Filtek™ Silorane
Low Shrink Posterior Restorative
Silorane System Adhesive
Self-Etch Primer & Bond
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Introduction

Filtek™ Silorane Low Shrink Posterior Restorative and Silorane System Adhesive Self-Etch Primer and Bond is a complete system for Class I and II direct posterior restorations.

Filtek Silorane restorative is offered in 4 radiopaque shades (A2, A3, B2, C2) with one opacity. This restorative is based on a new resin chemistry – Silorane technology – which has achieved the lowest shrinkage currently available. The reduced shrinkage leads to greatly reduced polymerization stress.

Filtek Silorane Posterior Restorative is used with Silorane System Adhesive. The dedicated adhesive is an advanced self-etching formulation delivered in vials. The formulation of Silorane System Adhesive specifically fits the chemistry of the Filtek Silorane restorative.

The specially-adapted Silorane adhesive and the reduced shrinkage of the Filtek Silorane composite lead to restorations with excellent marginal integrity.

History

Composite materials have been used in dental practices to restore teeth since 3M first introduced a composite to the dental market in 1964. Composites consist of fillers embedded in a chemically-reactive organic resin matrix. Fillers are typically inorganic materials like glass or quartz which are generally functionalized on the surface (silanization), enabling chemical linkage to the resin matrix.

The early materials were chemically-cured, two-component systems. These tooth-colored materials provided better esthetics than amalgam. However, much had to be learned about the chemical and physical properties that were required to withstand the aggressive oral environment. High shrinkage, high wear, color changes and lack of bonding to tooth surfaces were the issues associated with these early materials.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901</td>
<td>Synthesis and polymerization of methyl methacrylate</td>
</tr>
<tr>
<td>1930</td>
<td>Use of PMMA as denture base resin (Germany)</td>
</tr>
<tr>
<td>1944</td>
<td>First acrylic filling material</td>
</tr>
<tr>
<td>1951</td>
<td>Addition of inorganic fillers (non-bonded) to direct filling materials (Knock and Glenn)</td>
</tr>
<tr>
<td>1955</td>
<td>Investigation of epoxy resins as direct filling materials</td>
</tr>
<tr>
<td>1955</td>
<td>Acid-etch technique introduced (Buonocore)</td>
</tr>
<tr>
<td>1958</td>
<td>Dimethacrylates (Bis-GMA) and silanized inorganic filler investigated as direct filling material (Bowen)</td>
</tr>
<tr>
<td>1964</td>
<td>Bis-GMA composites marketed</td>
</tr>
<tr>
<td>1968</td>
<td>Development of polymeric coatings on fillers (Dental Fillings Ltd)</td>
</tr>
<tr>
<td>1973</td>
<td>UV-cured dimethacrylate composite resins</td>
</tr>
<tr>
<td>1977</td>
<td>Visible light-cured dimethacrylate composite resins</td>
</tr>
<tr>
<td>2007</td>
<td>Introduction of Filtek™ Silorane System to the market</td>
</tr>
</tbody>
</table>

Table 1: History of major developments in composite resins (From 1901 – 2007)

Significant improvements have been made since then (Table 1). On the one hand, adhesive systems have been developed that adhere well not only to enamel, but even to moist dentin. On the other hand, composites have been made stronger, with higher wear resistance and color stability. And, both composites and adhesives have been modified to be curable on demand by exposure to light.
Improvements on the composite side were achieved, to a great extent, by optimizing the fillers – while the chemistry behind the organic resin matrix remained essentially the same since the pioneering work of R. L. Bowen in the 1960s. Practically all composites employ dimethacrylates such as TEGDMA, Bis-GMA or UDMA, which are radically polymerized as the primary resin (Fig. 1).

It is striking, that during these decades of improvement, polymerization shrinkage was only incrementally reduced to a somewhat lower level. Reducing the polymerization shrinkage of composite materials without compromising physical and handling properties remained the major challenge for material scientists.

Shrinkage is one of the major drawbacks of composite materials. Shrinkage results in a built-in polymerization stress which challenges the tooth/composite interface. To achieve long-term marginal integrity of restorations, technically-perfect bonding to enamel and dentin with high bond strength is necessary to counteract the shrinkage and polymerization stress.

Polymerization shrinkage is an intrinsic property of the resin matrix. Upon curing, the single resin molecules move towards each other and are linked by chemical bonds to form a polymer network. This reaction leads to a significant volume contraction.

To date, the main strategy to reduce shrinkage focused on increasing the filler load, thereby reducing the proportion of the methacrylate resin (Fig. 2). Since the shrinkage is caused by the resin, the lower the proportion of resin in a composite, the lower the shrinkage will be. However, the shrinkage intrinsic to the methacrylate resin has remained a major challenge. Therefore, exchanging the resin seems the most promising pathway to solve the shrinkage problem.
It’s time to face the next challenge: the fundamental improvement of the resin matrix by advancing beyond the current methacrylate resin systems.

Filtek™ Silorane Low Shrink Posterior Restorative resin is based on the silorane chemistry and does not contain methacrylates. The silorane ring-opening monomers provide for low polymerization shrinkage.

The new silorane platform provides a fundamental solution to the long-standing customer need for low shrinkage.

Rationale
Polymerization shrinkage and the resulting shrinkage stress, lead to microleakage which is among the major factors for composite material failures in the oral environment. Moreover, shrinkage stress can lead to tooth deformation, enamel cracks and stress-induced post-operative sensitivity (Fig. 3).

Materials which remain dimensionally stable upon polymerization, coupled with an advanced bonding to the enamel and dentin, will markedly enhance the stability of the restoration under functional stress.

Filtek Silorane Low Shrink Posterior Restorative is designed to minimize shrinkage and polymerization stress.

[Diagram showing clinical challenges associated with high shrinkage and polymerization stress]
Overview of Materials
Filtek™ Silorane Low Shrink Posterior Restorative

Chemistry of the Resin System
The development of dental restorative composites began in the late 1940s. Since then many technological developments have significantly improved the clinical performance of dental resin composites. However, the common chemical basis for all restorative composites remained the radical polymerization of methacrylates or acrylates. The low-shrinking Filtek Silorane restorative is based on the new ring-opening silorane chemistry.

Siloranes are a totally new class of compounds for the use in dentistry. The name silorane derives from its chemical building blocks siloxanes and oxiranes (Fig. 4).

Siloxanes are well known in industrial applications for their distinct hydrophobicity. By incorporating the siloxanes into the dental silorane resin, this property was transferred to the Filtek Silorane composite.

Oxiranes have been used for a very long time in many technical fields, especially where high forces and a challenging physical environment are expected, such as in the manufacture of sports equipment like tennis rackets or skis, or in the automotive and aviation industries and many more. The oxirane polymers are known for their low shrinkage and the outstanding stability toward many physical and chemophysical forces and influences.

The combination of the two chemical building blocks of siloxanes and oxiranes provides the biocompatible, hydrophobic and low-shrinking silorane base of Filtek Silorane Low Shrink Posterior Restorative. This innovative resin matrix represents the major difference of Filtek Silorane restorative compared to conventional methacrylates. Also, the initiating system and the filler were adapted in order to provide the best performance of the new technology (Fig 5).
**Ring-Opening Polymerization**

The polymerization process of Filtek Silorane restorative occurs via a cationic ring-opening reaction which results in a lower polymerization contraction, compared to the methacrylate-based resins which polymerize via a radical addition reaction of their double bonds.

The ring-opening step in the polymerization of the silorane resin significantly reduces the amount of polymerization shrinkage which occurs in the curing process. The reduced amount of shrinkage is illustrated schematically in Fig. 6. During the polymerization process, molecules have to approach their “neighbors” to form chemical bonds. This process results in a loss of volume, namely polymerization shrinkage. In contrast to the linear-reactive groups of methacrylates, the ring-opening chemistry of the siloranes starts with the cleavage and opening of the ring systems. This process gains space and counteracts the loss of volume which occurs in the subsequent step, when the chemical bonds are formed. In total, the ring-opening polymerization process yields a reduced volumetric shrinkage.

Besides shrinkage, another parameter of paramount importance to the performance of a restorative material is polymerization stress. Polymerization stress is generated when composites are cured in the bonded state and the polymerization shrinkage develops forces within the cavity walls. The rigid tooth structure will withstand this force to a certain degree, however, these tensions can lead to marginal gaps or to damage of healthy tooth structure by its deformation. These forces or tensions are summarized under the term “polymerization stress.”

From the restorative material perspective, polymerization stress is mainly determined by three factors: 1) the polymerization shrinkage, 2) the internal flowability of the material, and 3) the polymerization kinetics (polymerization speed). A highly-shrinking material with a small, internal flowability and very fast curing speed in the first few seconds, will exhibit the highest polymerization stress.

Silorane technology was developed to minimize shrinkage, and is thus also predestined for low stress development. Moreover, the kinetics of the initiation and polymerization of the Filtek Silorane resin were optimized to provide very low polymerization stress, as will be shown in the Test Result chapter.
Initiator System

One component of the initiating system is camphorquinone, which matches the light spectrum of conventional dental polymerization light sources. 3M™ ESPE™ Filtek™ Silorane Low Shrink Posterior Restorative can be cured with halogen, as well as LED devices.

Further components of the initiating system are iodonium salts and electron donors, which generate the reactive cationic species that start the ring-opening polymerization process (Fig. 7).

![Initiation chemistry for siloranes](image)

The initiating system of Filtek Silorane restorative was tailored so that the resulting polymerization kinetics leads to a minimized polymerization stress. A unique property of the three-component initiating system is that a “critical mass” of initiating reactive cationic species has to be generated to start the polymerization. This threshold behavior brings one major advantage: it allows the practitioner to work longer under full operatory light than with any conventional methacrylate-based composite.

While developing low stress and being stable against ambient light, the curing times for 2.5 mm increments of Filtek Silorane restorative could be kept at a level comparable to conventional composites:

<table>
<thead>
<tr>
<th>Halogen light devices</th>
<th>Exposure time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave length spectrum 400-500 nm</td>
<td>40 sec, standard mode</td>
</tr>
<tr>
<td>Output 500-1400 mW/cm²,</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LED light devices</th>
<th>Exposure time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave length spectrum 430-480 nm</td>
<td></td>
</tr>
<tr>
<td>Output 500-1000 mW/cm²,</td>
<td>40 sec, standard mode</td>
</tr>
<tr>
<td>Output 1000-1500 mW/cm²,</td>
<td>20 sec, standard mode</td>
</tr>
<tr>
<td>(e.g., Elipar™ FreeLight 2, manufactured by 3M ESPE)</td>
<td></td>
</tr>
</tbody>
</table>

However, the threshold behavior of the Filtek Silorane restorative initiator system requires a minimum curing time of **20 seconds**, which can not be compensated by higher intensities. Very high intensity light sources like plasma arc lamps and lasers do not allow sufficiently-long curing times due to heating of the tooth. Therefore, plasma arc lamps, lasers and other light sources with very high intensities are contraindicated to be used with Filtek Silorane restorative.

Filler Technology

Filtek Silorane restorative is filled with a combination of fine quartz particles and radiopaque yttrium fluoride. From the filler side, Filtek Silorane restorative is to be classified as a microhybrid composite. The quartz surface is modified with a silane layer which was specifically matched to the silorane technology in order to provide the proper interface of the filler to the resin for long-term, excellent mechanical properties (Fig. 8).

![Filler-size distribution of Filtek™ Silorane Low Shrink Posterior Restorative](image)

Source: 3M ESPE internal data
Silorane System Adhesive

Chemical Background
Recently, self-etch adhesives have gained increasing popularity among dentists. Their success is mainly based on their ease of use, low technique sensitivity and ability to reduce post-operative sensitivity as compared to total-etch adhesives.

Silorane System Adhesive Self-Etch Primer and Bond is a new member of the 3M ESPE family of successful self-etch adhesive materials. Silorane System Adhesive has been specially designed to provide strong and long-lasting bonding of Filtek Silorane Low Shrink Posterior Restorative to enamel and dentin, providing the basis for excellent marginal integrity of the restorations.

The extraordinary low shrinkage and polymerization stress of Filtek Silorane restorative have been achieved by developing the new silorane resin system. Curing of this resin system involves chemical mechanisms different from conventional methacrylate-based composites. From a scientific standpoint, it is obvious that a new adhesive is needed. Adhesives currently available on the market have been developed for traditional methacrylate materials and will, therefore, lead to insufficient results in combination with Filtek Silorane restorative.

Due to its siloxane backbone, the silorane resin is more hydrophobic than conventional methacrylate resins, so it results in reduced water uptake and related phenomena, as described in the Test Results section. That means this adhesive has to bridge a larger difference between the hydrophilic tooth substrate and the hydrophobic silorane material as compared to conventional methacrylate materials. Therefore, Silorane System Adhesive has been designed as a two-step adhesive (Fig. 9):

- Silorane System Adhesive Self-Etch **Primer** is rather hydrophilic, and ensures strong and durable adhesion to the tooth.
- Silorane System Adhesive **Bond** is optimized for wetting and adhering to the hydrophobic Filtek Silorane Posterior Restorative.

![Figure 9: Different regimes of hydrophilicity/hydrophobicity at the interface between the tooth and Filtek™ Silorane Low Shrink Posterior Restorative](image-url)
Silorane System Adhesive Self-Etch Primer

In principle, self-adhesion is generated by acidic monomers that etch dental substrates and thus create a retention pattern for micromechanical interlocking of the cured adhesive with the tooth. Furthermore, they provide chemical bonding to the calcium-containing hydroxyapatite of the mineralized tissue. Most of today’s self-etch adhesives contain phosphorylated methacrylates as acidic monomers; some contain carboxylic acid functionalized monomers, or a combination of both.

Silorane System Adhesive Self-Etch Primer contains phosphorylated methacrylates, as well as the Vitrebond™ copolymer with its carboxylic acid functionality used in many 3M™ ESPE™ resin-modified glass ionomers, and adhesives for adhesion to enamel and dentin. Furthermore, comonomers like BisGMA and HEMA, a solvent system consisting of water and ethanol for wetting and penetrating the dental substrates, and a photoinitiator system based on camphorquinone for thorough and fast curing are included. A silane treated silica filler with a primary particle size of about 7 nm has been added for improving the mechanical strength and film-forming properties of Silorane System Adhesive Self-Etch Primer. This filler is very finely dispersed in order to prevent settling.

Special attention has been devoted to providing a stable formulation that combines acidic monomers and the water/ethanol solvent system. Refrigeration is required in order to prevent loss of ethanol or water by evaporation.

With a pH of about 2.7, Silorane System Adhesive Self-Etch Primer provides rather mild etching and demineralization of the tooth structure, yet strong and durable bonding through its nanoetching pattern, as well as chemical bonding to the hydroxyapatite. If Silorane System Adhesive is to be applied to uncut enamel, a separate etching of the unprepared tooth structure is recommended. It is not required to etch prepared enamel but it may be done if desirable.

On dentin, well-defined resin tags are visible and penetration of the dentin structure by Silorane System Adhesive Self-Etch Primer (Fig. 10).

Figure 10: SEM micrograph of the composite/adhesive/ dentin interface after consecutive etching with hydrochloric acid and sodium hypochlorite solution

Source: 3M ESPE internal data
Silorane System Adhesive Bond is also based on methacrylate chemistry. As a main component, it contains a unique 3M™ ESPE™ hydrophobic bifunctional monomer in order to match the hydrophobic silorane resin. An immediate result of this feature is the easy adaptation of Filtek™ Silorane Low Shrink Posterior Restorative on cured Silorane System Adhesive Bond. Other components include acidic monomers that initiate the ring-opening cationic cure of Filtek Silorane restorative, thus providing chemical bonding to Filtek Silorane (Fig. 11). The photoinitiator system is based on camphorquinone.

Silorane System Adhesive Bond contains a silane-treated silica filler that not only improves the mechanical strength of the material, but also allows for carefully adjusted viscosity properties. Silorane System Adhesive Bond may appear very viscous at first glance – you may have to flick it to the tip of the vial in order to dispense it. However, once you apply it with the brush or air-thin it, the viscosity drops by several orders of magnitude (Fig. 12), and it can be very easily dispersed as an even, uniform film. This phenomenon is called shear thinning.

The benefits are obvious: it does not drop from the brush; and you can direct it with the air stream where you want it to be and it stays there – especially on the cavity walls and preparation margins – and it does not pool. With Silorane System Adhesive Bond, the resulting film thickness is in the range of other two-step self-etch adhesives, despite of the apparently higher viscosity.

![Figure 11: Mechanism of chemical bonding between Silorane System Adhesive Bond and Filtek™ Silorane Low Shrink Posterior Restorative](image1)

![Figure 12: Viscosity of Silorane System Adhesive Bond at low shear and under application conditions. Application and air thinning reduces the viscosity by several orders of magnitude, thus allowing for formation of an even and homogeneous film](image2)
Test Results

Filtek™ Silorane Low Shrink Posterior Restorative has been tested extensively, both in-house as well as at renowned universities worldwide – and many results have been published in peer-reviewed journals. In this evaluation care was taken to address the most important quality parameters for composite restorations.

Polymerization Shrinkage

Polymerization shrinkage is still a major concern. Prof. Swift and co-workers stated only recently that “although composites are now the material of choice for most restorations, their polymerization shrinkage remains a problem. The contraction stress associated with this shrinkage can cause debonding at the composite/tooth interface and can contribute to post-operative sensitivities, enamel fracture, recurrent caries marginal staining and eventually failure of the restoration.” (Yamazaki, Bedran, Russo, Pereira and Swift, 2006)

Filtek Silorane restorative has been developed to minimize polymerization shrinkage and polymerization stress, while providing a high-performance bond to the tooth. Extensive testing of polymerization shrinkage has been conducted which shows Filtek Silorane restorative to have a significantly lower shrinkage than all methacrylate composites tested, irrespective of the method employed (Fig. 13, Fig. 14, Fig. 15).

Most common measurements for polymerization shrinkage are the bonded-disc method, also referred to as Watts method (Watts & Cash 1991), and the Archimedes method which was recently developed into a German Standard (DIN 13907/2005). The bonded-disc method results in lower shrinkage values since only the linear shrinkage of a bonded composite disc is measured and then converted into % of volume. Whereas the Archimedes method measures the actual shrinkage in volume according to the buoyant force principle. However, both methods show a high correlation (Weinmann et al., 2005).

The bonded-disc method revealed shrinkage values for Filtek Silorane restorative of 0.9 % (Fig. 13), while the polymerization shrinkage is about 1% when measured with the Archimedes method (Fig. 14).

![Figure 13: Polymerization shrinkage (bonded-disc method) of Filtek™ Silorane Low Shrink Posterior Restorative and methacrylate composites](source: 3M ESPE internal data)
A third method to determine volumetric shrinkage is employing video imaging to determine dimensional changes. The so-called AccuVol method (J. Burgess, U.S.A.) results in a value of 0.66 % volumetric shrinkage for Filtek Silorane (Fig. 15) and confirms Filtek Silorane restorative to be the lowest shrinking material among all composites tested.
Polymerization Stress

Polymerization stress builds up during polymerization as a consequence of polymerization shrinkage when the gel point is reached, and further contraction cannot be compensated for by additional flow of the material.

Filtek™ Silorane Low Shrink Posterior Restorative develops a very low polymerization stress compared to methacrylate composites, with all methods employed (Fig. 16, Fig. 17, Fig. 18).

A wide range of shrinkage-stress data are available for a tensilometer method developed at ACTA (University of Amsterdam). Here a composite sample is luted between a glass and a metal plate. The metal plate is attached to a load cell. While the composite is cured through the glass plate, the height of the composite sample is held constant by the testing device. The force needed to keep the height constant is recorded.

Watts et al. (2003) developed a method to determine the photopolymerization shrinkage-stress kinetics in resin composites with the Bioman device. Filtek Silorane restorative shows significantly lower polymerization stress than the methacrylate composites tested (Fig. 17).
Another method for the evaluation of shrinkage stress was performed by Prof. Ernst (University of Mainz) by means of a photoelastic investigation. Composite specimens were bonded in Araldit plates and cured with a halogen curing light. The strain forces induced by the polymerization shrinkage of the composites into the Araldit plate can be visualized as isochromatic rings in a polarizing microscope. The polymerization stress was calculated from the diameter of the first order isochromatic rings, at 4 minutes and again at 24 hours after exposure.

The results reveal that Filtek Silorane restorative generated the lowest polymerization stress among all composites tested (Fig. 18). Additionally, all methacrylate-based materials continued to build up stress: the values measured after 24 hours are always higher than after 5 minutes. Filtek Silorane restorative was the only material which maintained the same low-stress value observed after 5 minutes and did not continue to build up stress (Ernst et al. 2004).
The low stress development of Filtek™ Silorane Low Shrink Posterior Restorative can be visualized by Finite Element Analysis. Dr. Versluis (University of Minnesota) simulated the spatial distribution and the intensity of polymerization stress compared to a low-shrink methacrylate (Fig. 19). Note that the Filtek Silorane restoration shows an absence of “gray” high-stress areas where enamel cracks and leakage in the margin can occur.

The correlation between polymerization shrinkage and polymerization stress can be seen in Fig. 20, which shows the unique position of Filtek Silorane restorative made possible through silorane technology.
Cusp Displacement

A clinical implication of high polymerization stress and polymerization shrinkage is cusp displacement, which can result in the damage of healthy tooth structure (e.g., enamel cracks) and strain-induced hypersensitivities. Prof. Bouillaguet (University of Geneva) showed that Filtek™ Silorane Low Shrink Posterior Restorative generates a much lower cusp displacement compared to methacrylate-based composites (Bouillaguet et al. 2006, Fig. 21).

![Graph showing cusp displacement over time for different composite materials.](image-url)

**Figure 21:** Time resolved cusp displacement of teeth with Filtek™ Silorane and methacrylate composites placed in Class II MOD cavities. [Electronic speckle pattern interferometry (ESPI)]

**Source:** Prof. Bouillaguet, University of Geneva
Adhesion

Adhesion with sufficient high-bond strength is a key factor determining the seal of a filling and the stabilization of the restored tooth. To ensure optimal linkage of Filtek™ Silorane Low Shrink Posterior Restorative to the tooth, a dedicated Silorane System Adhesive has been developed.

Bond strength of the Silorane System Adhesive in combination with Filtek Silorane restorative was evaluated with the widely-used tensile bond test where load is applied perpendicular to the tooth surface, and shear bond testing where load is applied parallel to the tooth surface. Prof. Powers (University of Michigan) determined tensile bond strengths to enamel and dentin for the Filtek Silorane System to be higher than a variety of clinical successful bonding systems (Fig. 22).

Similarly, shear bond strength of Silorane System Adhesive revealed bond strength values similar to or better than current adhesive systems (Fig. 23).

Prof. Fischer (University of Zurich) investigated the durability of the adhesive interface by thermocycling and subsequent determination of shear bond strength. Filtek Silorane System showed a significantly higher bond strength after thermocycling compared to a leading methacrylate system (Fig. 24).
Marginal Quality of the Restoration

Due to the low shrinkage and low polymerization stress of the Filtek Silorane Restorative System, a smaller portion of the bond strength has to be invested to counteract forces resulting from shrinkage. Thus, more effective bond strength remains to counteract mastication forces and forces resulting from temperature changes. The low polymerization shrinkage of Filtek Silorane restorative, in combination with the excellent bond strength, leads to excellent marginal integrity of the restoration (Fig. 25).

Filtek Silorane Restorations were challenged in a chewing-simulation test device which combined 450,000 cycles of loading with 50 N per load and thermocycling for 1,550 cycles between 5°C and 55°C. The results showed that Filtek Silorane System provides better marginal integrity before and after chewing simulation, as compared to leading methacrylate systems (Fig. 26).
Wear

The wear rate of Filtek™ Silorane Low Shrink Posterior Restorative was determined in a three-body abrasion test according to the ACTA method. In this test, a sample wheel filled with composites (Body 1) is rotated against a structured stainless steel wheel (Body 2) in a millet suspension (Body 3). As the stainless steel wheel is narrower than the sample wheel, it leaves an abrasion mark on the samples, the depth of which can be determined by means of a profilometer. The deeper the abrasion mark, the less resistant the material is to wear. The three-body wear of Filtek Silorane restorative corresponds to that of the clinically-tried and proven composites (Fig. 27).

Flexural Fatigue Limit

Restoration fracture due to material fatigue is one of the main reasons for failure of direct restorations. To obtain insight into the fatigue behavior of the Silorane it’s flexural fatigue limit was determined and compared with conventional methacrylate composites. In this test 10,000 cycles of 3-point loading were applied with the frequency of 2 Hz, which is the upper limit of chewing frequency, under wet conditions and a constant temperature of 35°C. Several tests were done for each material, increasing the stress compared to the previous test if a material did not fail, and decreasing the stress if the material broke under loading. This procedure is referred to as the staircase approach.

The flexural fatigue limit of Filtek Silorane restorative under wet conditions reaches top level, indicating a long-term durability of Filtek Silorane restorative under clinical conditions (Fig. 28).
Compressive Strength and Flexural Strength

A high compressive strength and a high flexural strength of the restoration material protects from fractures and stabilizes the tooth at the same time, especially when used in posterior restorations. The compressive strength of Filtek Silorane restorative was determined by increasing the load on specimens of 3x3x5 mm until fracture. Flexural strength was determined using the a three-point bending test. In this test the material is fixed at two points and stress is applied to a third point until fracture. During the test, compressive forces built up on the upper side and tensile forces at the lower side.

Both the compressive strength and flexural strength of Filtek Silorane restorative rank within the range of clinically proven composites and are substantially above the ISO 4049 limit of 80 MPa (flexural strength) (Fig. 29).

Flexural Modulus

The flexural modulus defines the rigidity of a material and is determined on the basis of the same experimental set-up as flexural strength. There are no standard values indicating how high the flexural modulus of a restoration material should be. If the flexural modulus is too high, the material is more brittle and filling fractures are more likely. If the flexural modulus is too low, the tooth would not be provided with adequate stability. The flexural modulus of Filtek Silorane restorative ranks within the range of clinically-proven composites (Fig. 30).
Fracture Toughness ($K_{IC}$)

Fracture toughness is a measure of the resistance of a material to crack formation. A notch is sawed into rod-shaped test bodies, which are then pulled apart with increasing energy until the notch propagates as a crack and the specimen breaks. The fracture toughness of Filtek™ Silorane Low Shrink Posterior Restorative is in the range of clinically proven methacrylate composites (Fig. 31).

![Fracture Toughness Graph](image)

Source: Prof. Kunzelmann, University of Munich

Depth of Cure

The depth of cure was determined by a scratch test in accordance with ISO 4049:1999. For the test, composite cylinders are light cured in a brass mold. After polymerization, the brass mold is removed and the non-polymerized soft composite is scraped off with a spatula. The height of the remaining composite cylinder is measured. On the basis of these measurements Filtek Silorane restorative may be placed in increments of up to 2.5 mm (Fig. 32).

![Depth of Cure Graph](image)

Source: Dr. Ilie, University of Munich
Ambient Light Stability

Ambient light stability contributes to the convenience of handling of a composite material. The ambient light stability of Filtek Silorane restorative was evaluated according to ISO 4049, which requires stability of a composite to be at least 60 seconds at 8000 Lux illumination (Fig. 33).

The Silorane technology of Filtek Silorane restorative offers the dentist up to 9 minutes to place and shape the restoration under operatory light illumination.

Figure 33: Ambient light stability of Filtek™ Silorane Low Shrink restorative and methacrylate composite at 8000 Lux (Method based on ISO 4049)

Source: 3M ESPE internal data
**Water Sorption and Exogenic Staining**

The water sorption of composite restorations leads to swelling and possibly reduction in material properties – and it also facilitates exogenic discoloration. Filtek™ Silorane Low Shrink Posterior Restorative was compared to methacrylate systems regarding water uptake according to ISO 4049 and its tendency to acquire staining in a coffee-stain test. In the course of this test specimens are immersed in a coffee solution over extended periods of time and the resulting discoloration is expressed as a Delta E-value (Fig. 34).

Water sorption for Filtek Silorane restorative is very low due to the hydrophobicity of the silorane matrix, which results in a very low tendency for exogenic staining.

![Figure 34: Water uptake (ISO 4049) and exogenic staining (coffee-stain test)](image)

Source: 3M ESPE internal data

**Clinical Studies**

*Prof. Ernst, Johannes Gutenberg University of Mainz, Germany*

Filtek Silorane restorative is being studied in Class II restorations with an experimental adhesive, together with QuiXfil posterior restorative and Xeno III adhesive, in a split-mouth design. 102 restorations were placed in 46 patients. At baseline and at one year, the restorations were evaluated according to the Ryge/CDA criteria. After one year, all restorations showed clinically excellent and acceptable results. No Charlie or Delta scores were documented (Schattenberg et al. 2007).

*Prof. Eliasson, University of Iceland*

In this study the clinical performance of Filtek Silorane restorative is being tested with an experimental adhesive system, and is compared to Tetric Ceram and a self-etching adhesive, AdheSE. At least one pair of restorations was placed in each patient according to research protocol. At one year, 53 restoration pairs in 31 patients were examined using the modified Ryge/CDA scale. No Charlie and Delta scores were seen. Color match was unchanged. One Tetric Ceram restoration was removed because of sensitivity. At one year, both materials appeared to be clinically acceptable and comparable.
3M ESPE Application Test

To evaluate the handling of the Filtek Silorane system, an *in-vivo* application test with 43 general practitioners in five European countries was conducted.

Dentists were asked to rate several handling criteria of the Filtek™ Silorane Low Shrink Posterior Restorative. On a 5-point scale, rating 1 stands for an excellent performance and rating 5 for a poor performance (Fig. 35).

With over 1,100 fillings placed during the 6-week trial period, this application test confirmed the convenient handling of Filtek Silorane restorative.

In a second *in vivo* application test, 1,145 fillings were placed by 43 general practitioners in Germany. No cases of post-operative sensitivity were reported. 86% stated they were satisfied with the overall handling of the Filtek Silorane System, and 84% found the system easy to use.
Clinical Case

Clinical Application of Filtek™ Silorane System

The direct restorative filling with the Filtek Silorane System requires no special technique. It works just like state-of-the-art composite/adhesive systems with one substantial improvement. Due to its greatly reduced sensitivity to ambient light, Filtek™ Silorane Low Shrink Posterior Restorative can be placed, shaped and modeled under full operatory light illumination for as long as 9 minutes.

The case shown is typical: A Class II composite filling had to be replaced due to the occurrence of secondary caries after marginal gap formation.

Initial situation  Shade selection  Prepared cavity with rubber dam, wedge and matrix after removal of old filling and excavation of secondary caries.

Application of Silorane System Adhesive Self-Etch Primer

Application of Silorane System Adhesive Self-Etch Primer for 15 seconds with black microbrush, followed by gentle air dispersion and 10 seconds of light curing.

Application of Silorane System Adhesive Bond

Application of Silorane System Adhesive Bond with green microbrush, followed by gentle air dispersion and 10 seconds of light curing.
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Application of Silorane System Adhesive Bond

Application of Silorane System Adhesive Bond with green microbrush, followed by gentle air dispersion and 10 seconds of light curing.

Application of Filtek Silorane Low Shrink Posterior Restorative

Placement and shaping of Filtek™ Silorane Low Shrink Posterior Restorative under full operatory light conditions.

20 seconds light curing (Elipar™ FreeLight 2).

Finishing and Polishing (Sof-Lex™).

Final Filtek™ Silorane Low Shrink Posterior Restorative filling after rehydration of the teeth.
technique guide

filtek™ silorane
low shrink posterior restorative

silorane system adhesive
self-etch primer and bond

⚠️ use only as a system!
Indications
Filtrek™ Silorane Posterior Low Shrink Restorative, together with Silorane System Adhesive Self-Etch Primer and Bond, is a system for direct, posterior restorative filling. It can be used for the following posterior restorations:

- Class I
- Class II

Filtrek Silorane restorative and Silorane system adhesive may be used together with glass ionomer cements or resin-modified glass ionomer cements, as cavity liners or bases.

Composites and compomers (including flowable composites and compomers), which are bonded to the tooth substance using an adhesive, may not be used as a liner or base under a Filtrek Silorane filling.

Shades
Filtrek Silorane posterior restorative is offered in the shades A2, A3, B2 and C2. All shades are radiopaque.

Composition
Filtrek Silorane Posterior Restorative:

- Silorane resin
- Initiating system: camphorquinone, iodonium salt, electron donor
- Quartz filler
- Yttrium fluoride
- Stabilizers
- Pigments

Silorane System Adhesive Self-Etch Primer:

- Phosphorylated methacrylates
- Vitrebond™ copolymer
- BisGMA
- HEMA
- Water
- Ethanol
- Silane-treated silica filler
- Initiators
- Stabilizers

Silorane System Adhesive Bond:

- Hydrophobic dimethacrylate
- Phosphorylated methacrylates
- TEGDMA
- Silane-treated silica filler
- Initiators
- Stabilizers
Questions and Answers

• What is the difference between Filtek™ Silorane Low Shrink Posterior Restorative and conventional composites currently on the market?

Filtek Silorane restorative is based on the new silorane technology which allows shrinkage of <1% – which is exceptionally low compared to conventional methacrylate composites. (Volumetric shrinkage tested by bonded disc method) The new resin matrix technology requires a dedicated adhesive.

• How can I trust a “new” chemistry like siloranes? Has it been thoroughly tested?

Yes, the Filtek Silorane System has been thoroughly tested and evaluated. The data shows that the Filtek Silorane System performs well in both *in vitro* and *in vivo* studies and is biocompatible.

• For what indications can I use the Filtek Silorane restorative/Silorane adhesive system?

Filtek Silorane restorative and Silorane System Adhesive form a system for direct posterior filling procedures: Class I and II.

• Do I need any special moisture-control precautions when placing fillings with the Filtek Silorane System?

With the Filtek Silorane restorative/Silorane System adhesive you can place your fillings like with any other composite/adhesive system; i.e., under dry conditions with rubber dam being recommended, but not mandatory.

• Do I need to prepare the cavity in a special way for Filtek Silorane fillings?

Filtek Silorane restorative/Silorane System adhesive requires no special cavity preparation. Preparation has to follow the usual guidelines for adhesive restorations; i.e., minimal invasive treatment, no special undercuts and beveled margins as needed.
• **Why do I need a dedicated adhesive? Can I use Filtek Silorane restorative with other adhesives than Silorane System adhesive?**

All adhesives on the market today have been developed for conventional methacrylate-based filling materials. As the Filtek Silorane resin system is based on a completely new chemistry, an adhesive is needed that takes into account the different curing mechanism. Silorane System adhesive is the only adhesive that reliably delivers excellent bond strength with Filtek Silorane restorative. The use of a different adhesive will lead to insufficient bond strength.

• **Can the Silorane System Adhesive be used with conventional methacrylate composites?**

Silorane System Adhesive has been specially developed for the use with Filtek™ Silorane Low Shrink Posterior Restorative. We recommend its use solely with Filtek Silorane restorative.

• **Why didn’t 3M ESPE make Silorane System Adhesive a 5th generation adhesive? I don’t believe in self-etch adhesives.**

With more than 70 million fillings placed worldwide today, using 3M ESPE self-etch adhesives, 6th generation adhesives are clinically-proven and well accepted in the market. This is also due to their ease of use.

One major goal of silorane technology is reduced shrinkage and polymerization stress, which can result in reduced post-operative sensitivity. In order to provide a truly low-sensitivity system, we decided to provide Filtek Silorane restorative with a self-etch adhesive, as these adhesives are known for their reduced risk of post-op sensitivity compared to total-etch systems. In case you would like to etch enamel selectively, this can be done.

• **What happens if I separately etch enamel and/or dentin before applying the Silorane System Adhesive?**

On dentin and prepared enamel, the self-etching Silorane System Adhesive needs no additional etching step. However, due to its rather mild etching, it is recommended to use phosphoric acid on uncut enamel prior to application of Silorane System Adhesive and you can optionally also do so on cut enamel.
• **What kind of bond strengths do I get with Silorane System Adhesive?**

Studies by Dr. John Powers, Prof. Jens Fischer, and 3M ESPE in-house measurements using different techniques, show that the bond strength of Silorane self-etch adhesive is comparable to that obtained with clinically-proven, state-of-the-art, self-etch adhesives for methacrylate composites. Therefore, with the exceptionally low polymerization shrinkage and stress of Filtek Silorane, the Silorane system provides excellent results.

• **Can I wet my instrument with Silorane System Adhesive for placing and modeling of Filtek Silorane restorative?**

Using an adhesive to lubricate an instrument for placing Filtek Silorane restorative is not recommended. The bonding agent or adhesive will penetrate the composite and will change the composition of the material at the wetted surface. This compromises the mechanical properties of the material. The interface between increments placed with a wetted instrument is also believed to be less strong than when placed “dry.”

• **Can I use a flowable composite as a liner?**

As of now, flowable composites and compomers may not be used as a liner or base under a Filtek Silorane filling. These materials require usage of an adhesive other than Silorane System self-etch adhesive, which in turn is not compatible with the Filtek Silorane Low Shrink Posterior Restorative. Silorane System Adhesive offers handling properties which allow proper placement without using a flowable as a liner. The stress-relief properties of a flowable liner are not important for a silorane restoration due to the low stress developed by the Filtek Silorane restorative.

• **Can I use the Filtek Silorane System in a “sandwich” technique with GIC/RMGIC on the bottom?**

Yes, Filtek Silorane restorative and Silorane System adhesive may be used together with self-adhesive materials such as glass ionomer cements or resin modified-glass ionomer cements as a cavity liner or base.

• **Can I use Filtek Silorane restorative as a base filling and cover it with a methacrylate composite?**

Yes, conventional adhesives can be used to bond methacrylate composites to cured Filtek Silorane restorative.
• Can Filtek Silorane fillings be repaired with a conventional methacrylate composite system?
Yes, conventional adhesives can be used to bond methacrylate composites to cured Filtek Silorane restorative.

• Why is Filtek Silorane restorative employing a quartz filler?
The silorane resin matches with the surface chemistry and the refractive index of quartz.

• Can I use a “bulk placement” technique with Filtek Silorane restorative?
What is the depth of cure?
Filtek Silorane restorative has to be used with a conventional layering technique with a layer thickness of 2.5 mm or less in order to obtain perfect results.

• Do I need to dim the operatory light during placement and modeling of Filtek Silorane restorative?
No, Filtek Silorane restorative has an outstanding ambient light stability and offers up to 9 minutes of working time under full operatory light conditions.

• Why am I not allowed to use high-power curing lights, like plasma arc lamps or lasers, for curing Filtek™ Silorane Low Shrink Posterior Restorative?
In the first few seconds, the ring-opening polymerization reaction of Filtek Silorane restorative is somewhat slower than the radical polymerization of methacrylates. However, after 20 seconds, the cure has proceeded to a degree equivalent to that of methacrylate composites. This difference in cure time for Filtek Silorane restorative is due to its different chemistry and cannot be compensated by a higher intensity; e.g., of a plasma curing light.

• “Low shrinkage” is a rather academic term. How can I see the benefits in my everyday work?
The low shrinkage of Filtek Silorane restorative results directly in low-polymerization stress. The latter potentially reduces the risk of post-operative sensitivity, cusp deflection and enamel cracks.
• **Why do different methods of shrinkage measurement give different results?**

One method that measures the volume difference upon curing is the Archimedes method, based on the buoyancy principle. Other methods, like the Watts bonded disk, yield different results, because here several approximations have to be made. More fruitful than discussing absolute numbers is to compare numbers received within one method. Filtek™ Silorane Low Shrink Posterior Restorative provides the lowest shrinkage compared to methacrylates with the Archimedes method, the Watts bonded-disk method, the AccuVol device and the ACTA linometer.

• **Why is Filtek Silorane restorative not a 0% shrinkage composite?**

Filtek Silorane restorative represents a balance of shrinkage versus swelling due to water uptake. Even though the water uptake is very low for Filtek Silorane restorative, a 0% shrinkage material could lead to pressure on the tooth structure caused by hydrolytical expansion.

• **If I carefully layer my methacrylate composite, don’t I compensate for the shrinkage?**

The layering technique does compensate for shrinkage to a certain degree. However, even when applying a sophisticated layering technique, methacrylate composites will produce a significantly higher polymerization stress compared to the low-shrink and low-stress optimized Filtek Silorane System.

• **Low shrinkage is nice, but what about stress?**

The Filtek Silorane System also provides for an exceptionally low polymerization stress. The benefits for patient and dentist are reduced risk of post-op sensitivity, reduced cusp displacement and, thus, less enamel cracks and improved margins.

• **What’s the difference between shrinkage and stress?**

Shrinkage is the process of volumetric contraction upon curing of the composite. Stress is the force that the shrinking composite exerts on the surrounding tooth structure, and which has been related to post-operative sensitivity, marginal gaps, cusp deflection or enamel cracks.

• **At the moment I am using a universal composite for anterior and posterior restorations. Why should I switch to a “posterior only” system?**

Posterior restorations have to function under very tough conditions. Filtek Silorane restorative with Silorane System adhesive is a specially-designed posterior restorative system providing the lowest shrinkage and exceptionally low polymerization stress.
Managing polymerization shrinkage, especially in the posterior region, is one of the most pressing challenges that is still not fully addressed with state-of-the-art composite filling materials. Over the last ten years several attempts were made to gain a low-shrinking material, but today still the vast majority of composites on the market show volume shrinkage values in the range of 2-3%.

3M™ ESPE™ Filtek™ Silorane Low Shrink Posterior Restorative is part of a revolutionary new filling system that will herald a new era in restorative dentistry. In contrast to conventional, methacrylate-based composites, Filtek Silorane restorative is polymerized in a ring-opening polymerization reaction. Filtek Silorane restorative is characterized by the lowest polymerization shrinkage on the market. Featuring a polymerization shrinkage of less than 1% also contributed greatly in reduction of polymerization stress. Lower polymerization stresses potentially reduce the risk of post-operative sensitivity, cusp deflection and, therefore, enamel cracks.

Furthermore, low polymerization shrinkage and stress, in combination with excellent adhesive properties of the 3M™ ESPE™ Silorane System Adhesive Self-Etch Primer and Bond, result in an excellent marginal integrity of Filtek Silorane restorations.

The Silorane system adhesive is a dedicated adhesive leveraging 3M ESPE's long-term experience on self-etch adhesives. The composition of Silorane System adhesive especially addresses the technological needs of adhesive bonding of the new Filtek Silorane resin to enamel and dentin.

Filtek Silorane and Silorane System Adhesive represent the next generation of restorative filling materials, combining esthetics and mechanical properties you know for conventional hybrid composites with low polymerization shrinkage due to a revolutionary new resin system. The system is well proven by scientific researchers all over the world, confirming the mechanical strength and convenient clinical handling of the Filtek Silorane system.
Literature


## Technical Data

Filtek™ Silorane Low Shrink Posterior Restorative

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<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Resin Matrix</td>
<td>Siloranes</td>
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<tr>
<td>Filler</td>
<td>Quarz and Yttrium fluoride</td>
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