

A Review on Fibre Reinforced Composite Resins

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Key words: Fibre reinforced composite, Fracture toughness, Polymerization shrinkage.

Introduction

Composite resins has revolutionized our field of dentistry and composites have now become the material of choice. The use of adhesive material to reinforce weakened teeth, and undermined enamel was first given by Denehy and Torney in 1976.¹

There was the stress development within the tooth structure, due to polymerization shrinkage and mastication. Fibre reinforced composite promise to overcome these problems.

The first attempt to use fibre reinforcement in clinical dentistry began more than 55 years ago. In the 1960's and 1970's, investigators sought to reinforce standard polymethyl methacrylate dentures with glass or carbon fibres.^{2,3} In 1980's, similar attempts were repeated,^{4,5} and initial efforts were made to fabricate fibre-reinforced prosthodontic frameworks for implants, fixed prosthodontic restorations, orthodontic retainers, splints, fibre posts and reinforcement of fibres for post endodontic restorations.^{6,7}

Fibre reinforced composites consist of fibre material held together by a resinous matrix. They offer good flexure strength and other physical qualities required in a prosthesis substructure material and for replacement of lost tooth structure.^{8,9}

Fibre reinforced composite can be classified according to the type of fibre incorporation (glass, carbon or polyethylene), the fibre architecture (Mesh, Unidirectional, Weave, Braid, Leno Weave) and depending on the method of incorporation of fibre (Pre impregnated dental laboratory products, Pre-impregnated chairside products, Impregnation required chair side product, Pre-impregnated prefabricated posts). Fibre-reinforced materials exhibit various advantages such as:

1. They have highly favourable mechanical properties and their strength-to-weight ratios are superior to those of most alloys.
2. When compared to metals they offer many other advantages as well, including non-corrosiveness, translucency, good bonding properties and ease of repair.

3. Superior mechanical property of fibre reinforced composite makes them ideal material for restoration of large cavities and for post endodontic filling.
4. Fibre reinforced composite can be even cured upto 4-5mm.
5. Fibre reinforced composite restorations offer a minimally invasive, low cost alternative to conventional restorative dentistry.
6. Fibres reinforced composite prevents crack propagation in a restored teeth.
7. It also offers exciting applications in the repair and strengthening of dentures, orthodontic retainers and the provision of aesthetic custom-made posts and cores.
8. They also offer the potential for chair side and laboratory fabrication.
9. Fibre reinforced composite have the following disadvantages.
10. The most frequently experienced problems with fibre reinforced composite restorations are fractures and occlusal wear due to abrasion of the composite veneer, chipping of the composite veneer, delamination and secondary caries. However most of the problems can be easily, quickly and economically repaired.
11. The mechanical properties of fibre-reinforced composites decrease after hydrolytic aging.

Fibre-reinforced composites have prospective for use in many applications in dentistry and are expected to gain increasing application and popularity in dentistry.

Composition and Architecture

The fibre orientation and types can be: Unidirectional fibres (long, continuous, parallel), Braided and Woven fibres. Typically, fibres are 7 to 10 µm in diameter and span the length of the prosthesis or appliance. The particles used in standard restorative dental composites are 1 to 5 µm in diameter, or submicron in size and up to few millimeters in length.

Polymers: Most commonly used polymers are based on poly methyl methacrylate/ methyl methacrylate (PMMA/MMA) mixtures. Activation of the polymerization, by heat or chemically, initiates free radical formation from benzoyl peroxide (BPO) and an exothermic free radical addition polymerization takes place. The polymerization leads to interpenetrating polymer network (IPN) formation by combining the PMMA beads and monomer-based polymer matrix¹², because PMMA becomes partly (large PMMA beads) or totally (small beads) dissolved in the monomer. The addition of cross-linking agents may improve many of the physical properties of polymers.¹³

Fibre-Reinforced Polymers: The strength of polymers can be improved by adding reinforcing fibres.¹⁴ By combining two or more materials to make a composite, better mechanical properties than those obtained by the polymers alone can be achieved.

In dentistry, glass fibre reinforcement is frequently used for the following applications. Post endodontic restoration, Restoration of grossly carious tooth, Crowns, Fixed partial dentures (FPD), Implant prostheses, Facial prosthesis, Splinting teeth, Root canal posts and Orthodontic retention devices.

Resin Matrix: Special considerations are required for developing a resin material for the fibre reinforcement. Ideal requirements are that a resin material intended for incorporation of fibres must possess mechanical properties that tolerate masticatory forces, the material should be biocompatible, be able to resist degradation, should have low water sorption and solubility, low residual monomer concentration.

Orientation of Fibres: Mechanical and physical properties are related to the orientation of the reinforcement. Fibre orientation can influence the Strength, Modulus and Coefficient of thermal expansion. Fibre orientation can change the properties of a fibre-reinforced polymer from isotropic to anisotropic and even orthotropic. Continuous unidirectional fibre-reinforced polymers give anisotropic properties to the composite. Continuous bidirectional fibres (weaves) give orthotropic properties in a plane and Random-oriented fibres give isotropic properties. Unidirectional longitudinal fibres exhibit superior mechanical properties along their long axis.

Quantity of Fibres Fibre quantity in a polymer matrix can be given in weight percent (wt. %) or in volume percent (vol. %). Due to the differences in the density of fibres, presentation in volume percent is recommended.¹⁵ Increasing the content of fibre-reinforcement improves flexural properties.¹⁶ However, higher fibre content does not always result in higher mechanical properties. With a controlled manufacturing process, a volume fraction of glass fibre incorporation into matrix can be 45-65%

.Maximum flexural strength in dry condition for glass fibre with 65% fibres is 1230 MPa. Increasing the fibre content also reduces water sorption as the relative portion of water absorbing polymer matrix decreases.¹⁷

Adhesion of Fibres to the Polymer Matrix: The adherence of fibres to the resin matrix is an important quality for good mechanical properties. Fibre reinforcement is effective only when a given load can be transferred from the matrix to the reinforcement, and this can be accomplished when there is complete adhesion between resin matrix and fibres. Insufficient adhesion of fibres by resin matrix results in voids and porosities in the fibre-reinforced composite that are susceptible to water sorption. Voids and porosities in the fibre reinforced composite may lower flexural properties and silane coupling agents can optimize chemical and physical bonding between different components in composite materials.

Properties of Fibre Reinforced Composite

Water sorption: Water sorption of a material includes both water adsorbed on the surface and water absorbed into the body of the material during preparation and while the material is in service. Poly (methyl methacrylate) absorbs water because of the polarity of the water molecule and because it is smaller than the inter chain distance in the polymer. The volume of water uptake by a polymeric material is determined by polymer structure, content of various polar and hydrophilic groups in the polymer structure, temperature, concentration of various additives, presence of voids within the matrix, Physicochemical and mechanical properties can be affected by absorbed water.

Flexure Strength: These materials are often tested in the laboratory, although the mode of failure and many other properties affect clinical performance. Investigators accentuate the importance of fatigue and fracture toughness in predicting clinical performance of several classes of dental materials, including fibre composites. It is important to note that test methods, procedures for preparing the samples, and, in particular, the geometry of the test specimens all affect the calculated flexure strength. Flexure strength for commercial laboratory-processed fibre-reinforced composites may range from approximately 300 to 1,000 MPa, depending on the specimen preparation and geometry.

Fracture toughness: The fracture toughness of a material reflects the resistance of a material to fracture and represents the energy required to propagate a crack through the material to complete fracture. Fracture toughness of polymer composites depends on the type of polymer and reinforcement. Fracture toughness of a monomethacrylate-based material is lower than in a dimethacrylate-based material. Generally, "intrinsic" physical aging and/or storage in a humid environment at

elevated temperatures can decrease fracture toughness, as well as other mechanical properties. However, an increase in fracture toughness can be achieved by adding reinforcing fibres to a polymer to prevent or slow down crack growth.

Linear coefficient of thermal expansion: The variation of the coefficient of thermal expansion between different materials is important because a mismatch can lead to strains, resulting in stress formation and adverse effects on the interface. Therefore, thermally induced strains and stresses adversely affect long-term stability of intraoral multiphase materials. By adding fibres to a polymer, the coefficient of thermal expansion decreases. In general, the thermal coefficient varies with the direction of the fibres in a composite rigid fibres appear to prevent expansion of the matrix in the longitudinal direction so the matrix is forced to expand in the transverse direction. One of the major concerns in the development of dental materials is physical and chemical durability.

Biocompatibility

Solubility: Over time, components such as stabilizers, plasticizers, monomers, residuals of initiators and degradation products may be released to the oral environment. Thus, the quantity of such components should be as small as possible, ensuring that the polymer retains its characteristic properties and that no components adversely influence biocompatibility.

Residual monomer: Biological features, as well as mechanical properties, of polymeric materials are highly influenced by the monomer-polymer conversion. Residual monomer will alter the property and may leach out to pulp if a protective layer of base is not given.

Cytotoxicity: Some substances released from materials are cytotoxic and residual monomers leached out into the oral environment may induce toxic and allergic reactions.

Polymerization shrinkage: In the last decade, the continuous improvement in adhesive systems and increased awareness among clinicians to protect and reinforce the remaining sound tooth structure, resulted in the increased use of particulate filler composite resin materials (PRFC) both at the anterior and posterior regions. Despite the continuous improvement through modifications in formulation, polymerization shrinkage seems to be a problem for the PRFC.

Various steps have been undertaken to evaluate and improve restorative composite resin against wear and lower the polymerization shrinkage. Attempts have been made to change type of filler or filler size and their silanization, by changing the polymerization kinetics of resins and to influence to degree of monomer conversion. Reinforcing the resin with glass fibres with fibre-reinforced composite (FRC) substructure whiskers

particulate ceramic fillers (dense and porous) and optimization of filler content are among the methods that have been studied.

Clinical Applications of Fibre Reinforced Composite

The properties of fibre-reinforced composites (FRCs) that make them well suited for various clinical applications include strength; desirable esthetic characteristics; ease of adaptability to various shapes; and potential for direct bonding to tooth structure.

Restoration: Restoring teeth with minimal sacrifice of sound tooth structure depends mainly on adhesives that provide strong and durable bonding to the remaining sound enamel and dentin. Laboratory reports¹⁸ have proven that modern adhesives do effectively bond to tooth tissue in the short term.

However, clinically, marginal deterioration of composite restorations remains problematic in the long term and still forms the major reason to replace adhesive restorations.^{19,20} When resin composite is bonded to tooth structure using adhesives, the initial and residual polymerization stresses that are present along the cavity walls may result in gap formation, leakage, recurrent caries and pulp irritation.²¹

Restoration of anterior tooth need quick, aesthetic and functional repair. Along with aesthetics, the physical properties of restorative material should also be considered for long-lasting restoration. Fibre reinforcement has been tried as a newer technique to improve the physical properties of composite materials. High fracture resistance of the restorative material is required in the clinical situations where the high impact stresses are experienced and incisal angle restoration is one such demand. Attempts have been made to improve the fracture resistance of restoration by using different bonding agents, adhesive resins and different restorative techniques using fibre reinforced technique.

Tooth Stabilization and Splints: Fibre reinforced composite materials are an excellent choice for the stabilization of mobile teeth due to periodontal reason or due to any trauma. Chair side-fabricated fixed splints have previously been made from material combinations that have included resin composites, wire, wire mesh, wire embedded in amalgam and resin and fibre mesh embedded in composite.^{22,23,24} All of these materials suffered from various problems like Poor handling characteristics, Over bulking, Insufficient bonding of the internal structural materials to the dental resins, Poor esthetic outcome, Fibre splints overcome these drawbacks and provide ease in tooth splinting. Splinting can be done on palatal/lingual surfaces, labial surface or both the surfaces.

Conservative treatment of missing tooth replacement: Chair side tooth replacement is an

excellent application for fibre reinforcement composite technology. Previous attempts at chair side tooth replacement involved the use of pontics derived from extracted teeth, acrylic resin denture teeth with or without lingual wire reinforcement, and resin composite. These were attached to abutment teeth with acid-etched bonded particulate composite. The abutment teeth used for these approaches were usually not prepared; most often, tooth replacement was only for the anterior region and the procedure was considered a short-term solution.

The chair side fibre reinforced composite prosthesis offers a fast, minimally invasive approach for tooth replacement that combines all of the benefits of the fibre reinforced composite material for an esthetic, functional, and potentially durable result. A denture tooth or a natural tooth (in the case of an extraction of a periodontally involved incisor) can be used as the pontic. Selection criteria for this tooth replacement approach include:

1. A patient who desires an immediate, minimally invasive approach
2. A patient who requires an extraction in an esthetic area and desires an immediate replacement
3. Abutment teeth with a questionable long term prognosis
4. Anterior disarticulation during mandibular protrusive movements
5. A non-bruxing patient
6. Cost considerations

Post Endodontic Restorations: To prevent the failure of root canal treatment, a simple, quick, high strength, direct and cost effective restorative procedure may be desirable. Adhesive technology is advancing by leaps and bounds every day, making it possible to create conservative and highly aesthetic restorations with direct bonding to the teeth. A significant increase in the fracture resistance of root filled teeth was observed when they were intra coronally restored with a resin composite material. Reinforcing composites with polyethylene fibres and glass fibres has successfully provided superior resistance.

Endodontic Fibre Reinforced Composite Posts: FRC posts are a recent addition to the systems traditionally used to retain a core in severely broken down, endodontically treated teeth: custom-made metal or cast posts and cores and prefabricated metal and zirconium posts.

The FRC posts offer greater flexure and fatigue strength, a modulus of elasticity close to that of dentin, the ability to form a single bonded complex within the root canal for a unified root post complex, and improved aesthetics when used with all-ceramic or FRC crowns as compared to custom-made cast or metal-prefabricated posts.^{25,26} The properties of this post design have the potential to reinforce a compromised root and to distribute stress more uniformly on loading to prevent

root fracture moreover, the FRC post will yield prior to catastrophic root failure better than will custom-made cast metal or prefabricated metal post systems.²⁷

Two categories of FRC posts are available: chair side-fabricated and prefabricated. Chair side fabricated posts are custom designs that use polyethylene non pre-impregnated woven fibres (Ribbond, Connect) or glass fibres (Glass Span) to reinforce the root and hold a composite core. 18 Prefabricated posts are constructed of two kinds of fibre: carbon fibres embedded in an epoxy matrix (C-Post, U-M CPost, and Aestheti-Post) and S-type glass fibres embedded in a filled resin matrix (FibreKor Post).^{28,29} Fibre-reinforced composite posts consist of a resin matrix, in which structural reinforcing carbon fibres or quartz/glass fibres are embedded. Black carbon fibre-reinforced composite posts are, on the one hand, poorly suited for combination with translucent full ceramic restorations due to their unfavourable optical properties. On the other hand, carbon fibre posts also have unfavourable biomechanical properties

The favourable optical properties of tooth-colored fibre posts (glass- and quartz-fibre), which are consistent with natural teeth in their ability to conduct light, facilitate the goal of esthetic, high-quality restorations when they are combined with full ceramic materials. The posts can be processed in one time-saving surgery visit that eliminates the laboratory step, due to the direct technique in combination with an adhesive composite build-up. They also permit a procedure that is gentle to the tooth substance: Thin dentin walls are stabilized by the plastic build-up composite and the composite cement. Moreover, the areas underneath can be saved and maintained as additional retentive areas for the plastic build-up composite restoration.

Repair of Acrylic Resin Prosthesis

Both unidirectional and woven light-polymerized FRC strips can be used effectively for chair side repairs of fractured acrylic resin prostheses. As mentioned earlier, FibreKor (Jeneric/ Pentron) and Vectris (Ivoclar/ Williams) are unidirectional materials available for laboratory use. Splint-It (Jeneric/Pentron), another chairside material, is available either as a unidirectional or a woven fibre. All of these materials have significantly greater flexural properties than unreinforced resin. As explained earlier, woven FRC has a shorter memory than unidirectional FRC, which makes it easier to handle; however, unidirectional FRC has superior flexural properties and will likely provide a stronger repair.

Indications for Chair side Repairs with Light-polymerized FRC

Virtually any acrylic resin prosthesis or appliance can be repaired with light-polymerized FRC:

1. Complete dentures
2. Acrylic bases of partial dentures
3. Provisional removable partial dentures

4. Provisional FPDs
5. Obturators
6. Palatal lift appliances
7. Orthodontic retainers
8. Occlusal splints and night guards

Short Fibre Reinforced Composite: A New Alternative for Direct Only Restorations

Particulate filler composite resin (PFC), at one time considered only as a treatment option for anterior teeth, has steadily been found to have wider applications.

With the improvements in the mechanical properties of PFCs, their use has been widened not only to the posterior intra-coronal area, but also to extra-coronal restorations, and even complete crowns and fixed partial dentures.³⁰ Many studies have been undertaken to investigate the filler phases, resin compositions, and curing conditions to improve the mechanical properties of PFC.^{31,32,33} However, further significant improvements are needed in order to extend the use of PFC to high stress-bearing applications such as direct posterior restorations involving cusps and indirect restoration, inlays and onlays.^{31,33}

Recently, short fibre reinforced composite FC resin was introduced as a dental restorative composite resin.^{34,35,36} The composite resin is intended to be used in high stress bearing areas especially in molars. The results of the laboratory mechanical tests revealed substantial improvements in the load bearing capacity, the flexural strength and fracture toughness of dental composite resin reinforced with short E-glass fibre fillers in comparison with conventional particulate filler composite resin.³⁴ The short fibre composite resin has also revealed control of the polymerization shrinkage stress by fibre orientation and, thus, marginal micro leakage was reduced compared with conventional particulate filler composite resins.³⁶ It can be hypothesized that by using a FC composite substructure under PFC, the static load-bearing capacity of the material combination could be improved. Load application over the restoration is one of the factors that could influence the load bearing capacity.

Applications of Reinforced Fibre Material in Orthodontic Practice

Applications of fibre reinforced composite in orthodontic practice

1. Fixed orthodontic retention appliance
2. Fixed space maintainer
3. Temporary esthetic retention appliance
4. Posttraumatic stabilization splint

Conclusion

FRC has shown to be very use full in many clinical situations such as restoration tooth Stabilization and Splints, conservative treatment of missing Tooth Replacement, denture tooth modification, post endodontic restorations, endodontic fibre reinforced composite posts, repair of acrylic resin prosthesis, repair

of acrylic resin prosthesis and applications of reinforced polyethylene fibre material in orthodontic practice.

Incorporation of fibres have improved the physical properties of fibre reinforced composite. It has shown to be highly biocompatible. Which has made its use in all the areas of the tooth convenient of the clinicians. Degradation of the Fibre reinforced composite over the time is a major concern for its use as a long term permanent restoration. However the future holds great promise for fibre reinforced composites in all areas of clinical and laboratory dentistry.

Conflict of Interest: None

Source of Support: Nil

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