Review Article

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Types, characteristics and environmental degradation of composite materials

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ABSTRACT

Research has offered many advances in the dentistry field and variable types of dental composites have been widely validated to be effectively used with many favorable outcomes. Among the differently reported composites, hybrid ones are the most commonly reported and used in clinical settings. However, the characteristics of these composites vary hugely based on the materials and the environmental factors that they might be potentially exposed to. In this literature review study, we have discussed the types and characteristics of the dental composites, elaborating the effect of different environmental factors on the degradation of the different composite materials. Our results indicate that dental composites are hugely affected by environmental factors as temperature, moisture, chemical reactions and impact blunt. Furthermore, enhancing the quality of the materials by using more flexible approaches might enhance their quality in achieving better outcomes. Moreover, research should be directed within this area to improve the functions of the dental composites and improve the quality of life for the corresponding patients. Composites based on nanotechnology seem promising. However, these are not adequately investigated, and further research is encouraged for adequate validation.

Keywords: Dentistry, Composite, Restoration, Degradation, Function

INTRODUCTION

Many dental composites are nowadays widely available to be used for restoration approaches. Furthermore, in the 1940s, the primary objective for which composite resin was introduced in the field of dentistry. The objective was to reduce the disadvantages that were reported with acrylic resins that had also replaced silicate cement, which was the only used substance for aesthetic purposes.

Moreover, in 1950, an approach by Buonocore aimed to enhance the quality, effectiveness and adhesion of the acrylic resins by adding orthophosphoric acid to the compound. In the same context, and in 1962, bis-GMA monomers were first introduced by Bowen aiming at enhancing the physical characteristics of the dental acrylic resins, because these previous modalities were associated with the development of polymer chains only. However, these first initiatives were associated with

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many problems regarding color stability, mixing process, and proportions.² In 1970, further approaches were announced to overcome these disadvantages by introducing electromagnetic radiation polymerization.3 Following these approaches, research has offered many advances in this field and variable types of dental composites have been widely validated to be effectively used with many favorable outcomes. Among the differently reported composites, hybrid ones are the most commonly reported and used in clinical settings.^{4,5} However, the characteristics of these composites vary hugely based on the materials and the environmental factors that they might be potentially exposed to. In this literature review study, we will discuss the types and characteristics of dental composites, in addition to elaborating the effect of different environmental factors on the degradation of composites.

This literature review is based on an extensive literature search in Medline, Cochrane, and EMBASE databases which was performed on 5th August 2021 using the medical subject headings (MeSH) or a combination of all possible related terms. This was followed by the manual search for papers in Google Scholar while the reference lists of the initially included papers. Papers discussing the types and characteristics of dental composites were screened for relevant information, with no limitation placed on date, language, age of participants, or publication type.

DISCUSSION

Types and characteristics

The classification of dental composites is based on many factors based on their composition, which facilities the identification and use of these composites by dentists for therapeutic purposes and enhances the associated outcomes. ^{10,11} Classifications based on filler sizes are the most common among studies in the literature, and they have been extensively discussed by many studies. ^{4,5,12} The different types of dental composites are presented in Table 1.

The structure of the dental composites is an important factor to determine the mechanical, physical, and aesthetic characteristics of these composites. It is known that dental composites basically consist of three different chemical materials. These include the inorganic matrix, disperse, or filler phase, the organic matrix or phase, and the organosilane or coupling agent. Moreover, the latter is mainly consisted of a methacrylate group at one end and silane groups at the other end to act as a coupling agent that bonds the organic resin with the filler. The organic matrix is composed in a certain way that enables rapid curing and enhances the lifetime and stability of the dental composites making sure that adequate and favorable outcomes can be obtained. Materials that absorb ultraviolet rays are also involved in the structure of the dental composite which eradicates the harmful

effects of the ultraviolet rays and enhances the color stability of the modality. The effectiveness and optimal structures of the monomer systems are also very important in the assessment of the stability of dental composites. For instance, it is acceptable that the rate of shrinkage of the dental composites is inversely proportional to the mean molecular weight of the monomer. Dental resin composites, which are highly viscose. They are generally combined with low viscose monomers as urethane dimethacrylate (UDMA), and ethylene dimethacrylate (EGDMA). glycol Polymerization is an important process to consider because it is usually associated with a degree of shrinkage that might affect the characteristics of dental composites. Accordingly, approaches have been directed to choose monomers with more flexible shrinkage abilities to reduce the negative impact on the overall composite structures and functions. In another context, the mechanical and physical characteristics of the dental composite are mainly dependent on the inorganic filling material. These substances are usually added to the organic material to enhance its physical properties and obtain better outcomes. Some of the reported advantages for using these substances might include reducing the total curing shrinkage, decreasing the thermal expansion, improving handling and aesthetic outcomes, and providing favorable radio-opacity. However, it should be noted that the filling materials are hugely variable according to the morphology, chemical composition, and dimensions. Recent advances were mainly directed to use less hard materials that can induce less wear on the corresponding teeth and enhance the relevant outcomes. Nanotechnological advances were also introduced to this field with favorable outcomes, obtaining a high load, that was previously estimated to be up to 79.5%.

Table 1: Classification and types of composites.¹³

Composite type	Filler
Densified composites	
Midway-filled	<60% by volume
Ultrafine	-Particles<3 microgm
Fine	-Particles>3 microgm
Compact-filled>60% by volume	>60% by volume
Ultrafine	-Particles<3 microgm
Fine	-Particles>3 microgm
Microfine composites	
Homogeneous	Average particle size=0.04
Heterogeneous	microgm
Miscellaneous composites	Blends of densified and microfine composites
Traditional composites	Equivalent to what are termed macrofill composites in other classification
Fiber-reinforced composite	Industrial use composites

Environmental degradation

Many studies in the literature have evaluated the ability of different environmental factors as temperature, moisture, and chemical parameters on the mechanical properties of dental composites and the related outcomes. Furthermore, high-temperature levels can significantly impact the matrix of a dental composite. Besides, it has been noticed that high-temperature levels might also aid to the value of other degradation factors and further impacting of the dental composite. For instance, elevated temperature levels can facilitate chemical reactions by obtaining the optimal temperature levels needed for such reactions to occur. Moreover, previous studies have summarized and indicated the effect of temperature on the oxidation of hydrocarbons and the potential effect on the matrix of dental composites. 14,15 The formation of free radicals has been noticed with the different forms of energy production and heat transfer. This can result in impaired mechanical properties of the underlying composite as a result of the different reactions that occur with the free radicals and ambient oxygen particles. 16 Additionally, some studies have evaluated the impact of using aircirculating ovens to obtain thermal oxidation in the employment of isothermal heating. 17-21 By this method, authors have allowed the presence of atmospheric oxygen within the reaction and potentially preventing degradation as a result of the even distribution of heat and prevention of other parameters that might be responsible for a potential heat transfer. In addition, most of the included studies in the literature have reported a significant reduction in the mechanical properties of different composites as a result of the prolonged exposure to elevated temperature levels. Also, an investigation by Akay and Spratt reported that their used dental composite had a significant reduction in the mechanical properties as a result of thermal aging that induced cracks and mass loss to the composite bodies. 19 Dao et al also reported that different temperatures were associated with different surface chemistry parameters.²² The authors showed that thermal heating at 70°C for 7500 hours was associated with minimal changes to the surface chemistry of the dental composites. However, as the authors prolonged the exposure of the dental composites and elevated the temperature, they noticed that changes were deeper into the bulk, indicating the impact of prolonged exposure to excessive heating.

Studies have also evaluated the degradation effects of combined temperature and moisture on the characteristics of the dental composites. These studies have demonstrated that increased rates of degradation of dental composites were associated with increased moisture secondary to high-temperature levels.²³⁻²⁵ In this context, a previous investigation by Chateauminois et al evaluated the impact of submerging exposy-glass composites within the water at temperature levels of 30-90 °C.²⁶ The authors showed that the tested composites showed a significant reduction in mass over time and at the different temperatures that were approached by these authors.

Studies have demonstrated the effect of water on composite materials. Water can reach the composite through different approaches including precipitation, bulk liquid, and humidity or fog with many different outcomes among the included studies regarding the severity of impact based on the hygrothermal and hydrothermal affection. Additionally, it has been reported that the route of affection is a major contributor to the severity of the impact and the extent of degradation.²⁷ As a result of the potential chemical reactions that occur to the polymer matrix, reduced mechanical properties to the composite materials are expected secondary to moisture, which is an irreversible process.^{27,28} Chain scission might also occur secondary to moisture as what has been reported and observed with ultraviolet radiation and temperature exposure which can significantly induce chain shortening and reduced polymer molecular weight.²⁹ Hydrolysis and oxidation reactions are the main causes for these events according to previous studies.30,31

It is important to note that the severity of degradation in such events depends on whether water can coordinate and interact with the affinity and reaction sites of the polymer or not. This can be achieved and measured by how well moisture can diffuse within the composite materials.³² Accordingly, shrinkage of matrix material during curing should be observed by dentists to determine the effectiveness of the diffusion because in cases of reduced adhesion between the fibers and matrix, capillaries can effectively develop around these fibers.²⁸ The swelling coefficient that is due to moisture and to the mechanical properties. Also, it differs between the different composite materials. The material mismatch can lead to strain-induced expansion secondary to moisture, which is similar to the effect of temperature. Although it has been indicated that such events do not necessarily impact material stiffness, it has been indicated that they can lead to the development and propagation of cracks. 33,34 Accordingly, this might be associated with a significant reduction in strength and can lead to channel formation due to increased moisture ingress. In addition, in a previous investigation of vinyl ester carbon composite, Siriruck and Penumadu evaluated the fatigue ability of these compounds on exposure to seawater and reported that they noticed a 50% reduction in the fatigue cycles compared to 85% for single-side exposure and complete immersion, respectively. 35 Previous studies have also indicated the diffusion rates are higher within the sample's edge than the face. 36-38

Chemical degradation was also reported among studies in the literature. However, it should be noted that it is usually induced by the same mechanisms that were observed with water and moisture degradation. Temperature elevation might also lead to a significant impact on the severity of degradation and the mechanical properties of the exposed dental composites. However, it should also be noted that the mechanisms of the chemical reactions in inducing degradation are hugely variable because of the variously present chemical reactions. A

previous investigation by Yoshino et al reported that after immersion the lap joint and neat samples in hydraulic fluid, anti-acing additives, aviation, and water fluids for 10-555 days at different temperatures, the authors have indicated that immersing the samples in hydraulic fluid and anti-acing additives were significantly associated with more increased uptake of mass than what has been observed with water and aviation fuel at the different estimated temperatures.41 Besides, the authors also indicated that a 5-7% mass gain was associated with water immersion in the different temperature levels, and aviation fuel was the most significantly associated with a minimal mass reduction in the room temperature. Another investigation by Landry et al also evaluated the effect of immersing carbon-epoxy composites in hydraulic fluid, distilled water, and de-icing fluid for over one month.⁴² The authors reported that an increase in the rate of exposure delamination was observed to be 4% only with hydraulic fluid and up to 25% with water. The characteristics of aramid-epoxy composites were also investigated by d'Almeida after immersion in salt water. 43 Furthermore, the authors reported that saltwater absorption was more significant than distilled water, which indicated that interlaminar shear distress was notably more reduced with distilled than saltwater. Similar findings were also reported by previous investigations. 44-46 The impact of low-velocity blunt was also reported by studies in the literature. Back-face matrix cracking, delamination, and fiber failure were all observed events following the impact of these parameters. 47,48

CONCLUSION

Dental composites elaborates the effect of different environmental factors on the degradation of the different composite materials. Dental composites are hugely affected by environmental factors as temperature, moisture, chemical reactions and impact blunt. Furthermore, enhancing the quality of the materials by using more flexible approaches might enhance their quality in achieving better outcomes. Research should be directed within this area to improve the functions of the dental composites and improve the quality of life for the corresponding patients. Composites based nanotechnology seem promising. However, these are not adequately investigated and further research encouraged for adequate validation.

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