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Composite Polymerization Problems and Solution

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بسم الله الرحمن الرحيم

قالُوا سُبْحَانَكَ لا عِلْمَ لَنَا
إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ
الْعَلِيمُ الْحَكِيمُ

صدق الله العظيم

سورة البقرة الآية (32)

Supervisor Declaration

This is to certify that the organization and preparation of this project have been made by the under graduated student " **Linah Adnan Jabar**" under my supervision at the College of Dentistry, University of Baghdad in a partial fulfillment of requirements of the degree of B.D.S in Conservative Dentistry.

Signature

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1.1. Dental Resin Composites

1.2. Introduction

The composition of resin-based dental composites has evolved significantly since the materials were first introduced Until recently, the most important changes have involved the reinforcing filler, which has been purposely reduced in size to produce materials that are more easily and effectively polished and demonstrate greater wear resistance. The latter was especially necessary for materials used in posterior applications, but the former has been important for restorations in all areas of the mouth. Current changes are more focused on the polymeric matrix of the material, principally to develop systems with reduced polymerization shrinkage, and perhaps more importantly, reduced polymerization shrinkage stress, and to make them self-adhesive to tooth structure ***(Ferracane, 2011)***.

1.2.1. Composition

In general, terms resin composites are a combination of inorganic particles surrounded by a coupling agent, dispersed in an organic resinous matrix ***(Schneider et al., 2010).***

1.2.2.1. Organic phase (Matrix)

The organic monomers are added in the fluid state and are converted into rigid polymers through a polymerization process, during the material's clinical application. The traditional monomers used in dental composites are Bis-GMA, TEGDMA, UDMA and BisEMA***(Schneider et al., 2010).***

Bis-GMA (Bisphenol-Aglycidyldimethacrylate):

1. Stiff nature that increase the viscosity of the composite.

2.Lower polymerization shrinkage.

3.superior mechanichal properties.

4.negatively affect the conversion rate.

TEGDMA (TriethyleneglycolDimethacrylate):

1.presents a much lower viscosity than Bis-GMA

2.TEGDMA results in resins with higher conversion rate.

2.increase of the water sorption by the material and shrinkage ***(Schneider et al., 2010).***

UDMA (Urethane Dimethacrylate): 1.is a molecule that can be used alone or in combination with Bis-GMA and TEGDMA ***(Asmussen and Peutzfeldt, 1998; Chung et al., 2002; Palin et al., 2003).***

2.The advantages of UDMA have been reported to be lower viscosity and a greater flexibility.

3. improves the mechanical properties of the composite materials ***(Asmussen&Peutzfeldt, 1998, Palin et al., 2003)***

.BisEMA (EthoxylatedBis-phenol A Methacrylate)

1.the BisEMA is less viscous than the Bis-GMA ***(Schneider et al., 2010).***

2. low shrinkage compared to resin composites.

3.there is a difference in chemistry , is that methacrylate are cured by ***radical intermediates.,*** siloranes on the other hand polymerize via ***cationic intermediates.*** During polymerization, the epoxy ring of the oxirane monomer is opened to form a linear chain, which reduces the volume loss during polymerization, thus reducing polymerization shrinkage ***(Ardu et al., 2010).***

1.2.2.2. Inorganic phase (Filler)

The dispersed filler particles in polymer matrix in contemporary dental composites may comprise several inorganic materials such as quartz (fine particles), silica glasses containing barium or strontium, other silica-based glass fillers including colloid silica (microfine particles), lithium-aluminum silicate glass, or zirconia-silica nanoclusters and silica nanoparticles which are produced by nanotechnology ***(Yu-Chih, 2009).***

There are essentially two types of filler particles: microfil particles and macrofil particles while a combination of microfil and macrofil particles are termed “hybrids". Whereas macrofil particles are reserve more strength, while microfil particles are more often easier to polish, allowing for a much more aesthetic finish ***(Roeters et al., 2005).***

Nano filled resin composites contain nano-fillers which form cluster called nano-cluster. Essentially these clusters are similar to microfillers and can be very well polished, but can act similar to a large particle providing strength and tend to have less shrinkage ***(Mitra et al., 2003; Beum et al., 2007).***

With increasing filler content the polymerization shrinkage, the linear expansion coefficient and water absorption are reduced. On the other hand, with increasing filler content, the compressive and tensile strength, the modulus of elasticity and wear resistance are generally increased. The filler content of a composite is sometimes determined by11 the shape of the filler. In a study with different types of composite, those materials with pre-polymerized composite fillers were shown to have the lowest filler content and thus also the lowest flexural strength and hardness. Composites with round fillers had the highest filler content, which was associated with higher hardness and high flexural strength. For mixed filler particles (hybrid composites), there was no linear relationship between filler content and flexural strength ***(Kim et al., 2002).***

The role of incorporated fillers offers five potentially majorbenefits (Van Noort, 2007):

(1) The considerable amount of polymeric matrix is relatively decreased by incorporating large amount of inorganic fillers and the fillers do not go to the polymerization process, in consequence, the polymerization shrinkage is much decreased.

(2) Mechanical properties such as hardness and compressive strength can be enhanced.

(3) By adding the glass fillers, the high thermal expansion coefficient of methacrylate based monomers (~ 80 ppm/°C) could be quite compensated to obtain a similar expansion coefficient to tooth tissue (8-10 ppm/C).

(4) Various aesthetic features such as color, translucency, and fluorescence can be moderated by the given fillers.

(5) The glass fillers can act as carriers to resist secondary caries with fluoride-containing fillers, and to exhibit radiopacity by using heavy metals like barium or strontium.

1.2.2.3. Coupling Agent (Connector)

Since polymeric matrix is hydrophobic, whereas the silica-based filler is hydrophilic, a durable connection must form between these two phase to obtain an acceptable properties of resin composite during polymerization. Bonding is achieved by the manufacturer treating the surface of the fillers with a coupling agent (i.e. filler salinization) before incorporating them into polymeric matrix. The most common coupling agent, called silane (3methacryloxypropyltrimethoxysilane) ***(Yu-Chih,***2000)

The stable bond between the filler and matrix further influences the material properties. The quality of the bond affects the abrasion resistance of the restorative material ***(Manhart et al., 2000).***

1.2.2.4. Initiators and Accelerators

The curing of composites is triggered by light or a chemical reaction. Light activation is accomplished with blue light at a peak wavelength of about 465 nm, which is absorbed usually by a photosensitizer, such as camphorquinone, added to the monomer mixture during the manufacturing process in amounts varying from 0.1% to 1.0%.The reaction is accelerated by the presence of an organic amine. The amine and the camphorquinone are stable in the presence of the oligomer at room temperature, as long as the composite is not exposed to light. Although camphorquinone is the most common photosensitizer, others are sometimes used to accommodate special esthetic considerations. Camphorquinone adds a slight yellow tint to the uncured composite paste. Although the color bleaches during cure, sometimes clinicians find shade matching difficult with the color shift ***(Craig, 2012).***

Chemical activation is accomplished at room temperature by an organic amine (catalyst paste) reacting with an organic peroxide (universal paste) to produce free radicals, which in turn attack the carbon double bonds, causing polymerization. Once the two pastes are mixed, the polymerization reaction proceeds rapidly ***(Craig, 2012).***

Some composites, such as core and provisional products, are dual cured. These formulations contain initiators and accelerators that allow light activation followed by self-curing or self-curing alone ***(Craig, 2012)***.

1.2.2.5. Pigments and Other Components

Inorganic oxides are usually added in small amounts to provide shades that match the majority of tooth shades. The most common pigments are oxides of iron. Numerous shades are supplied, ranging from very light shades to yellow to gray. Various color scales are used to characterize the shades of the composites.

Darker and more opaque shades of composites cannot be cured to the same depth as the lighter translucent shades ***(Craig, 2012).***

1.3. Classification of Resin Composites

During the 1970s and 1980s, the development of new resin composites focused mainly on the size and amount of filler particles. Resin composites were classified in three main groups concerning filler content: macrofilled, microfilled, and hybrid composites ***(Lindberg,***2005).

Table (1)Filler sizes and materials in dental composite materials ***(Lindberg, 2005).***

Composite type	**Filler size (^m)**	Filler material **Quartz or glass**
Macrofilled	10-40	Colloidal silica
Microfilled	0.01-0.1	Glass and colloidal silica
Hybrid	15-20 and 0.01-0.05	Glass, zirconia and colloidal
Modern hybrid	0.5-1 and 0.01-0.05	silica
Nanofiller	< 0.01(10 nm)	Silica or zirconia

<u>According to (Van Noort, 2007), it is possible to classify dentalresin composites according to the following:</u>

Traditional Resin Composites: They are usually formulated with quartz. This class of material shows a mean particle size of 10-20 ^m but can present particles up to 40 ^m size. This kind of filler was used in the first materials that appeared in the market, but its use decayed due to the low wear resistance and poor aesthetic properties.

Microfilled Resin Composites: They were launched in the market to overcome the problems of poor aesthetic properties. These materials are usually formulated with an average particle size of 0.02 ^m and a range of 0.01-0.05 ^m. Unfortunately, the mechanical properties are considered low for application in regions of high occlusal forces.

Hybrid Resin Composites:

This kind of material offers intermediate aesthetic properties but excellent mechanical properties by the incorporation of fillers with different average particle sizes (15-20 ^m and 0.01-0.05 ^m).

Small Particle Hybrid Dental Composites: They are usually formulated with particles with an average size of less than 1 ^m, and a range of 0.1 0.6 ^m. These filler distributions ensure that a polished surface can be obtained.

In (Table 1-2), a summarized classification of dental composites based on the particle size, shape, and distribution of fillers with a comparable data of Silorane-based resin composite, methacrylate-based resin composite ***(Yu-Chih, 2009).***

Table (2) Classification of Direct Resin Composite Restoratives *(Yu-Chih, 2009).*

Composite classification	**Filler content**		**Volume shrinkage**	**Average particle size**
	Weight %	**Volume**		
Hybrid	74-87	57-72	1.6-4.7	0.2-3.0
Nanohybrid	72-87	58-71	2.0-3.4	0.4-0.9 (macro) 0.015-0.05 (nano)
Microfills	35-80	20-59	2-3	0.04-0.75
Flowables	40-60	30-55	4-8	0.6-1.0
Compomers	59-77	43-61	2.6-3.4	0.7-0.8
Silorane-	50-70	-	0.94-0.99	0.015-5

*Data was obtain from (puckett et al., 2007; Weinmann et al., 2005)

1.4. Novel Formulations of Resin Composite

The development of resin composite has mainly focused on filler technology, while the composition of the polymer matrix remained principally unchanged since the introduction of Bis-GMA resin by Bowen in the early 1960s ***(Bowen,1963).*** Shrinkage is an inherent property of dimethacrylate-based formulations. However, recently, novel monomer combinations and alterations of the resin-composite formulation have been developed and evaluated with the goal of decreasing polymerization shrinkage stress ***(Schneider et al., 2010).***

The most recent modification on the polymer matrix is based on using ring opening polymerization of the silorane molecules, instead of free radical polymerization of dimethacrylate monomers ***(Guggenberger and Weinmann, 2000).***Silorane resin reveals lower polymerization shrinkage compared to the dimethacrylates. These “cyclic” monomers have provided particularly interesting and commercially viable results. Such monomers “open” their molecular structures with local volumetric expansion and this may partly or totally compensate for volumetric shrinkage from C=C ***(Guggenberger and Weinmann, 2000; Eick et al., 2002; Eick et al., 2007).***

1.5. Nanotechnology in Composites

Nanotechnology, or nanoscience, refers to the research and development of an applied science at the atomic, molecular, or macromolecular levels (i.e., molecular engineering, manufacturing) ***(Kirk et al., 1990).***

Recently, a new concept based on nanofillers in composite resin has developed. Due to improvement in both esthetic and physicomechanical properties, nanocomposites are becoming the popular esthetic and durable restorative materials in clinical practice. Nanotechnology also known as molecular engineering is the production of functional materials and structures in the range of 0.1 to 100 nanometers by various physical and chemical methods. A nanomer is 1/1,000,000,000 (one-billionth) of a meter or 1/1000 of a micron ***(Kaur et al., 2011).***

The newly available nanomaterials are nanocomposites and nanohybrids. Nanocomposites use nanometer-sized particles throughout the resin matrix, whereas nanohybrids take the approach of combining nanometer-sized particles with more conventional filler technology. Both approaches can provide good composite materials, but the nanohybrid approach still may suffer from the loss of larger particles and the potential loss of initial gloss ***(Swift, 2005).***

Nanoparticles are available in two forms: a ***single nanomer***particles and a ***group*** of nanoparticles (nanocluster). The ***nanomer particles*** are individual filler particles mainly spheroidal in shape. The size of nanomer-sized filler is 5-75nm as compared to the size of approximately (1 micron) for conventional fillers. ***Nanoclusters*** are loosely agglomerated collections of these nanoparticles and size of approximately 2-20 nm ***(Kaur et al., 2011)*** (Figure 1-5).

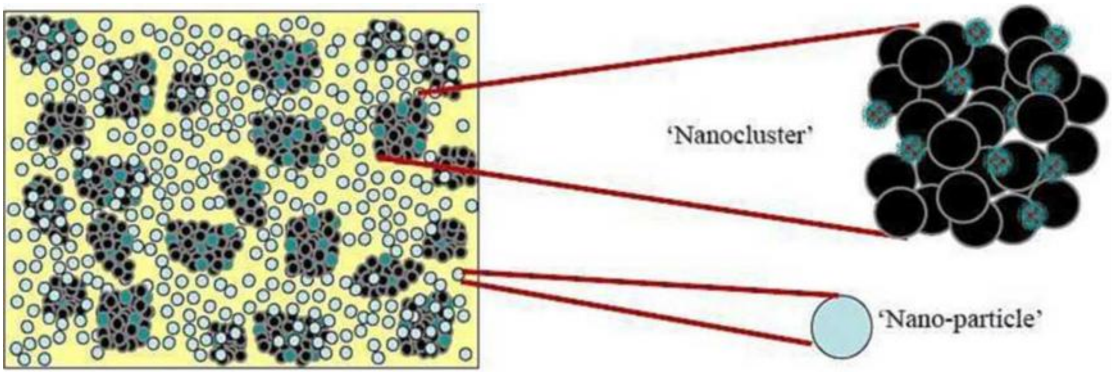


Figure (1-1) Schematic representation of silica-zirconia nanoclusters and individually dispersed nano-sized filler particles embedded in the methacrylate resin matrix ***(Curtis, 2008)***.

The particle concentration depends on viscosity, the filler loading that can be attained 69% by volume and 84% by weight, results in reduced polymerization shrinkage and shrinkage stress ***(Kaur et al., 2011)***.

**How to chamge physiomechanichal properties of composite.

Alteration of the filler component remains the most significant development in the evolution of composite resins, because the filler particle size, distribution, and the quantity incorporated dramatically influence the mechanical properties and clinical success of composite resins. In general, the mechanical and physical properties of composites improve in relation to the amount of filler added. Many of the mechanical properties depend on this filler phase, including compression strength and/or hardness, flexural strength, elastic modulus, coefficient of thermal expansion, water absorption, and wear resistance ***(Mitra et al., 2003).***

The particle size of conventional composites are very dissimilar to the structural sizes of the hydroxyapatite crystal, dentinal tubule, and enamel rods, that there is a potential for loss of adhesion between the macroscopic (40 nm to 0.7 nm) restorative material and the nanoscopic (1nm to 10 nm in size) tooth structure. Nanocomposite resin system has the ability to improve this continuity between the tooth structure and the nanosized filler particle to provide a good marginal seal between the mineralized hard tissues of the tooth and these improved restorative biomaterials ***(Kaur et al., 2011).***

Finally, Nanocomposite restorative materials have excellent aesthetics, polishabilityand very low degree of polymerization shrinkage. The development of the nanofilled composite restorative materials that have enhanced aesthetic features of high translucency and luster still maintaining strength and wear resistance provides clinicians a reliable option for anterior and posterior restorations ***(Mitra et al., 2003).***

1.6. Flowable Composites

These are low-viscosity composite resins, making them more fluid than conventional composite resins. The percentage of inorganic filler is lower and some substances or rheological modifiers which are mainly intended to improve handling properties have been removed from their composition ***(Garcia et al., 2006).***

Their main advantages are: high wettability of the tooth surface, ensuring penetration into every irregularity; ability to form layers of minimum thickness, so improving or eliminating air inclusion or entrapment; high flexibility, so less likely to be displaced in stress concentration areas (cervical wear processes and cavitated dentine areas); radio-opaqueness and availability in different colors.

The drawbacks are: high curing shrinkage, due to lower filler load, and weaker mechanical properties ***(Garcia et al., 2006).***

1.6.1. SDR (Smart Dentin Replacement)

SDR "Smart Dentin Replacement" is a one-component, fluoride-containing, visible light cured, radiopaque resin composite restorative material. It is designed to be used as a base in class I and II restorations. SDR material has been handling characteristics typical of a flowable composite, but can be placed in 4mm increments with minimal polymerization stress. SDR material has a self-leveling feature that allows intimate adaptation to the prepared cavity walls. Available in one universal shade, it is designed to be overlayed with a methacrylate based universal/posterior composite for replacing missing occlusal/facial enamel. The advantage of SDR is compatible chemistry, allowing us to combine material with conventional adhesives. Dentist can use any bond on methacrylate base (total-etch technique or self-etching adhesives) ***(DENTSPLY, 2010).***

It was claimed that resin systems based on the SDR technology with a polymerization modulator being chemically embedded in the polymerizable resin backbone controlling thus polymerization kinetics would induce lower polymerization shrinkage in the flowable composite based on it ***(Ilie and Hickel, 2011).*** (Figure 1-8).

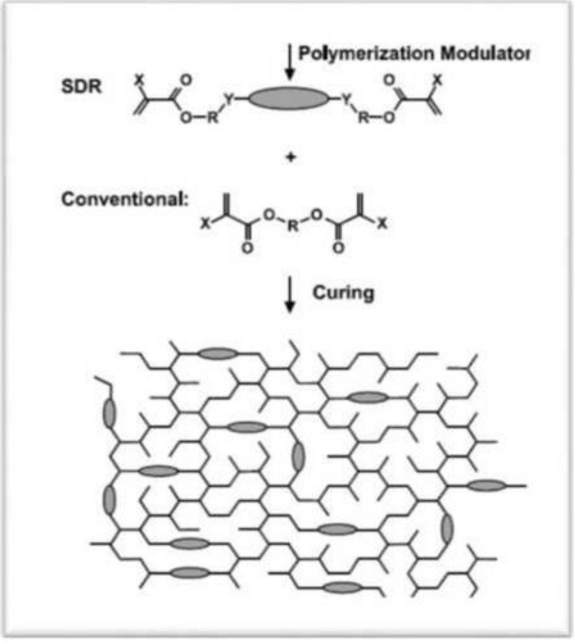


Figure (1-2) Chemistry of SDR Technology. Note the inclusion of a "Polymerization Modulator" within the backbone of the SDR resin ***(DENTSPLY, 2010).***

1.6.2. Self-Adhering Flowable Composite (Vertise Flow)

Vertise Flow composite is a self-adhesive, light cured, resin-based composite dental restorative designed for direct. By incorporating Kerr's OptiBond adhesion technology, Vertise Flow composite eliminates the additional steps of etching/priming/bonding otherwise necessary to bond a resin composite to dentin and enamel. Vertise Flow bonds in two ways: primarily through the ***chemical bond*** between the phosphate functionalgroups of a GPDM (glycero-phosphate dimethacrylate) monomer and calcium ions of the tooth.

And, secondarily, through a ***micromechanical bond*** as a result of an inter-penetrating network formed between the polymerized monomers of Vertise Flow and collagen fibers (as well as the smear layer) of dentin. Vertise Flow composite offers high bond strength, high mechanical strength, and other physical attributes comparable to traditional flowable composites. Vertise Flow composite is indicated for small Class I and base/liner for Class I and II restorations ***(Kerr, 2009).***

1.7. Polymerization Shrinkage of Resin Composite

Full polymerization of the material is determined by the degree of conversion of monomers into polymers, indicating the number of methacrylate groups that have reacted with each other during the conversion process. Shrinkage depends solely on the organic matrix and, within this, on the number of reactions that take place. It rises with the degree of conversion and falls with increasing monomer molecular weight.

Polymerization of dimethacrylate-based composites is always accompanied by substantial volumetric shrinkage in the range of 2 to 6% ***(Bowen, 1967; Walls et al., 1988; Labella et al., 1999).*** During polymerization the conversion of monomer molecules into a polymer network results in a closer packing of the molecules leading to bulk contraction ***(Loshaek and Fox, 1953; Patel et al., 1987; Venhoven et al., 1993).***

The factors that influence on the degree of conversion of the composite are shown in (Table 1-4) ***(Albers, 2002)***.

Table (3) Factors that influence on the composite resin polymerization *(Albers, 2002).*

Factor	Clinical Repercussions
Curing time	It depends on: resin shade, light intensity, box deep,
Shade of resin	Darker composite shades cure more slowly and less deeply than lighter shades (60 seconds at a maximum
Temperature	Composite at room temperature cure more
Thickness of resin	Optimum thickness is 1-2 mm.
Type of filler	Microfine composites are more difficult to cure than
Distance between light and resin	Optimum distance < 1 mm, with the light positioned 90 degrees from the composite surface.
Light source quality	Wavelength between 400 to 500 nm. A power density about 600 mW/cm^2 is required to ensure that

1.8. Shrinkage Stress of Resin Composite

Clinically composite strain is hindered by the confinement of the material bonded to the tooth; as a result, shrinkage manifests itself as stress. It is widely accepted this condition often results in heavily prestressed restorations which may have adverse clinical consequences such as the following ***(Versluis et al., 1996):***

(1) Polymerization contraction stress is transferred to the tooth and caused deformation. This tooth deformation may result in enamel

fracture, cracked cusps, and cuspal movement (Jensen and Chan, 1985; Suliman et al., 1994; Meredith and Setchell, 1997).

(2) Polymerization shrinkage stress has the potential to initiate failure of the composite tooth interface (adhesive failure) if the forces of polymerization contraction exceed dentin bond strength ***(Davidson et al., 1984),*** Such gaps between the resin and cavity walls may cause postoperative sensitivity ***(Pashley, 1990),*** micro-leakage, and secondary caries ***(Jensen and Chan, 1985).***

(3) Stress has the potential to initiate microcracking of the restorative material ***(Lai and Johnson, 1993).*** If the bonding to the cavity walls was strong enough to avoid gap formation during hardening, the stress concentrated inside the composite material would produce micro-cracks before complete setting ***(Davidson et al., 1991).*** However, this never occurs since the compliance of the surrounding structures sufficiently reduces the setting stress to a level below the cohesive or adhesive strength. The remaining stress (residual stress) is maintained by the total elastic deformation of all materials involved in the tooth's restoration. As a result of this phenomenon, a restored tooth remains under stress even when there is no functional loading on it. This, therefore, implies a greater risk of failure during the tooth's function ***(Davidson and Feilzer, 1997; Versluis et al., 2003).***

(4) The shrinkage stress depends on the size of the restoration and, therefore, on the thickness of the cavity wall. The tooth resistance to polymerization shrinkage diminishes with loss of hard dental tissue. Larger restorations result in lower stress levels in the restoration and tooth restoration interface but increase stress in the tooth ***(Versluis et al.,***2003).

1.9. Factors Responsible for Polymerization Shrinkage Stress

1.9.1 Filler Content

Composite resins consist of polymer matrix and filler material. Shrinkage is a direct function of the volume fraction of polymer matrix in the composite. The more monomer entities unite into polymer chains and form networks, the higher the composite contraction. On the other hand, the space occupied by filler particles does not participate in the curing contraction. Therefore, the presence of high filler levels is fundamental to reduce shrinkage of the composite during polymerization ***(Munksgaard et al., 1987).*** Filler content directly influences the mechanical properties and wear resistance of a composite resin ***(Chung and Greener, 1990; Condon and Ferracane, 1997).*** Because of its effect on elastic modulus and volumetric shrinkage the amount of filler contained in a resin based composite is a major factor in terms of polymerization contraction stress development ***(Condon and Ferracane, 2000).***

(Condon and Ferracane, 1998) Suggested that addition of nonbonded40nm colloidal silica might act as stress-relieving sites through plastic deformation. They also verified that composites with nanofiller particles treated with a nonfunctional silane developed 50% less stress than composites fully treated with the functional coupling agent.

(Bogra et al., 2012) compare microleakage in Class II cavities restored with a nano-ceramic restorative (Ceram X) and Filtek™ silorane composite. They shows Filtek™ silorane exhibit much less microleakage as compared with the nanohybrid composites.

1.9.2 Degree of Conversion (DC)

There is a direct relationship between degree of conversion and shrinkage ***(Venhoven et al., 1993; Silikas et al., 2000).*** For a given composite, a reduction in the final degree of conversion will lead to lower shrinkage and lower contraction stress. However, a low degree of conversion might compromise some of the material's mechanical properties ***(Ferracane and Greener, 1986).*** In contrast, small increases in the degree of conversion will produce substantial increases in stress but will improve the mechanical properties of the material ***(Braga and Ferracane, 2002).***

2 Elastic Modulus

In vitro studies have shown the interfacial stress during the setting shrinkage of a resin composite is positively correlated with the stiffness rate of the setting material known as elastic modulus or Young's modulus ***(Feilzer et al., 1990).*** Therefore, at a given shrinkage value, the most rigid material (the material showing the highest elastic modulus) will cause the highest stress. Obviously, the elastic modulus also increases as the polymerization reaction proceeds ***(Braem et al., 1987).*** The higher the elastic modulus and polymerization shrinkage of the composite, the higher the contraction stress. Stress is determined by the volumetric shrinkage multiplied by the elastic modulus (Hooke's Law) ***(Giachetti et al., 2006).***

3 Water Sorption

The phenomenon of water sorption of resin composites and their resulting hygroscopic expansion ***(Smith and Schoonover, 1953; Bowen et al., 1982; Feilzer et al., 1988).*** Although hygroscopic expansion may lead to a substantial relaxation of polymerization contraction stress, bonded surfaces are kept from direct contact with water and are restricted in their expansion. As a result, hygroscopic expansion will contribute to the relaxation of shear stress parallel to the adhesive interface. In contrast to the rather rapid polymerization contraction, stress development hygroscopic relief proceeds slowly and might require days. Neither the original contraction stress nor the hygroscopic expansion will be uniform throughout the restoration ***(Giachetti et al., 2006)***.The particular configuration of the restoration will influence the rate and degree of water sorption ***(Feilzer et al., 1990)*** thus, generating a gradient from the outer surface to the bulk of the restoration adding new stress ***(Davidson and Feilzer, 1997)***.Despite reducing polymerization shrinkage stress, water sorption causes a series of negative consequences on the composite such as deterioration of mechanical properties and alteration of color stability ***(Giachetti et al., 2006).***

4 Configuration Factor (C-factor)

There is a relationship between cavity configuration and stress development, relationship between bonded to unbounded surfaces by following manner ***(Feilzer et al., 1987; Braga et al., 2005):***

Bonded surface

C — factor =

Unbonded surface

Flat surfaces and shallow cavities represent the most favorable conditions for the formation of a durable composite-dentin bond ***(Hansen, 1984).*** In these cavities polymerization contraction is restricted to one direction, thus, allowing the composite to flow freely in the early rigid stage ***(Davidson and De Gee, 1984)*** (Figure 1-12, A). This condition prevents the contraction forces from producing stress and helps to create a strong bond to the cavity walls. When the contraction is hindered in three dimensions, the stress will be less compensated for by flow ***(Davidson et al., 1984)*** (Figure 1-12, B).

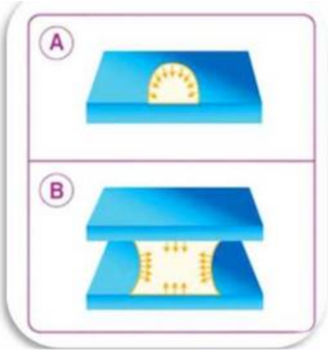


Figure (1-3) A. schematic representation of resin composite shrinkage on flat surface. B. Schematic representation of resin composite shrinkage vectors between two opposite walls.***(Feilzer et al., 1987)***

Developed the C-factor concept, which is the relationship between the ratio of the free and restrained composite surface area of a dental restoration. Based on this overview they performed polymerization stress development experiments on cylindrically shaped specimens, and the results were inclusive of restorations with similar C- ratios (Figure 1-13).

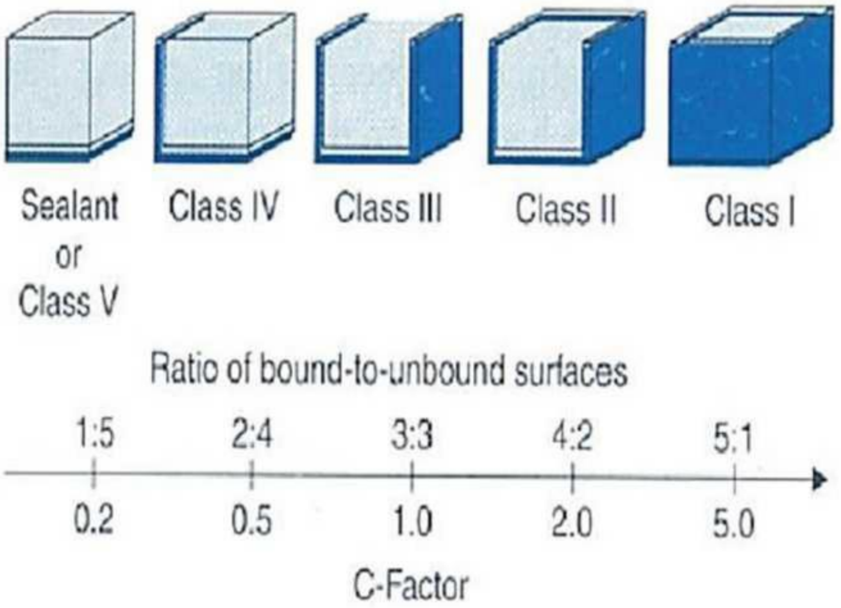


Figure (1-4) C-factor for class I, II, III, IV and V cavities.

Box-like class I cavities have five bonded walls and only one un bonded surface (i.e., surface of composite). The C-factor is 5/1 = 5 if all of the walls have the same surface area. Class V wedge-shaped lesions have lower C-factors, usually between 1.5 and 3, depending on the design. Most clinical restorations have C-values of approximately 1 to 2. Class II and class III restorations may account for these ratios. Values of C<1 refer to class IV restorations and composite layers applied to flat or shallowly curved surfaces. An increased C-value leads to a decreased flow capacity, which causes a higher rate of shrinkage stress development. ***(Feilzer et al., 1987).***

If two class I cavities have the same volume but a different design, the deeper and narrower cavity will have a higher C-factor than the shallower and larger one ***(Giachetti et al., 2006).***

1.10. Strategies to Reduce Shrinkage Stress in Clinical Procedures

1.10.1 Incremental Layering Technique

Since difficulties imposed by the cavity configuration (C-factor) play an important role in stress development, many researchers have suggested the use of “incremental layering techniques” for resin- composite restoration to reduce the polymerization shrinkage stress and cusp deflection ***(Lutz et al., 1986; Suliman et al., 1993; Davidson and Feilzer, 1997; Lee et al., 2007; Park et al., 2008).***

The rationale is that shrinkage may be less detrimental when there are fewer bonded cavity walls involved at each stage of the restoration procedures. Incremental curing also enhances the degree of cure as thin sections undergo higher degree of cure due to lower light attenuation, thus the net degree of conversion is greater. This yields better mechanical properties but higher shrinkage as well; however, the C-factor changes as well. In class I cavity, for example, by using a single increment, the resin composite would polymerize within five bonding surfaces (one base and four surrounding walls) while free shrinkage would only occur at the upper surface, producing a very high level of stress between the bonded surfaces. However, by using an incremental technique, the bonded/unbonded ratio would be reduced and, consequently, the stress level within the cavity might be lower, preserving the bonded area. ***(Schneider et al., 2010).(Versluis et al., 1996)***

Assessed the developing stress fields for different incremental filling techniques by using a theoretical study with Finite Element Analysis (FEA) methods. It was concluded that the incremental filling technique increased the deformation of the restored tooth and could produce higher polymerization stresses at the restoration interface compared with bulk filling. Multiple increments showed to induce greater cuspal movement than a bulk increment in cuspal deflection measurements of premolars ***(Abbas et al., 2003).***

(Loguercio et al., 2004a) evaluated the effects of polymerization shrinkage such as gap width, adhesive bond, strength and the cohesive strength of the resin composite were not reduced by the filling technique under the different C-factor cavities.

(Mereuta et al., 2012) assessed the clinical performance of class II composite resins restorations performed using different restorative techniques (oblique, centripetal and horizontal). They shows that the oblique technique is better than centripetal and horizontal, without significant difference with centripetal technique and significant difference with horizontal technique.

Despite the controversy over the advantages of incremental buildup of resin composites, this technique has been broadly recommended in direct resin-composite restoration, because it is expected to decrease the C-factor, allowing a certain amount of flow to partially dissipate the shrinkage stress ***(Schneider et al., 2010).***

1.10.2 Stress Absorbing Layers with Low Elastic Modulus Liners

Flowable composites are low viscosity resin-based restorative materials, which differ from conventional resin composites in their filler load and resin content ***(Antoniades et al., 2006; Baroudi et al., 2007).*** These materials are less rigid and could have a modulus of elasticity (20 - 30%) lower than conventional hybrid composites ***(Laughlin et al., 2002).***

The use of a flowable resin composite as an intermediate thin layer has been suggested as a mean of overcoming polymerization shrinkage stress based on the concept of an “elastic cavity wall” suggested for filled adhesives ***(Kemp and Davidson, 1990; Van Meerbeek et al., 1993; Choi et al., 2000; Braga et al., 2003).***

According to the “elastic cavity wall concept”, the shrinkage stress generated by a subsequent layer of higher modulus resin composite can be absorbed by an elastic intermediary layer, thereby reducing the stress at the tooth-restoration interface ***(Unterbrink and Liebenberg, 1999).***

However, restorative materials encompass a wide variety of shrinkage and elastic modulus values. Consequently, some combinations might give reduced performance compared with the common restorative material applied alone. Flowable resin composites have shown shrinkage stress comparable to conventional resin composites, supporting the hypothesis that the use of flowable materials does not lead to marked stress reduction and the risk of debonding at the adhesive interface as a result of polymerization contraction is similar for both type of materials ***(Cadenaro et al., 2009).***

(Matthias et al., 2011) evaluated marginal integrity of Class II cavity restored with posterior resin composite fillings at enamel and dentine with and without (4 mm) SDR bulk fill flowable composite, before and after thermo-mechanical loading. They shows that none of the SDR groups caused less gap-free margins compared to incrementally layered resin composites.

2 Light Curing Procedures

One mechanism to reduce shrinkage stress is to delay the gel point. From the chemically point of view, the gel point represents the increase of viscosity by network formation. In the pre-gel phase, the formed polymer chains are very flexible so that material can flow from the free surface of the cavity. The viscosity of the developing polymer is still low; consequently shrinkage stress can be compensated by plastic flow occurring during the pre-gelation phase such that internal stresses within the material undergo stress relaxation ***(Davidson and De Gee, 1984).***

Therefore, initial light exposure at lower irradiance values might lead to the formation of a reduced number of polymer growth centers, reducing the reaction rate and decreasing stress development due to the increased opportunity for resin flow before the vitrification stage ***(Uno and Asmussen, 1991; Charton et al., 2007).***

There are many types of alternative light-curing methods. The "soft-start" protocol consists of initial light exposure with reduced irradiance for a certain period of time, followed by full irradiance. Another protocol is "pulse-delay" method, where the clinician may apply the initial exposure with reduced light irradiance for a very short period of time of a few seconds and follows a waiting period without irradiance (seconds or even minutes) and fully irradiate later.

One important consideration is that some different outcomes may appear among different studies, and these differences may be related with the light curing type used, the irradiance used at the beginning of the light curing procedure, and/or the period without irradiance ***(Schneider et al., 2010).***
Although the alternative light-curing protocols may not significantly affect final properties of the hardened material, some considerations should be noted:

(1) The flowability of a material, during an extended preset stage, may have minimal consequences, because most shrinkage stress is developed during and after the vitrification stage ***(Charton et al., 2007).*** Therefore, opportunities for polymer relaxation would be restricted during the short period of light activation ***(Lu et al., 2004).***

(2) Concurrent experiments on degree of C=C conversion (DC) and stress development show that soft-start irradiation procedures give somewhat lower DC levels, associated with reduced stress ***(Lu et al., 2005).***

(3) A reduced polymerization rate is associated with decreased cross-link density (CLD), manifest as greater solvent-softening and/or lower final elastic modulus ***(Feng and Suh, 2006).***

3 Preheating

Recently, preheating resin composites have been advocated as a method to increase composite flow, improve marginal adaptation and monomer conversion. The benefits of preheating composites may have an impact on daily restorative procedures as well, with the application of shorter light exposure to provide conversion values similar to those seen in unheated conditions ***(Daronch et al., 2005).***

The reasons for increased conversion are based on many factors. Increased temperature decreases system viscosity and enhances radical mobility, resulting in additional polymerization and higher conversion. Therefore, at raised temperatures, in theory, it would be possible to obtain higher degree of conversion before the vitrification point, decreasing the magnitude of stress ***(Bausch et al., 1981).***

Composite pre-heating (60 C) under an isothermal condition is capable of increasing monomer conversion, as molecular mobility is enhanced and collision frequency of reactive species is increased ***(Lovell et al., 1999; Lovell et al., 2001; Daronch et al., 2005; Daronch et al.,***2005).

Composites with increased conversion are expected to be highly cross-linked and to have better mechanical properties ***(Asmussen and Peutzfeldt, 2001).*** As a consequence of this enhanced cross-linking; the free volume within the polymer network is reduced ***(Ferracane, 2006).***

The resin composites exhibit a (6 to 8) times greater thermal expansion than the surrounding tooth structures , polymerization shrinkage along with thermal contraction might create high interfacial stresses in pre-heated composites upon thermal equilibrium, with detrimental effects on marginal adaptation, integrity and seal ***(Sidhu et al., 2004; Watts et al., 2008).***

After 24 hour, the pre-heated groups showed better marginal adaptation than the room-temperature composites. This could be attribute to the reduction in the composite viscosity and better adaptation to the cavity, especially in angled areas. This is an important clinical finding, as perfect sealing is essential to improve restoration longevity and to prevent postoperative sensitivity ***(Wilson et al., 2000; Forss and Widstrom,***2004).

1.11 Composite Placement Techniques

1.11.1 Gingivo-Occlusal Layering (Horizontal)

The thickness of each increment of resin composite is not more than 2 mm. Each increment should be fully polymerized before the next one is inserted into the cavity ***(Lindberg, 2005)*** (Figure 1-14).

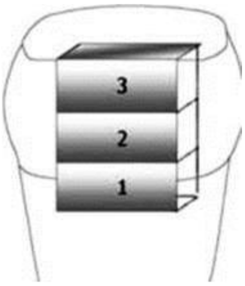


Figure (1-5) Horizontal placement technique *(Reis et al., 2003)*.

1.11.2 Wedge-Shape Layering (Oblique)

In this technique wedge-shaped composite increments are placed and polymerized only from the occlusal surface ***(Weaver et al., 1988).*** The first oblique increment was applied with a composite instrument to contact the gingival, axial, and buccal walls. After the first increment was cured, the second oblique increment was inserted to contact the occlusal, axial, and lingual walls. The increments was applied to cover the other increments, until sealing the cavosurface margin ***(Bagis et al., 2009)*** (Figure 1-15).

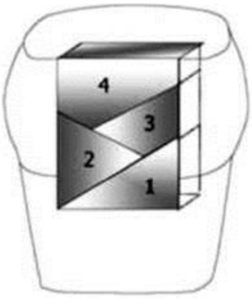


Figure (1-6) Oblique placement technique *(Reis et al., 2003)*.

2 Bulk Technique

It is recommended by some authors to reduce stress at the cavosurface margins ***(Lutz et al., 1991; Versluis et al., 1996).*** The preparations were restored using resin composite bulk placement (single increment) and light cured ***(Duarte et al., 2007)*** (Figure 1-16).

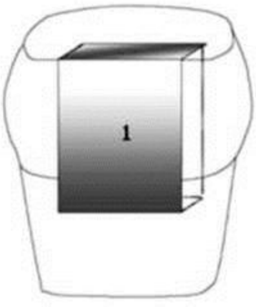
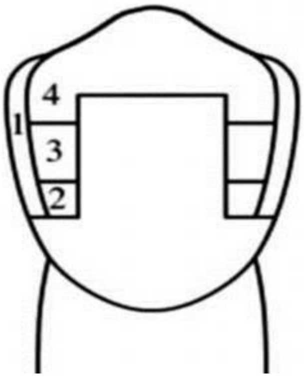


Figure (1-7) Bulk placement technique *(Reis etal., 2003)*.

3 Centripetal Build-up Technique

This technique was especially developed for class II cavity restorations. An initial vertical composite increment is applied on the cervical margin against the metal matrix. Cavity filling is then completed by horizontally layering the composite. This technique allows transformation of class II cavities into class I cavities ***(Bichacho, 1994)*** (Figure 1-7).



1.11.3 Three-Site Technique

This is a layering technique associated with the use of a clear matrix and reflective wedges. First, the curing light is indirected through the matrix and wedges in the attempt to guide the polymerization vectors toward the gingival margin, thus, preventing any gap formation, then wedge-shaped composite increments are placed to further prevent distortion of cavity walls and reduce the C-factor. This technique is associated with polymerization first through the cavity walls and then from the occlusal surface in order to direct the vectors of polymerization toward the adhesive surface (indirect polymerization technique) ***(Giachetti et al., 2006)*** (Figure 1-8).

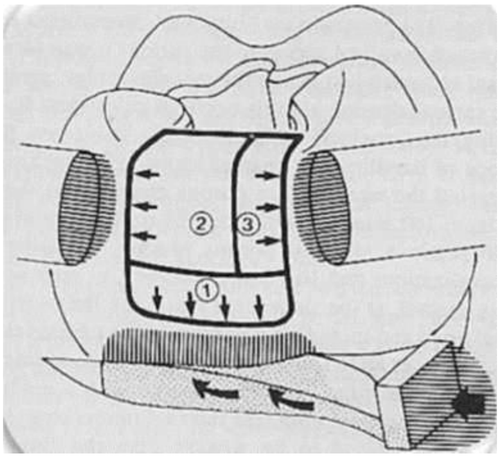


Figure (1-8) Three-Site Technique: the first increment is cured through the light- reflecting wedge; the large second and the smaller third from the buccal and lingual directions in order to ensure that the shrinkage vectors run towards the cavity margins. A fourth increment is added to the occlusal surface *(Giachetti et al., 2006).*

1.11.4 Successive Cusp Build-up Technique

In this technique the first composite increment is applied to a single dentin surface without contacting the opposing cavity walls, and the restoration is built up by placing a series of wedge-shaped composite increments to minimize the C-factor. Each cusp is then built up separately ***(Giachetti et al., 2006)*** (Figure 1-9).

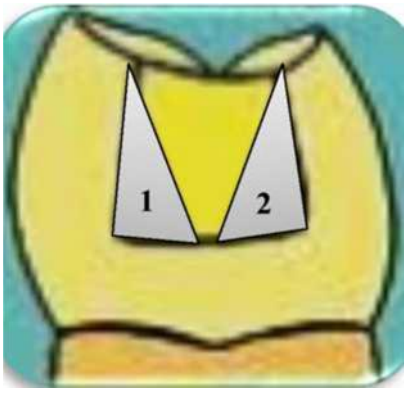


Figure (1-9) Successive Cusp Build-up technique *(Giachettietal., 2006)*.

1.11.5 Pin Hole Technique

This technique is achieved by a two-step type incremental technique. In the first step, the resin is placed in the cylindrical cavity with a metal pin embedded in the middle of the composite restoration (Figure 1-20). After polymerization, the metal pin is removed and the cylindrical hole is filled with the second layer of composite. Finally, the second layer in the center of the composite restoration is polymerized. This study confirmed that the proposed incremental type placement technique reduces marginal deboning (Petrovic et al., 2010).

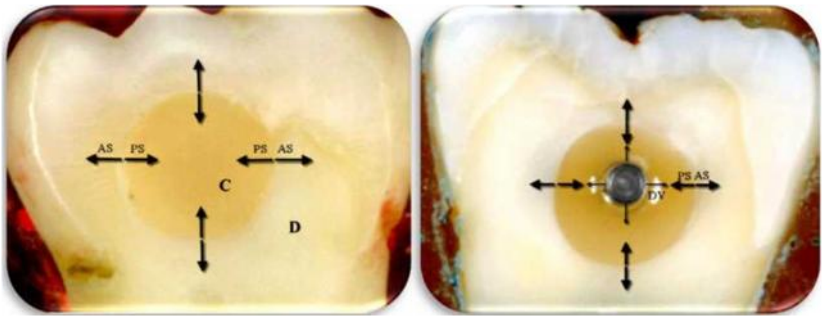


Figure (1-10) Pin Hole Technique: (A) Composite restoration without the pin.

AS-Adhesive Stresses, PS-Polymerization Stresses, C-Composite, D-Dentin. (B) Composite restoration with metal pin. DV-Displacement Vector (Petrovic et al., 2010).

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