Original Article: Analyzing the Chemical and mechanical properties of advanced composites and their applications in the medical field

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ABSTRACT

This study investigates the chemical and mechanical properties of advanced composite materials and their potential applications in the medical field. By analyzing various composite formulations, we assess their tensile strength, elasticity, and biocompatibility, which are critical for medical applications such as implants, prosthetics, and drug delivery systems. The interplay between the chemical composition and mechanical performance is explored to determine optimal material combinations that meet the rigorous demands of biomedical applications. Our findings highlight the significant potential of advanced composites in enhancing patient outcomes through improved durability and functionality in medical devices. This research paves the way for future innovations in medical technology, emphasizing the importance of material science in healthcare advancements.

Introduction

Fiber-reinforced composite material (FRCM) consists of fibers in a matrix. If the fibers are oriented in a specific direction, the material is non-isotropic. A layered composite sheet consists of layers of FRCM, in which the fibers in each layer are oriented in a different direction from the fibers in the other layers [1].

Advanced layered composites can be designed to have high strength-to-weight and stiffness-to-weight ratios. The field of nanocomposite materials has attracted the attention of scientists and engineers in recent years. The results of the study of the use of building blocks at the nanoscale make it possible to design and create new materials with flexibility and significant improvements in their physical properties [2].

The possibility of upgrading composites by using building blocks with heterogeneous

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chemical species has been discussed in various scientific disciplines and departments. The simplest examples of such designs occur naturally in bone, where a nanocomposite is made of ceramic pellets and organic binders. Because the components of a nanocomposite have different structures and compositions and their respective properties, they offer many applications [3].

Hence, the materials produced from them can be multifunctional. Taking inspiration from nature and based on the needs of emerging technologies to produce new materials with different functions at the same time for various uses, scientists have used many combination strategies to produce nanocomposites. Advanced strategies have obvious advantages over the production of similar coarse-grained materials. The driving force in the production of nanocomposites is the fact that they offer new properties compared to conventional materials [4].

The decision to improve the properties and characteristics of materials by creating multiphase nanocomposites is not a new issue. This idea has been pursued since the beginning of civilization and humanity, with the production of materials for more efficient applications [5]. In addition to the wide variety of nanocomposites found in nature and in organisms such as bone, an excellent example of the application of composite nanocomposites in ancient times is the recent discovery of the structure of Mayan paintings that were created during the Mesa Merica period. State-of-the-art descriptions of advanced paintings reveal that the structure of the paints consists of a matrix of clay mixed with organic pigment molecules [6].

They also contain impurities of metal nanoparticles encased in an amorphous silicate layer with oxide nanoparticles on the layer. Advanced nanoparticles are formed by heat treatment and are made from impurities (Cr, Mn, Fe) that are present in the raw materials such as clay [7], but their size and composition affect the optical properties of the final paint. The combination of the clay present forms a superlattice that is associated with the metal and oxide nanoparticles supported on the amorphous layer, making this paint one of the first composite materials similar to modern functional nanocomposites [8].

Nanocomposites can be considered solid structures that have repeated dimensional properties with nanometer-sized differences between the different phases that make up the structure. Advanced materials consist of an inorganic solid containing an organic component or vice versa, or they can consist of two or more organic/inorganic phases in several combined forms, with the restriction that at least one of the phases or compounds is in the nanoscale [9].

Composite structure

Composites are composed of three main parts:

1- Fibers or filaments.

2- Filler or matrix.

3- Adhesive [10].

Usually the matrix has lower stiffness and strength than the fibers, but the mixing of fibers and matrix results in a product that has low density and at the same time has high compressive and tensile strength. Such as epoxy materials such as Narmco, which has density, compressive strength and tensile strength [11].

Fibers: The smaller the diameter of the fiber, the stronger the fiber will be than the matrix material. Materials used as reinforcing fibers have high tensile strength. Based on the diameter and characteristics of the fibers, they are divided into 3 categories: whiskers, filaments, and wires. Whiskers are very thin single crystals with an extremely high length-to-diameter ratio. They are the strongest materials known. Whisker materials include graphite, silicon carbide, silicon nitride, and aluminum oxide [12].

Matrix Phase: The matrix phase of filamentary composites can be metal, polymer, or ceramic. Metals or polymers are usually used as the matrix material because they have good flexibility. In ceramic matrix composites, a reinforcing component is used to improve fracture toughness. In selecting the matrix-filament combination, the most important factor is the bond strength [13].

Types of Composites

1- Types of composites based on the shape of the reinforcement, type of reinforcement: are divided into three categories:

A) Composite with random fibers: Technologically, the most important composites are those in which the dispersed phase is in the form of filaments. Reinforced filament composites have high strength or stiffness. The mechanical properties of advanced composites depend on the properties of the filament and the amount of force transmitted to the filament by the matrix phase [14]. Therefore, the critical length of the filament plays a role in the strength of the composite. Advanced materials have higher strength and stiffness than other forms of composites, which results from the reduction of crystal defects and the orientation of the crystals in the direction of their length. This is the simplest form of composite materials in which it is not possible to accurately determine the properties [15].

B) Layered composite: In advanced materials, which contain at least two different materials, the layers are placed on top of each other in such a way as to create the necessary strength in the desired direction. Such as materials made of two layers of metal with different coefficients of thermal expansion, coated metals, glass-plastic layers in which glass provides the necessary hardness for plastic and plastic provides the necessary flexibility for glass [16].

B1) Types of layered composites: Advanced types of composites are divided into three categories:

- ✓ **Single layer:** In advanced composites, fibers are located in one direction in a plate and can be reinforced in the other direction. Fibers are usually placed in the direction of load application due to their high hardness and modulus of elasticity, and the matrix provides appropriate load distribution [17].
- ✓ **Multilayer:** In advanced composites, forces applied to a plate can be applied in different directions and the layers are placed next to each other at different angles to achieve appropriate stiffness.
- ✓ **Hybrid plates:** In advanced composites, in addition to having layers with different directions, the material of the layers is also different. Here, the use of appropriate materials depends on the performance of different structures against mechanical forces and environmental factors [18].

C) Particulate composites: Advanced materials consist of a matrix and another material in which they are distributed in the form of small particles. The dispersed phase in particle-reinforced composites is coaxial and aligned, meaning that the particles are aligned in almost all directions [19].

C1) Types of particulate composites: Advanced types of composites are divided into two categories:

- ✓ Coarse particle composites.
- ✓ Composites reinforced by particle dispersion [20].

The difference between advanced two groups depends on the mechanism of strengthening or reinforcement. The word coarse is used to indicate that the interaction between the particle and the matrix cannot take place at the atomic or molecular scale and that the mechanics of continuous media are used [21]. In most of advanced types of composites, the dispersed phase is harder and stiffer than the matrix. Advanced reinforced particles restrain and stop the displacement and movement of the matrix phase in their vicinity. Basically, the matrix transfers some of the applied stress to the particles. The degree of reinforcement or improvement in mechanical behavior depends on the strength of the bond at the matrix-particle interface [22].

Types of composites are divided into three main categories based on the matrix phase:

A) Polymer matrix: Polymer matrix composites are composed of a large molecule reinforced plastic polymer resin as the matrix. The characteristics of this category of composites are diverse and extensive application, good properties at ambient temperature, ease of manufacture and low cost. Advanced types of composites are divided into glass, carbon and aramid based on the type of reinforcement [23]. Polymer fiber composites Glass fiber polymer composites include continuous or discontinuous glass fibers in the matrix. In the future, carbon will be used more as a reinforcing fiber in polymer composites instead of glass. Because carbon fibers have the highest specific strength and specific modulus among the reinforcing fibers. In polymer matrix composites, apart from the three types of reinforcing fibers glass, carbon, and aramid, boron, silicon carbide and aluminum oxide are sometimes used to a limited extent [24].

B) Metal matrix: In metal matrix composites, the matrix is: a flexible metal. The advantages of this type of composite over polymer matrix composites are higher operating temperatures, non-flammability and greater resistance to attack by organic fluids. However, their cost is higher and as a result their use is more limited. Super alloys, aluminum and magnesium alloys, titanium and copper are used as matrix materials [25]. Reinforcing materials may be in the form of particles, continuous and discontinuous filaments or whiskers, which constitute 10 to 60% of the volume of the composite [26]. Continuous filaments include carbon, silicon carbide, boron, alumina and refractory metals. Discontinuous filaments are formed from particles of advanced materials. On the one hand, cermets can be included in advanced (MMCs) [27].

C) Ceramic matrix: Ceramic matrix composites are the best choice for use at high temperatures and severe stresses due to their organic resistance to oxidation at high temperatures despite the possibility of brittle fracture. Especially in automotive engine parts and aircraft gas turbines [28]. The fracture toughness of advanced composites is common, while in most metals it is 15. The fracture toughness of the new and developed generation of ceramic matrix composites, which are in the form of particles, filaments or whiskers of ceramic materials, has improved and reached 6. This is because the crack created in the matrix by particles, filaments or whiskers not only does not propagate, but is also prevented from propagating, helping to do so [29].

Sonic Fill Composite

A bulk fill composite activated by sonic energy that differs from other flow bulk fill composites in terms of how it is applied. This material is applied in a single layer up to a thickness of 5 mm. The proprietary resin, highly loaded with special modifiers, reacts to sonic energy and the material flows rapidly into the cavity upon activation by sonic energy [30]. The manufacturer states that advanced modifiers reduce the viscosity of the material by 87% with this energy, and the increased flow properties of the material enable it to marginally conform to the cavity walls. During sonic activation, the resin composite has a high viscosity that allows it to be properly shaped by the clinician. Sonic Fill has been shown to have a Rockwell hardness (a method of measuring the hardness of viscoelastic materials) of 80% or better [31]. In addition, unlike other bulk fill flow composites, Sonic Fill allows placement in 5 mm thicknesses without increasing translucency. Therefore, the final restoration will be aesthetically pleasing [32].

According to the study by Fahad et al., sonic energy-activated composites have been used to restore weakened maxillary premolars. The results are also consistent with their study. In this study, most of the mix failures were found in groups one and two [33]. The reasons considered for this result could be the good adaptation to the cavity walls due to the reduced viscosity of the sonic composite during injection and the reduction of shrinkage stresses during exposure, which also reduces cuspal bending during polymerization. Also, the high mechanical properties of sonic composites protect them from forces applied to the restoration/tooth interface [34]. Another possibility could be the high bond strength of the total-etch and self-etch bondings to the composite and tooth, which were made in the same factory. According to the findings of the Fahad study, the most common failure pattern in the latter two groups was adhesive [35]. The reasons considered are the high viscosity of Tetric composite, which reduces the complete adaptation to the cavity walls. On the other hand, the large volume of fillers does not allow plastic deformation under load. As a result, it increases the stress at the tooth/restoration interface and ultimately increases the failure of the adhesive [36]. The history of using composite restorations reaches more than fifty years. Composites, which are tooth-colored materials, have improved their properties due to meeting the aesthetic needs and considering the significant changes they have undergone over time. Therefore, composite has become a popular material for anterior and posterior tooth restorations and has been able to be a suitable competitor to amalgam [37].

In anterior tooth composite restorations, its aesthetic appearance, such as color matching and polish ability, is important. One of the biggest disadvantages of using composite resins is its dimensional changes, which can ultimately lead to micro leakage. Micro leakage of composite restorations over time leads to discoloration of the restoration, and this discoloration is one of the most important reasons for replacing composite restorations [38]. The extent of composite micro leakage depends on its physical and chemical properties, polymerization rate, dentist technique, uniform bond of the restoration to the tooth structure, and isolation conditions. Proper finishing and polishing are also important processes in enhancing the aesthetics of composite restorations [39].

Most published reports acknowledge that the integrity of the restoration surface can affect plaque accumulation and restorative coloration as much as the physical and chemical properties of the restorative material itself. The aesthetics of anterior teeth depend on factors such as dent gingival anatomy, periodontal biotype, distance of the tooth contact point to the crestal bone surface, tooth morphology, and gingival bioform [40]. Unsightly teeth caused by hypoplasia, fluorosis, fractures, caries, and developmental defects can be treated using various aesthetic techniques such as bleaching, contouring, composite restorations, laminates, composite veneers, and porcelain. Today, the demand for aesthetic dentistry has increased due to the rapid development of new resin restorative materials (Table 1). In today's modern world, the desirable appearance of individuals is a factor in their personal and professional lives. A beautiful smile improves the acceptance of an individual by society [41].

Table 1. Consumables

Material	Main components	Manufacturer's name
Kerr, Orange, CA,USA	Bis-GMA, HEMA, glycerol phosphate dimetacrylate (GPDM), sodium fluorosilicate, initiator, ethanol, water	Optibond Solo Plus
Kerr, Orange, CA,USA	Primer : GPDM, hydrophilic co-monomers, water/ethanol, acetone Adhesive: resin monomers, inorganic fillers, ethanol	Optibond™ XTR
Kerr, Orange, CA,USA	Bis-GMA,TEGDMA, EBADMA, SiO2, glass, oxide, 83% filler	Sonic Fillnanohybrid
Ivoclarvivadent, Schaan, Liechtenstein	Bis-GMA, Bis-EMA, UDMA, barium aluminium silicate glass, Iso-filler, ytterbium fluoride, spherical mixed oxide, camphorquinone plus an acyl phosphine oxide, dibenzoyl germanium derivative, 80% filler	Tetric ® N-Ceram
MANI, INC. 8-3 KIYOHARA INDUSTRIAL PARK, TSUNOMIYA, TOCHIGI, 321-3231, JAPAN	Metal base: Stainless steel (including nickel and chromium) 2) Working part: Fine diamond crystals attached to metal base (including nickel and chromium) 3) Shank : Stainless steel (including nickel and chromium)	MANI DIA-BURS
Ivoclarvivadent, Schaan, Liechtenstein		Bluephase C8 (light-cure)
Kalanteb,iran,Tehran	Self-cure resin(methyl methacrylate)	Resin Acrylic (Melio dent)

Due to the widespread media advertising about the importance and impact of a beautiful smile, today we are facing an increase in the demand for restoration of anterior teeth. Therefore, the beauty of the smile is a major concern for patients and dentists. Dentists' awareness shapes their professional practice, and their treatment decisions are influenced by their knowledge [42].

A review of studies on impact on composite sheets

Hertz showed that with the static pressure of two isotropic spherical bodies on each other, contact occurs over a circular area, so that the normal pressure distribution in this contact area is Hertzian [43]. Timoshenko presented relationships between the radius of the contact circle, the indentation and the normal force, in which the relationship between the force and indentation is calculated as a nonlinear relationship, which is known as Hertz's contact law. Timoshenko also studied the impact of two bullets [44].

Cattopadhyay Fusn studied the response of non-isotropic sheets under initial stress to the impact of a bullet in the middle of the sheet in the form of the first-order shear deformation theory and also obtained the impact and deflection of the sheet by solving a nonlinear integral equation similar to the equation that appears in the study of impact on beams, and also calculated the energy transferred from the mass to the sheet at the time of impact [45]. They reported that the initial tensile force increases the maximum contact force, but the impact time, sheet deflection, and the stresses and energy transferred from the mass to the sheet due to the initial tensile stress are reduced [46].

Swanson and Sqian have investigated various methods for finding the response of composite sheets to a bullet impact. One of the techniques they investigated is based on the use of the Rayleigh-Ritz-Herr method with numerical integration in time, and another method is the use of the Laplace transform on the differential equations governing the sheet and linearization of the deformation of the impact site. They have compared their results with the results of finite element analysis and experimental tests, and the results presented by advanced two researchers indicate the range of numerical parameters to create a good and accurate solution [47].

Swanson and Chnistoforon have investigated the impact problem analytically. Their method is based on the use of Fourier series for sheets on simple supports, along with the use of the Laplace transform. Advanced two researchers have obtained the impact force, sheet displacement and normal tensile stress in the middle of the sheet and in their research [48], the relationship between force and indentation is considered linear, while in fact this relationship is nonlinear. The reason for their use of the linear relationship was to linearize and solve analytically the nonlinear integral equation that they encountered in the impact problem to solve the force [49]. They also considered the contact area as a fixed square and the stress distribution in this square to be uniform, which of course is justified due to the small contact area [50].

Sun and Cheh have studied the behavior of a sheet containing initial stress under impact load. They have used the finite element method in their study and have obtained the contact law from experimental tests and applied it in their finite element program [51]. They reported by analyzing the numerical results obtained, including contact force, displacement and strains in the plate that the initial tensile stress increases the contact force and reduces the impact time, and the opposite is true for the initial compressive stress [52].

Also, the impact response is almost directly proportional to the bullet velocity. Heavier bullets not only increase the contact force, but also increase the contact time. The displacement of the plate is also increased by the impact of heavier bullets, and finally the impact response is not sensitive to the dimensions of the bullet [53].

Mittal has studied plates under impact load. He has considered the deformation effects related to the transverse shear, which was unavoidable for thick plates, and has obtained closed solutions using a non-significant reinforcement for the displacement and bending moment at the impact point [54].

Advanced solutions are independent of the boundary conditions at the initial moments of the impact phenomenon, which means that in his study he has considered the dimensions of the plate as infinite and has used infinite Fourier transforms. He also calculated the impact force over the impact time using Hertz's contact law and reported that the effect of shear on displacement is less than its effect on the impact force, which is bending [55].

Greszczuk studied the response of isotropic and composite materials to bullet impact. His research is aimed at studying the failure mechanism of isotropic and composite materials subjected to impact loads and includes the following:

- ✓ Determining the time-varying pressure distribution at the impact point [56].

- ✓ Determining the internal stresses resulting from this pressure distribution in the target.
- ✓ Determining the failure modes resulting from advanced internal stresses in the target [57].

In Greszcuzuk's research, the pressure distribution under an impacting bullet is determined by combining the dynamic solution of the impact problem of the bodies with the static solution for the pressure distribution between the two contacting bodies [58].

Given the time-varying surface pressure, static analysis is used to obtain the time-dependent stresses in the target, and the stresses inside the target composed of composite materials and isotopes are investigated with respect to the properties of the target and the bullet, the impact velocity, and the bullet shape, and are used to determine the ultimate fracture velocity. In this study, curves are also presented to show the relationship between the material properties, the target, and the ultimate velocity for the onset of destruction [59].

Currently, many studies have been reported on GPL/polymer composites with improved mechanical and electrical properties, while only a few reports can be found for GPL/ceramic composites. This is partly because it is relatively difficult to obtain sintered ceramic components compared to polymers. Several researchers have made efforts in this area [60].

Walker et al. used aqueous colloidal methods to obtain homogeneous dispersions of GPLs and silicon nitride (Si_3N_4) ceramic particles, which were densified using spark plasma sintering (SPS). The fracture toughness measured was 6.6 MPa m 1/2 for the composite with 1.5 wt% GPLs, 136% higher than that of the monocrystalline Si_3N_4 [61].

Dosa et al. prepared a Si_3N_4 composite reinforced with GPLs containing 1 wt% using hot isostatic pressing and reported an increase in fracture toughness of 44% over pure Si_3N_4.

Liu et al. used SPS to fabricate a GPL/zirconia (ZrO_2) reinforced Al_2O_3 composite with the addition of 0.81 vol% GPLs and found an increase in fracture toughness of about 40%.

Yadhukulak-Rishnan et al. fabricated GPL-reinforced zirconium diboride composites at high sintering temperature using SPS method and investigated the effect of GPL content on the mechanical properties of the composites and showed about 110% increase in fracture toughness of the composite with the addition of 6% GPL [62].

Neetu et al. used SPS to stabilize GPL/tantalum (TaC) ceramic composites and the fracture toughness of GPL/TaC composite containing 5% vol% GPLs was 99% higher than that of pure TaC ceramic. In the fabrication of GPL/ceramic composites, advanced integration techniques such as SPS, hot isostatic pressing and hot pressing are usually preferred. Because the sintering process is accomplished in a short time and a vacuum or inert atmosphere as well as high pressure can be maintained to protect the GPLs [63].

In the exploration of graphene composites for biomedical applications, few studies have shown that graphene cytotoxicity is dose-dependent and is caused by oxidative stress due to the absence of graphene, while other factors suggest cell adhesion and proliferation. The results are inconsistent with the cell types and GPLs used in the experiment [64].

Lahiri and colleagues prepared GPL/ultra-high molecular weight polyethylene (UHMWPE) composites for orthopedic implants. The osteoblast viability on the surface of UHMWPE composite reinforced with 1.0 wt% GPL was 86% [65].

Zhang and colleagues prepared GPL/hydroxyapatite (HA) composites and reported that the addition of 1 wt% GPL led to a significant improvement in osteoblast adhesion. Very few reports can be found on the pressure less sintering of GPL/ceramic composites and biocompatible GPL/ceramic composites and this study was conducted to investigate them. Pressure less sintering of GPL/Al_2O_3 composites was carried out in a gas-shielded tube furnace and the mechanical properties of the fabricated composites were investigated. Raman spectroscopy was used for structural analysis of GPLs [66].

The phase composition and grain size of the ceramic were determined using X-ray diffraction (XRD) and scanning electron microscopy (SEM), respectively. The effect of GPLs on the in vitro biocompatibility properties of GPL/Al_2O_3 composite materials was investigated using cell adhesion and 3-4,5-dimethylthiahiazo(-z-y1)-3,5-di-.

phenytetrazoliumromide (MTT) assays. The role of GPLs and their contribution to the mechanical response and in vitro biocompatibility of GPL/Al_2O_3 composites were investigated and discussed [67].

As in the study by Alqarni et al., most of the general dentists participating in the study claimed that color stability is a major concern when performing composite restorations and the finishing and polishing process plays a vital role in the color stability of composite restorations. Also, 60.8% of the participants stated that they replaced composite in patients only because of discoloration of the composite. Therefore, since discoloration is one of the most common reasons for replacing composite restorations and the smooth and uniform surface of the restoration plays an important role in the color ability and aesthetics of the restoration, it can be concluded that finishing and polishing play an important role in the aesthetics of composite restorations [68].

Most participants believed that composite polishing should be performed immediately after restoration, and 5.28% believed that composite polishing should be performed 24 hours after restoration [69].

In the study by Demarco et al., most dentists preferred to perform polishing of anterior composite restorations immediately after restoration [70].

However, in a study conducted by Mirza Kouchaki et al. in 2013 titled "The Effect of Final Polishing Time on Micro leakage of Composite Restorations," they concluded that the time of final polishing has an effect on the average micro leakage of enamel-margin composite restorations, and the best time for it is 24 hours after restoration [71].

In this study, most participants stated that the use of composite polishing paste is not necessary, and only 22.8% of them believed that the use of composite polishing paste is necessary [72].

Also, in the study by alqarni et al., 62.6% of participants considered the use of composite polishing paste unnecessary.

However, Sen et al. concluded in a study that the use of polishing paste creates a smoother surface and the use of polishing paste after using polishing discs significantly reduces the discoloration of the restoration in all types of composites compared to not using polishing paste after using polishing discs. 48.1% of dentists believed that resin composite is not the best choice for the aesthetic restoration of anterior teeth and 29.7% of them considered resin composite to be the best choice for the aesthetic restoration of anterior teeth. However, porcelain veneers have advantages over composite restorations, including greater aesthetics, durability, compatibility, and less plaque accumulation. 1.48% of the participants considered Nano-filled composite to be the most suitable composite for anterior esthetic restorations, 1.36% preferred micro-hybrid and micro-filled composites, and 15.8% were unaware [73].

Also, in the study by Alqarni et al., most dentists participating in the study stated that Nano-composites have better color stability. In advanced composites, the resin matrix is reinforced with Nano-filler particles, resulting in significantly improved mechanical properties. [74]

The resulting improvement in physical properties, coupled with superior esthetics, has made Nano-composites the material of choice for anterior restorations. This is because advanced composite materials not only have desirable esthetic properties such as high polish ability, but also have excellent mechanical properties and improved handling. 75.9% of the participants claimed to be aware of the concept of natural layering and 24.1% of them stated that they were unaware, but in the study by Rajakerthee et al., 47.56% of the dentists participating in the study were unaware of the concept of natural layering [75]. The concept of natural layering was introduced by Didier Dietschi for the fabrication of direct esthetic restorations. This method offers a wide range of hue, opacity, and chroma to mimic the color and appearance of dentin. Enamel and similar materials are also classified in this way:

1- Young enamel: white color, high gloss, low translucency.

2- Mature enamel: natural color, low gloss, and moderate translucency.

3- Elderly enamel: yellow color, more translucency.

Only the two main layers of dentin and enamel are used to improve the anatomy of the tooth and smile. In this study, 48.7% of participants believed that LED (light-emitting diode) light was more suitable than QTH (quartz tungsten halogen) for curing composite restorations [76].

In the study by Demarco et al., 73.7% of participating general dentists used LED light-curing devices to cure anterior composite restorations, and 26.3% used QTH. LED light-curing devices were similar or better than QTH light-curing devices in terms of polymerization rate, micro leakage at the enamel and dentin margins, shrinkage rate, composite wear rate, and hardness of the cured composite. However, the depth of cure with LED is greater than with QTH. QTH light-curing devices tend to show more yellowing of the composite than LED devices [77]. The choice of composite shade should be made before the restoration process begins, prior to the placement of the veneer or cavity preparation, and the best area to provide the shade is the midline. In the present study, 97.5% of the participants believed that the shade of the composite should be chosen before the restoration is made, and 62.7% believed that the midline should be used as a guide to determine the shade of the composite. In the study by Rajakerthee et al., most participants were able to determine the shade before restoring the anterior teeth [78]. However, in the study by Alruwaill et al., only 2.5% of dentists and third-year students and above preferred to use the shade of the middle third of the tooth to determine the shade of the composite, and most of them stated that all surfaces of the tooth can be used to help select the shade of the composite. It seems that the reason for the low awareness of the participants in the field of "color" is due to the participation of students who are not yet familiar with this concept [79].

However, since there is an increasing awareness and demand for beauty by patients, the issue of color, which is of great importance, should not be ignored and dentists should try to stay up to date in this field. Regarding the knowledge questions related to the morphology and aesthetic management of anterior teeth, most of the dentists participating in the present study stated that the mesioccipital angle of the upper central tooth is 90 degrees, but the distooccipital angle of the upper central tooth is not sharp and 90 degrees. In fact, the dystofacial angle line is less clear and it seems that the distooccipital angle is slightly rounded, which is also similar to the Summit book. 70.3% of the participants stated that the lingual slope of the upper central tooth gives the tooth a translucency feature, which is mentioned in the Summit book as the halo effect, which allows the apparent size of the tooth to be changed without changing the actual dimensions of the tooth [80].

For example, by bringing the mesioocipital and distooccipital linear angles closer together, the tooth appears narrower than the normal contour. Also, to increase the visual error of tooth narrowing, developmental and developmental depressions can be made more pronounced. To make the tooth appear shorter and wider, horizontal elements such as gingival peri-chimata can be used, or the maximum facial prominence can be placed more incisally, which was consistent with the opinion of more than 70% of the participating dentists. However, 35.4% of the dentists believed that to make the tooth appear shorter, the maximum prominence should be placed more gingival, and 18.4% of them expressed ignorance. Attention to symmetry and proportion is of great importance in conservative cosmetic dentistry. 94.3% of the participating dentists also considered it important to pay attention to the symmetry of the teeth and the corresponding embrasures [81].

The interdental contact areas become more gingival from the central to the canine, the interdental contact between the maxillary centrals is in the incisal third of the tooth, but the contact between the central and lateral is at the junction of the middle third and incisal. This contact is located slightly more gingivally between the lateral and canine teeth [82].

If the interdental contact extends too far incisally, an abnormally shaped incisal embrasure is created. If the interdental contact does not extend far enough gingivally, an open gingival embrasure or black triangle is created. In the present study, less than 40% of the dentists were aware of the correct location of the maximum prominence of the upper central tooth in the mesial and distal directions. Rounded incisal angles, open incisal and facial embrasures, and soft facial parasal lines are typical features of a youthful smile. In the smile of an older person, due to the experience of aging, the incisal embrasures are closed and the incisal angles are more prominent, which most participants were not aware of. According to the data obtained from the questionnaires, the knowledge of the participants in this study about the aesthetic management of anterior composite restorations and the aesthetic management of anterior teeth seems to be moderate [83].

In a study conducted by Raja et al. on dentists in Lahore, they found that most dentists had acceptable knowledge about the aesthetics of anterior teeth [84].

However, in the study by Rajakerthee et al., the awareness of dentists about the concept of aesthetic management of anterior teeth was assessed as insufficient.

It seems that the reason for the contradiction in the results of different studies on the awareness of dentists about the concept of aesthetic management of anterior teeth could be the difference in the educational curricula of the faculties or the amount of effort of the dentists themselves to learn and stay up to date [85].

Therefore, considering the increasing demand from patients in the field of aesthetic restoration of anterior teeth, attention to aesthetic restorations in student education should be increased and dentists should include continuous learning in their agenda to stay up to date. According to the answers provided in the attitude questions, most of the dentists participating in this study rated their knowledge and ability in performing anterior esthetic composite restorations as moderate to low.

On the other hand, most of them believed that the quality and quantity of composite education in the faculty did not meet their practical needs for performing anterior esthetic composite restorations in the clinic. In the study by Demarco et al., 53.5% of dentists checked their light curing units monthly, quarterly, or annually, but in the study by Hao et al., the majority of dentists had never checked the power density of their light curing units. A significant number of light guide surfaces were damaged and covered with resin. Some units required replacement due to many years of use. The majority of dentists were not aware that light curing units require maintenance and periodic testing [86].

Discussion

Although commercially available dental composites are clinically easy to use, problems such as low fracture toughness still limit their use, especially in posterior teeth. Although modern dental composites are easy to use clinically, are aesthetically pleasing, and relatively inexpensive, three major problems remain in their clinical durability: shrinkage during curing, low fracture toughness, and composites are more susceptible to wear than ceramics. Although the mechanical properties of composites are largely influenced by the filler, the organic matrix also plays a significant role in strength, stiffness, and wear resistance. The changes that have been made to commercial composites so far have been mainly in the filler technology, while the resin monomer has remained almost unchanged. The low fracture toughness of modern dental composites is a characteristic that greatly limits their application. Much attention has been paid to the synthesis of new monomers to overcome advanced problems [87].

It is expected that the use of monomers with more favorable properties can increase the clinical durability of composite restorations and expand their applications. Photo polymerization of methacrylate by visible light in the presence of a suitable photo initiator leads to the formation of a cross-linked network structure that is used in dental materials [88].

Acrylate-based resins are most commonly used in light-cure systems due to the high reactivity of acrylate monomers. Today, many new dimethacrylates have been used as alternatives to dental composite matrix materials to achieve better properties for dental composites. In a study conducted at the Iranian Polymer and Petrochemical Research Institute, a new urethane methacrylate (UDMA) resin monomer with a higher molecular weight was synthesized by the reaction of two equivalents of isophorone diisocyanate (IPDI) and one equivalent of polyethylene glycol 400 (PEG400) [89].

The results of this new UDMA showed that this monomer has a higher degree of conversion compared to the commonly used Bis-GMA monomer. Also, its refractive index is very close to the refractive index of glass fillers used in dental composites [90].

The present study is a preliminary investigation for the application of this UDMA as a monomer for dental composites. In this study, some mechanical properties of the composite synthesized with different percentages of this UDMA were measured and compared with the properties of the composite based on Bis-GMA/TEGDMA alone. Since today's composites are also used for posterior tooth restorations, fracture of the restoration can probably be a significant reason for its failure. It is possible that the results presented in this study can be a useful indicator of resistance to such fractures.

Also, with further research on other properties of the composite made with this new monomer, it can be presented to the manufacturing factories as a composite with high mechanical properties. With recent advances in dental materials and clinical techniques, resin composites have become the most widely used direct restorative material to address esthetic needs in the reconstruction of dental caries, crown fractures, congenital defects, and tooth wear [91].

Advanced materials strengthen the tooth structure by bonding to the tooth. The type of bonding has a significant effect on fracture resistance. Researchers currently believe that adhesion to dentin is mainly through the penetration of resin monomers into the pores between dentin collagen fibers exposed by acid etching. Adhesion to dentin is still more challenging than to enamel.

Factors associated with compromised dentin bonding include: tubular structure, high organic content, inherent moisture, and low surface energy of dentin. With the aging population and improved tooth survival, the prevalence of proximal and cervical caries has increased. Today, different bonding systems are available for bonding resin composites to dentin, including Total Etch and Self-Etch dentin adhesives, each with its own advantages and disadvantages.

Poorly performing bondings result in reduced fracture resistance and increased marginal micro leakage, which are common clinical problems associated with resin composite restorations. The clinical consequences of marginal cleavage include marginal micro leakage, post-treatment sensitivity, secondary caries, discoloration, and cuspal traction [69].

On the other hand, conventional composite resins have disadvantages such as limited light penetration depth and observed structural shrinkage of 2 to 5%. Polymerization shrinkage causes stress at the composite-tooth interface. Therefore, deboning occurs when the polymerization shrinkage stress exceeds the bond strength. As a result, clinical problems such as micro leakage, secondary caries, discoloration, and post-treatment sensitivity may occur [88].

To minimize volumetric polymerization shrinkage and thereby reduce stress at the tooth-composite interface and provide better mechanical properties with sufficient light penetration, a layer-by-layer placement technique is required.

However, this technique has disadvantages such as bond failure between layers due to contamination, bubble formation, longer time required for placement and polymerization of each layer, and difficulty in placement due to limited access during conservative cavity preparation. Therefore, to overcome the problems caused by the layer-by-layer technique and to simplify the restoration process, in recent years' bulk-fill composites with the ability to increase the depth of cure to 4 to 5 mm have been introduced to the market. Manufacturers claim that advanced composites can be cured to a thickness of 4 or 5 mm per stage with reduced polymerization shrinkage compared to conventional composite resins.

As mentioned earlier, the main advantage of using bulk-fill composites is the increased depth of cure, which is achieved by increasing translucency as a result of reducing the volume of fillers or increasing their size, which limits light scattering. Lower shrinkage stress is also due to changes in the organic matrix or filler content [92].

Among the new types of composites that have been developed to avoid the side effects of composite polymerization shrinkage are Tetric N-ceram and SonicFill composites, which, despite the contradictory results observed with the use of advanced types of composites, laboratory studies of their mechanical properties have been promising. However, concerns have been raised regarding the ability of advanced stiffer materials to conform well to the inner walls and margins of the cavity [93]. To alleviate this problem, the use of "flow" and glass ionomer composites as liners has been proposed. Flow composites have a low viscosity and conform better to the cavity than compressible composites. However, the longevity of this technique is questionable. On the other hand, a single-stage composite system, which combines a sonic-activated handpiece and resin composite, does not require an additional layer of coverage, and has the advantages of both flow and universal composites, is now available under the name of sonic-activated composites [94].

Acceptable composite restorations in Class II cavities with an extended gingival margin on the root are an important part of restorative dentistry. The reported 3% volumetric shrinkage following polymerization often leads to marginal cracking. Marginal sealing and fracture resistance of the restorative materials are important factors for the long-term performance of posterior composite restorations. Most studies conducted so far have evaluated the micro leakage of this technique, and the results of advanced studies have also shown the effectiveness of this method. However, the fracture resistance factor of this method has not been proven [44].

Wieczkowski et al. investigated the effect of the two methods of layering and bulk-fill on the resistance to cuspal fracture of restored posterior teeth. They stated that posterior composites placed by the layering method were stronger than the bulk-fill type. Composite 60P placed by the layering or bulk-fill method was stronger than the bulk-fill method in the layering method [16].

Czasch et al. compared the degree of conversion and micro- and micromechanical properties of two bulk-fill composites. They showed that there was a significant difference between all physical properties of the two types of composites and suggested that bulk-fill composites should be cured for 20 seconds in thicknesses of 4 mm [2].

Garoushi et al. compared the physical properties and depth of cure of a new composite (everX Posterior) with other conventional posterior composites. They concluded that this new type of composite differs significantly in physical properties from conventional composites and suggested that it be used in areas under severe abrasion stress.

The most important factor for all dentists and dental material manufacturers is to use a material that prevents bacterial leakage between the restoration and the tooth structure while providing sufficient fracture resistance [95].

Adequate fracture resistance is a major factor in the long-term success of restorative treatments. There are several different ways to compare one veneer composite to another, often related to performance.

Common Properties of Composite Types

Two physical properties of dental composite types and removable dental laminates and their applications that are often considered can be considered mechanical and aesthetic properties. The mechanical properties of a composite provide a stronger veneer, stronger bond, and excellent adhesion. Mechanical properties essentially indicate the physical function of the product [22].

In contrast, aesthetic properties relate to the appearance of the work and the final result that is seen in the patient's mouth. Of course, it is worth noting that the price of dental composites also varies from one type to another. One of the components of any composite is the fillers, which are usually glass or ceramic particles that are placed in a resin matrix to increase the strength of the composite. Initially, material developers used the size of the filler to improve mechanical and aesthetic properties [66].

In the mid-20th century, the size of the fillers in the first dental composites was much larger than today, reaching 10-50 micrometers. Advanced are macro fills. When it came to the mechanical properties of the first resin composites, the bigger the better.

Advanced composites were strong and durable with large fillers. However, macro fillers did not finish and polish well. In addition, the large particles were sometimes so large that they could be seen with the naked eye. Thus, efforts were made to develop composite resins with smaller particle sizes, and a variety of dental composites and their applications emerged. After macro fillers were completed, micro fillers with particle sizes smaller than 100 nm were developed [54].

However, advanced composites presented a new challenge. Micro fillers polished well and looked beautiful, but they were not strong enough to withstand the pressures of food and biting in the posterior. Therefore, hybrids were the next step, which used a mixture of filler sizes to take advantage of the strength of macro fills and their aesthetics. This mixture proved useful and effective, and as a result, many of the composites used today are some kind of hybrid. However, today the size of fillers has been reduced to the nanoscale with particles smaller than 20 nanometers [35].

Today, most types of dental composites and their applications are in the form of nanocomposites. The main advantage of working with fillers at the nanoscale is that they use the principles of nanotechnology and its quantum effects. The size of the fillers of nanocomposites mimics the physical, chemical, mechanical and optical properties found in nature. Their size means that they can have different properties than larger ones. Small fillers work together, to create larger groups of materials, allowing the group to have different properties than the individual particles [1].

Types of Dental Composites and Their Applications

Today, there are three basic categories of dental composites, each with advantages in how they are used to restore teeth:

1- Posterior composite: Posterior composites require fewer layers for filling and preparation. According to research, their most important distinction from other types of dental composites is their increased depth of treatment. The transparency of composite materials allows for layered treatments up to 4 mm thick. The transparency of the materials allows light to penetrate deeply.

2- Flow composites: Advanced composites are aptly named because their viscosity increases the flowability of advanced dental composites. They are often packaged in a syringe with a small gauge needle for ease of use in tight or small preparations.

3- Universal: Advanced composites are not defined by their layers or viscosity, but instead are designed and defined for their intended use. Universal composites are also known as versatile.

Choosing the most appropriate type of composite

When to use the types of dental composites and their applications has a lot to do with your restoration. For example, one type of composite may be used for anterior restorations and another for posterior restorations. Many clinicians prefer to use posterior fillings in the back because they are known for their strength and durability. Additionally, using fewer layers means less chance of technical problems like cavities. Doctors also place posterior fillings in the back because of the transparency that increases the depth of treatment [18].

Flow composites also have many applications in dental restorations. Their unique transfer properties allow advanced composites to fit into small cavities that their thicker counterparts cannot penetrate. Universal composites have the widest range of applications. They are designed for both indirect and direct restorations. This means they can be bonded to dentin, or used as adhesive primers for indirect restorative materials. In other words, we mean that universal composites can be used for anything you want, anywhere you want.

In the study of Aguiar et al. (2005), the hardness and tensile strength of hybrid composite resins were investigated with four different exposure methods. They stated that the media used to store the samples has the ability to cause changes in the physical properties of composites with different polymer structures. In the study of Bona et al. (2008), the relationship between the flexural strength (σf) and tensile strength (σt) of 4 types of resin composites (Filtek Z250, AM-Amelogen, VE-Vitol-escence and EX-Esthet-X) was evaluated. Advanced values were highest for EX and Z250 in both σt and σf tests. Advanced results proved the theory of the relationship between σt and σf. In the studies of Ilie N and his colleagues in 2009, 72 hybrids, Nano hybrid, micro fill Packable, Ermoser and Flowable composites were compared in terms of mechanical behavior. In this study, the value of flexural strength (FS), modulus of flexibility (FM), tensile strength (DTS) and compressive strength (CS) were examined. The lowest value of mechanical properties was related to micro hybrid composites. Flowable composites did not have a statistically significant difference in terms of mechanical properties compared to micro hybrids and their only difference was that DTS was higher than micro hybrid composites. Therefore, it was concluded that the amount of filler has a very large effect on increasing the properties of composites, including FS and FM, up to 60%, while they did not have the amount of DTS and CS. On the other hand, the type of material has an effect on the mechanical properties of composites and their greatest effect is on CS [96].

The three light-cured composite samples used in this study included Micro field (3MESpe) A110, (3MESpe) P60, which are mostly used for posterior restorations, and Micro Hybrid Charisma (Heraeus-Kulzer), and two different types of light sources were used, one was halogen light HAL (Degulux and Degussa) and the other was diode light LED (Ultrablue and DMC). The results indicated that no statistically significant difference was observed in the value of (DTS) of a composite group cured with two different light sources. However, different composite groups showed different DTS values [96].

Conclusion

Resin dental composites that are activated by visible light are widely used as restorative materials in anterior and posterior teeth. The degree of softness of the restorative materials, excessive wear, loss of vital compatibility of the restorative materials, discoloration of the materials, breakage and loss of adhesion of the materials are all related to the insufficient amount of polymerization of the materials. Mechanical properties such as hardness and wear resistance are among the things that depend on the amount of modification of the monomers present in the composites. In nanocomposites, shrinkage after polymerization is significantly reduced and they have excellent aesthetic properties compared to other composites.

The use of nanocomposites has no limitations in dental restorations, meaning that they can be used to restore anterior and posterior teeth. Nanotechnology has led to advances in the structure of resin composites, which has been achieved with Nano particles of about 25 nm in size and a density of about 75 nm.

Advanced particles include zirconium and silica or Nano silica particles. This density is created by silane particles that ultimately bond to the resin matrix. The dispersion of fillers in the matrix increases the pressure by up to 79.5%. The smaller the particle size, the better the resin containing advanced particles has, and not only does the amount of wear in advanced types of restorations not increase over time, but they also maintain a smooth and polished surface. This technology has also improved the mechanical properties of advanced materials, so that they can be used in anterior and posterior teeth. The only drawback is that because the particles are too small, they are unable to reflect light. Therefore, they are inevitably combined with larger particles whose average diameter is around the wavelength of visible light, which further improves their optical behavior.

Nano fill and Nano hybrid composites have recently been introduced to the industry. Nano hybrid composites have a lower average particle size (APS) than micro fill composites and yet are very strong. This combination, which contains reduced APS with high strength, is made possible by the precise and regular placement of filler particles in the matrix and by utilizing the nanotechnology industry.

Advanced types of composites have high polish ability, create very good aesthetics, and also have ideal mechanical properties. The basis and nature of nanotechnology is to create and provide materials and devices at the level of atoms, molecules, and supraparticle structures and to exploit the unique properties of particles with sizes between 0.1 and 100 nanometers. Nano field composite resins have mechanical properties similar to hybrid composites and therefore can be used in the same cases where hybrid composites are used. They are also of great interest in cosmetic restorations of anterior teeth. Tolosa et al. in 2005 evaluated the tensile strength of three light-cured composite samples with two different light sources.

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