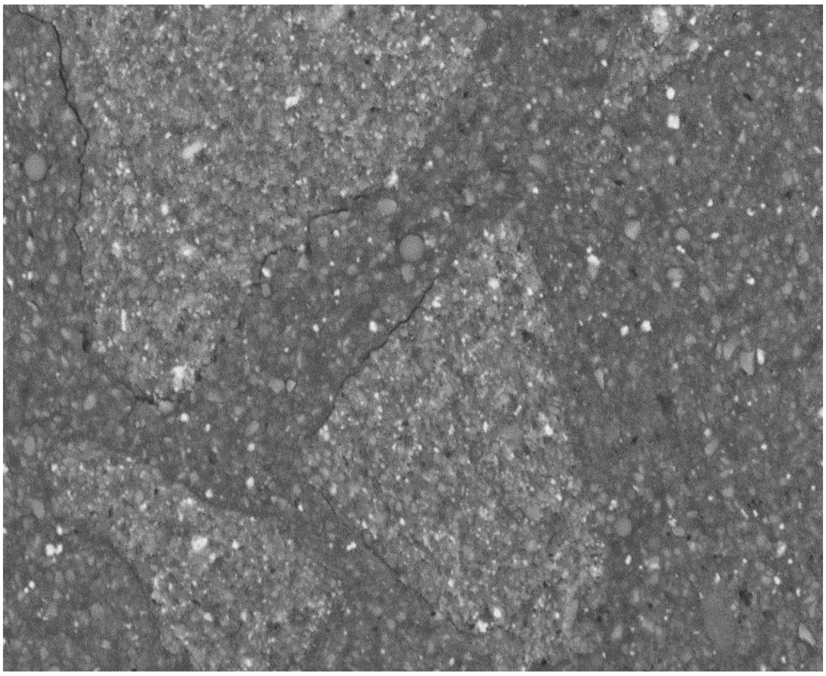

**Figure 39** SEM (2.500x) of Tetric® EvoCeram after generalized wear (Latta MA, 2015).

In contrast, pre-polymerized composite fillers are clearly visible on the abraded surface of Tetric® EvoCeram in Figure 39 with few signs of not perfectly smooth interfaces between composite fillers and surrounding composite.

## 3.3 Surface quality and shade stability

### 3.3.1 Finishing and polishing

Ferracane JL and Da Costa J, University of Portland, OR (United States)

Surface quality by means of gloss development while finishing and polishing a restoration is an important factor for direct restorative therapy as this procedure typically needs a lot of attention and consumes considerable amount of treatment time. Five composite specimens (5 x 12 x 2.5 mm) per group were roughened (600 grit) to obtain a standardized surface. Next, they were finished and polished by one experienced operator (da Costa J) using two different polishing systems:

- Enhance® Finisher and Enhance PoGo® Polisher – 2-step
- Sof-Lex® Finishing and Polishing discs – 3-step (M, F, SF were used)

Gloss values were periodically measured with a gloss meter on a 2x2 mm surface at an angle of 60° (see Figure 40). Specimens were repositioned after each period so that gloss from the same surface area per specimen could be followed-up over time. Gloss measurements were expressed in gloss units (GU). According to a publication of the American Dental Association (ADA), 40 GU are considered to represent a clinically accepted gloss (dotted line in Figure 41). Maximum gloss was determined after additional polishing until no further increase in gloss was visible.

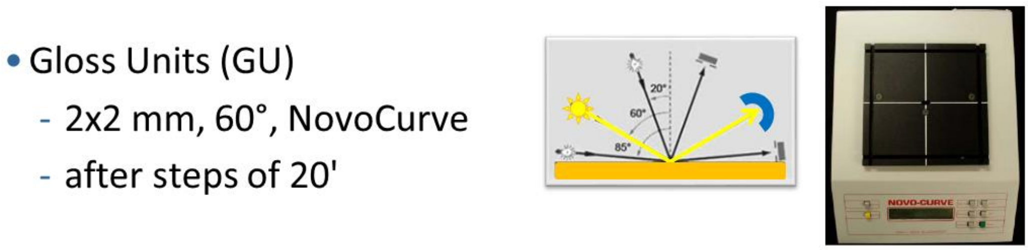


**Figure 40** Parameters and equipment for gloss measurement.

Figure 41 shows that Spectra ST and Spectra ST flow can be finished and polished with Enhance® Finishers and Enhance® Pogo® Polishers to 40 gloss units in a shorter time and in fewer steps compared to the control. Moreover, the study revealed that Spectra ST and Spectra ST flow composites can be polished to a higher gloss than Filtek® Supreme Ultra/XTE and Filtek® Supreme Ultra/XTE flowable.

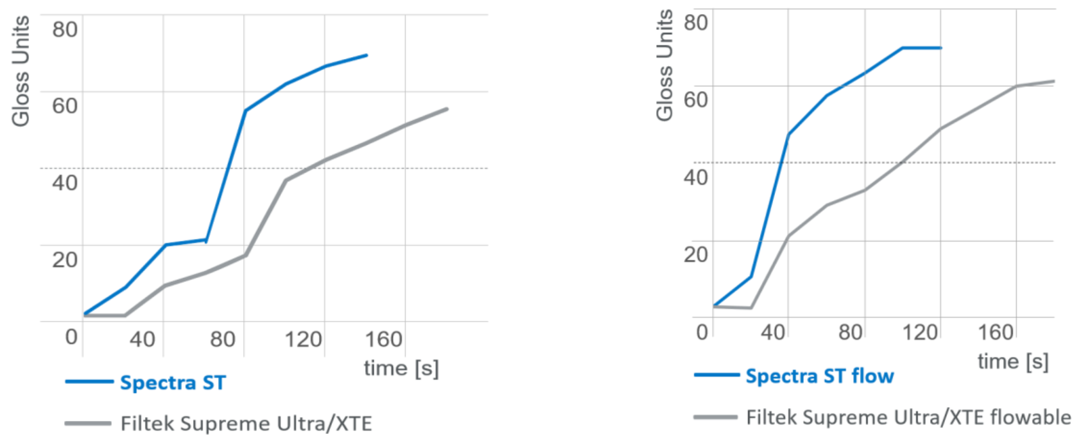


**Figure 41** Gloss over time while polishing Spectra ST composite (left; da Costa J and Ferracane J, 2017) and Spectra ST flow composite (right; da Costa J and Ferracane J, 2018) by using the respective polishing system.

### 3.3.2 Shade stability

R&D Dentsply Sirona, Milford (United States)

Besides mechanical stability, shade stability is of importance for the long-term esthetical success of a visible tooth colored restoration. Cured composite specimens were stored in distilled water for 24 h at 37°C. Next, the specimens were soaked in 30 ml red wine side-by-side with the control composite at room temperature for 24 h. The stained specimens were thoroughly rinsed and dried. The color values (CIELab values) of each color chip was determined by spectral photometry (X-rite Color Eye) before and after the red wine staining. Results of the shade measurements expressed as the color difference delta-E are shown in Figure 42. Spectra ST and Spectra ST flow composites showed significantly better stain resistance than Filtek Supreme Ultra/XTE.

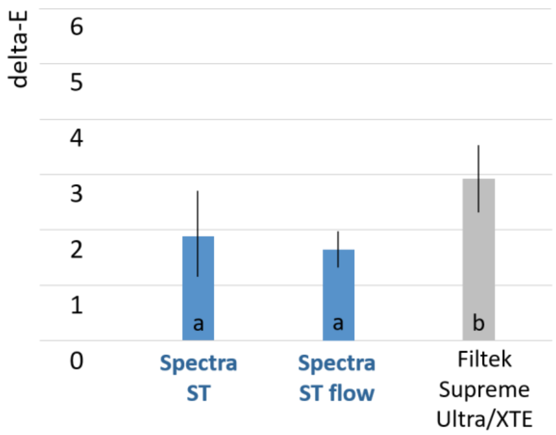


**Figure 42** Color difference after staining. The delta-E of Filtek Supreme Ultra/XTE is the overall mean of multiple sets of data and the delta-E of Spectra ST and Spectra ST flow composites is the respective ratio to that (R&D Dentsply Sirona, 2017 and 2018).

### 3.4 Data sheet

Material properties specified by ISO 4049:2009 (Polymer based restorative materials) and other key material properties are listed in Table 2.

| Property | | ISO 4049 | Spectra ST and Spectra ST Effects[2] | Spectra ST flow |
|---|---|---|---|---|
| **Compressive strength** | | - | 400 MPa | 331 MPa |
| **Flexural strength** | | > 100 MPa | 135 MPa | - |
| | | ≥ 80 MPa | - | 110 MPa |
| **Flexural modulus** | | - | 8.5 GPa | 4.8 GPa |
| **Vickers hardness (VH5/10s)** | | - | 60 | - |
| **Filler content[3]** | **weight** | - | HV: 78-80 wt.-%, LV: 76-78 wt.-%[4] | 62.5 wt.-% |
| | **volume** | - | HV: 60-62 vol.-%, LV: 57-60 vol.-% | 39.9 vol.-% |
| **Shrinkage** | | - | 2.3 vol.-% | 4.3 vol.-% |
| **Water sorption** | | ≤ 40 µg/mm³ | 16.8 µg/mm³ | 13.3 µg/mm3 |
| **Water solubility[5]** | | ≤ 7.5 µm/mm³ | -0.2 µg/mm³ | 1.1 µg/mm3 |
| **Curing time 2 mm** | **550 mW/cm²** | - | 20 s | 20 s |
| | **800 mW/cm²** | - | 10 s | 10 s |
| **Sensitivity to ambient light** | | > 60 s | 130 s | 120 s |
| **Radiopacity** | | ≥ 2 mm eq. Al | 2.3 mm eq. Al | - |
| | | ≥ 1 mm eq. Al | - | 1.8 mm eq. Al |

**Table 2** Overview on key material properties (typical data).

2 Spectra ST and Spectra ST Effects are shade/opacity variations of the same formula.

3 SphereTEC and conventional filler as well as ytterbium fluoride; content varies ± 2 % among shades.

4 Inorganic filler content: HV: 72-74 wt.-% / 50-52 vol.-%, LV: 71-72 wt.-% / 48-50 vol.-%.

5 Negative value due to very low solubility and remaining absorbed water.

# 4 References


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# 5 Glossary and Abbreviations

| | |
|---|---|
| GDP | General Dental Practitioner |
| HV | High Viscosity |
| IFU | Instructions for Use |
| LV | Low Viscosity |
| OCA | Occlusal Contact Area |
| QTH | Quartz Tungsten Halogen |
| SEM | Scanning Electron Microscope |
| TC | Thermo Cycling / Cycles |
| TML | Thermo Mechanical Loading |

# 6 List of Figures

# 7 List of Tables

# 8 Trademarks

The following materials are not registered trademarks of Dentsply Sirona, Inc.

Brand (abbreviation(s), Manufacturer):
Filtek® Supreme Ultra/XTE (3M ESPE)
Filtek® Supreme Ultra/XTE flowable
Sof-Lex® (3M ESPE)
Tetric® EvoCeram (Ivoclar Vivadent)
VITA® (Vita Zahnfabrik)