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Dental Composite Resin: A Review

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Abstract. Composite resin is one of dental material restoration that used in every dental office nowadays. Dental amalgam restoration had several problems in aesthetic and biocompatibility in oral cavity. To overcome the problem, dental composite resin which has great aesthetic, biocompatibility, physical, and mechanical properties has been developed. Composite resins are filled resin and have high compressive strength, abrasion resistance, ease of application, and high translucency. The objective of this review article is to review about dental composite resin including the composition, polymerization process, classification, and physical properties (water sorption, solubility, and polymerization shrinkage) of dental composite resin. Literature relating to dental composite resin and measurement of several physical properties, research methodologies, and contributing factors are selected and reviewed.

Keywords: classification composite resin, composite resin, dental material, restoration

INTRODUCTION

Dental amalgam restoration which contains mercury has been replaced by composite resin as the first choice for restorative material [1]. Beside the aesthetic appeal of composite resin, it is also caused on the toxicity controversy of dental amalgam [1]. Nowadays, the development of filler, bonding, and technology in aesthetic restoration material is growing rapidly [2]. Composite resins have an initial form of viscous liquid that will harden due to polymerization reactions. The polymerization reaction occurs when external energy activates the initiator to produce free radicals so they can form a polymer. Composite resin is the mixture of reinforcing phase and matrix phase. Reinforcing phase or filler is in fiber, sheet, or particle form. The reinforcing phase is embedded in another material called matrix phase. The reinforcing phase and matrix phase could be metal, ceramic, or polymer [1, 2]. Beside the material, the composition of composite resin consists of coupling agent and photo initiator [2, 3].

In late 1940 and in early 1950, Polymethyl methacrylate (PMMA) resin was introduced. But, the composite resin was shrunk severely during the polymerization. Polymerization shrinkage can lead marginal leakage, poor wear resistance, high coefficient of thermal expansion, and high water sorption [4]. To overcome these problem, quartz was added to PPMA resin as filler. The purpose of additional inert filler particle is to form composite structure. Currently, the development of composite resins is focusing on their composition to increase physical and mechanical properties. There are several measurement to measure physical and mechanical properties. The purpose of this study was to discuss about dental composite resin including the composition, polymerization, classification, and several measurement of physical properties (water sorption, solubility, and polymerization shrinkage) dental composite resin.

COMPOSITION

Resin matrix

The most commonly used monomeric matrices in composite resin distribution today are 2,2-bis[4(2-hydroxy-3-methacryloxy-propyloxy)-phenyl] propane (Bis-GMA) and urethane dimethacrylate (UDMA) [2,3]. Both monomers

have reactive carbon double bond at each end of monomer chain which will increase during polymerization [3]. Monomer has high viscosity, especially Bis-GMA, so diluter should be added to get clinical consistency after the filler is added [3]. Compound which has low molecular weight with difunctional carbon double bond is used to reduce and control the viscosity of composite resin mix, e.g. triethylene glycol dimethacrylate (TEGDMA), or Bis-EMA6 [5-6].

In 2018, a new type of methacrylate monomer to control the volumetric shrinkage and polymerization stress of a composite resin was introduced. Increasing the distance between methacrylate groups was conducted to reduce the density of cross bond. Another approach was increasing monomer rigidity [3]. Some examples of low shrink methacrylate monomer are dimer acid, DuPont monomer, and FIT-852 [7].

A new monomer system called silorane has been developed to reduce the shrinkage and internal stress produce by polymerization. The name silorane is from siloxane and oxirane (also known as epoxy). The function of siloxane and oxirane is giving hydrophobic property to composite resin and opening ring cross bond through cationic polymerization, respectively. The particular initiator system is needed for silorane polymerization [3].

Filler

Various transparent mineral fillers are used to reinforce composite resin and reduce the shrinkage in the curing process and thermal expansion (generally, filler composition is between 30% to 70% of the volume or 50% to 85% of the composite weight). It includes "soft glass" and "hard glass" of borosilicate, fused quartz, aluminum silicate, lithium aluminum silicate (beta-eucryptite, which has negative thermal expansion coefficient), ytterbium fluoride, and barium (Ba), strontium (Sr), zirconium (Zr), and zinc glasses [2, 6].

Quartz has the advantage of being chemically inert but also very hard, making it abrasive to tooth or opposite restoration, as well as difficult to grind or destroy into very fine particles. Therefore, composite resin is difficult to polish [2]. Amorphous silica have the same composition and refractive index as quartz. Amorphous silica is not crystalline and hard as quartz, so it can reduce the abrasiveness of composite surface structure and increase the ability to polish the composite resin [2].

Coupling Agent

Coupling agent is used to combine reinforcing phase and matrix phase. The most commonly used coupling agent is a silicon organic compound called silane coupling agent, 3-metakrilloxipropiltrimetoksisilan (MPTS) [3]. Composite with *low* shrink silorane monomer epoxy, 3-glycidoxypopyltrimethoxysilane, is used to bind filler to oxirane matrix.

Photo initiator

The polymerization process of composite resin starts with releasing free radicals from methacrylate monomer structure which requires an external energy in the form of heat, chemical, or radiant energy [9, 10]. Chemical activation resin consists of two pastes. One paste consists of benzoyl peroxide initiating material, and the other paste consists of tertiary amine activator [2]. Currently, the dental photoactivator commonly used is camphorquinon, which has canary yellow color which results in yellowish composite restoration. Light absorption which appears in camphorquinone is in the range of 425 – 495 nm. In the 1990s, the usage of tooth bleaching material increased, leading to the development of Lucirin® TPO as photoactivator. Light absorption which appears in Lucirin® TPO is in the range of 390 – 410 nm [10].

POLYMERIZATION PROCESS OF COMPOSITE RESIN

In dentistry, nearly all types of composite resin use monomer types in the same group and the same polymerization process. The polymerization process is vinyl-free-radical polymerization. The polymerization process of composite resin starts with releasing free radical from methacrylate monomer structure an external energy in the form of heat, chemical, or radiant energy. When free radical is formed, the monomer looks for the electron-rich monomer to form covalent bond. The combination of those monomers forms a new polymer [9-11]. Based on the activation energy, composite resin is classified into two type, i.e. chemically activated and light activated composite resins [2, 3, 9-11].

Chemically activated composite resin (chemical polymerization)

Chemically activated composite resin consists of two tubes contain different paste each. Polymerization occurs when both pastes are mixed. The chemically activated composite resin reaction was shown in Figure 1. The tubes contain benzoyl peroxide initiator and aromatic tertiary amine activator (N, N-dimethyl-p-toluidine). When both pastes are mixed, benzoyl peroxide initiator and aromatic tertiary amine activator will produce a free radical and the polymerization starts [2, 12-13].

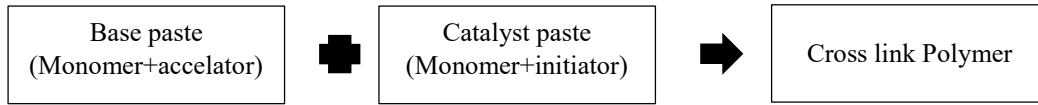


FIGURE 1. Chemically activated composite resin (chemical polymerization)

Light activated composite resin (photopolymerization)

Light activated composite resin consists of one type of paste in a syringe. The composition and the reaction of the light activated composite resin was shown in Figure 2. The paste consists of photosensitizer and amine initiator. When the composite resin paste is illuminated with the wavelength 468 – 470 nm, the resin will formed free radical. The photosensitizer commonly used is camphoroquinone which can absorb light with the wavelength of 400 – 500 nm and composition in the resin is $\leq 0.2\%$ of the weight of composite resin paste. The amine initiator type used together with camphoroquinone is dimethylaminoethyl methacrylate (DMAEMA). The composition in the resin is $\leq 0.15\%$ of the weight of composite resin paste. When the composite resin is illuminated with camphoroquinone, it will excite and interact with DMAEMA to produce free radical [2,10].

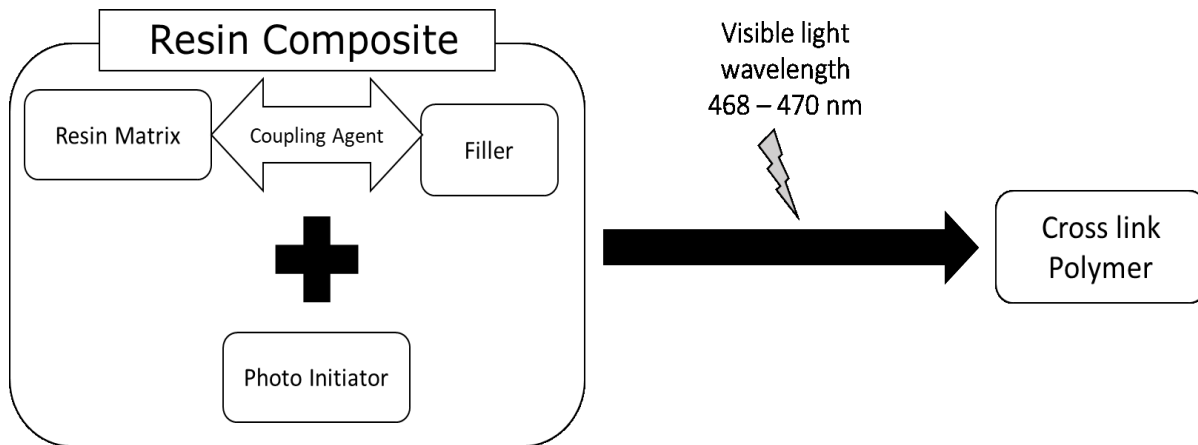


FIGURE 2. Light activated composite resin (photopolymerization)

CLASSIFICATION OF COMPOSITE RESIN

Macrofilled

Macrofilled composite resin or traditional composite resin contains quartz filler and strontium or barium glass. The filler particles are 10 – 100 μm . The filler of macrofilled composite resin has relatively large size and hard, thus difficult to polish and may cause antagonist tooth to be eroded during contact [2, 14].

Microfilled

In the late 1970, microfilled composite resin was developed. This resin has particle between 0.04 – 0.2 μm with filler loading of 30% wt. To increase filler loading up to 30 – 50 % wt., pre-polymerization resin was grinded with colloidal silica particles and also combined with resin matrix and micro-sized filler particle [4, 13, 14].

Microfilled composite resin has advantage of having high polishability compared with other composite resins [2, 14]. Increasing filler loading in microfilled composite resin reduces polymerization effect. This composite resin has disadvantages of not being able to be used as stress-bearing surfaces restoration material due to the weak bond between composite particle and matrix [2, 4].

Hybrid

Hybrid composite resin is a combination of macrofilled and microfilled. When it was first introduced, it had particle size of 15 – 20 μm and colloidal silica particle size of 0.01 – 0.05 μm [12, 13]. The combination of two filler types aims to combine the physical properties of macrofilled composite resin with the smooth polishing surface of microfilled composite resin [14]. Hybrid composite resin has good wear resistance and mechanical properties so it could be used for dental restoration which requires high stress – bearing ability [3].

Nanofilled

Nowadays, advances in nanotechnology produces composite resin which has nanoparticle of 25 nm and agglomerate nanoparticle 75 nm. Zirconium/silica and nanosilica particle is used as filler in nanofilled. Agglomerate particle is silanized so it can bond with resin. Combining nanoparticle with agglomerate nanoparticle increases the filler loading of composite resin up to 79.5%. The increasing filler loading occurs because of lower dimension and area distribution of filler particle. Increasing filler loading leads to reduced polymerization shrinkage and increased the mechanical properties of composite resin [16, 17].

Short Fiber Reinforced Composite

Short fiber reinforced composite resin is used as one of dental restoration materials. Adding 5% - 7.5% of short fiber filler into filler particle composite resin with filler loading of 60% wt. reduces polymerization shrinkage by 70% [18]. This filler increases the physical properties of composite resin, e.g. flexural strength, modulus, and work of fracture. Moreover, filler short fiber also increases stress bearing in application of posterior dental restoration [19 – 22]. The most commonly used short fiber reinforced type is glass fiber. Various types of polymeric fiber are also developed as composite resin filler, including poly (vinyl acetate) fibers, polyethylene and aramid fibers, and nylon 6 fibers [23].

PHYSICAL PROPERTIES AND MEASUREMENT

Polymerization Shrinkage

Composite resin polymerization can change from viscous liquid to viscoelastic solid [20]. These changes occur when composite resin monomers react to external energy to form polymers. During the process, the density increase due to decreasing the total volume of the composite resin. Factors causing polymerization shrinkage include the variation, the quantity, the degree of conversion, and the molecular weight of the monomers. In addition, variation, geometry, and amount of filler can affect polymerization shrinkage [29]. Several measurements of polymerization shrinkage have been developed in recent years, including digital image correlation (DIC) [30 – 32], finite element method (FEA) [20, 31, 32], and fiber optic method [33].

Polymerization shrinkage analysis uses the DIC method to measure composite in “free form” (the composite neither in mold nor cavity) and in the cavity of the tooth. Combining the results of DIC with numerical analysis can assess the influenced variables and study the function of these variables in kinetic shrinkage [30 – 32]. FEA can provide a description of shrinkage pattern when the composite resin is polymerized. FEA has the advantage providing detailed description of the intensity and distribution of internal stress [20, 31, 32].

Fiber optic methods have the advantage over traditional electrical and mechanical sensors of being able to do broad types of measurements. Since the size of the fiber optic sensor is small, sensors can be implanted into dental composite without affecting the inherent material properties. One of fiber optic sensor type used is Bragg gratings fiber (FBGs). When sensor is implanted in the material, the sensor can measure the changes in strain and temperature which reflected by wavelength of grating light [33].

Water Absorption and Solubility

Water absorption is the amount of absorbed liquid through surface material. Water absorption cause matrix interface - filling degradation and decreasing the mechanical properties of the composite resin. Water absorption take longer time than polymerization shrinkage [3, 24].

Solubility occurs due to imperfect polymerization which can be caused by inadequate curing light intensity of the unit and the depth of a restoration. When resins are immersed in water, some monomers or fillers that un-polymerized will be dissolved and leached out from composite resin. This will reduce the initial dimensions of restoration, color instability, and biocompatibility of the material [3, 25].

Water absorption and solubility standard of composite resins are regulated by the ISO 4049 standard. Based on ISO 4049, the standard for water absorption and solubility of polymer materials has a value less than 40 mg mm⁻³ and 7.5 mg mm⁻³, respectively. The formula for measuring water absorption and solubility is in accordance with the equation (1) and (2) [26, 28].

$$W_{Sp} = \frac{m_2 - m_3}{V} \quad (1)$$

$$W_{Sl} = \frac{m_1 - m_3}{V} \quad (2)$$

CONCLUSION

Technological developments affect the development of dental restorative materials such as composite resins. Several types of composite resin restoration materials were developed from their compositions (resin matrix, filler, coupling agent, and photo initiator) to improve the characteristics of the previous composite resin types. Technological developments also create new measurement techniques for material so that precise measurements can be obtained. This helps to develop new material to improve the properties or characteristics of the material.

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