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FIBER REINFORCED MATERIALS: A NOVEL APPROACH TOWARDS IMPROVED ESTHETIC DENTISTRY

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ABSTRACT

The treatment strategy in the field of dentistry is constantly evolving as a result of innovative therapeutically based solutions for the development of biomaterials, advanced technologies and more successful treatment techniques. One such material is fiber reinforced material. Amongst this Fiber reinforced composites (FRC) are the best example for this. Not only in the field of dentistry, but have shown wide industrial scale application as well (boat hulls, bullet proof jacket, sports equipment). These materials are metal free with light weight having good mechanical properties including high fatigue resistance and fracture toughness. They are cost effective, showed good esthetic results and showed better strength. Because of their excellent adhesive properties and esthetics they have been the main highlight in dentistry for the last two decades. Some of the clinical applications are such as fixed prosthodontics, restorative dentistry, periodontology, orthodontics and in repair of prosthetic devices. In restorative dentistry the applications include repairing fractured porcelain veneers, root canal posts, reinforcement of composites. FRC restoration is a tooth conserving technique which is minimally invasive. It is so, because of the adhesive technique clubbed with physical properties of the restoration, along with the orientation of individual fibers and its position.

KEYWORDS: Composite, Fiber reinforced material, Mechanical properties.

INTRODUCTION

Fiber reinforced composites (FRC) are the material of the new era which are defined by moral mechanical properties including high fatigue resistance and fracture toughness. They are metal free materials with light weight. They have not only been used in dentistry but have shown wide industrial scale application as well (boat hulls, bullet proof jacket, sports equipment). The first evidence of use in dentistry dates back to the 1960s where fiber reinforcements were used to reinforce denture base acrylics.[1] The constant advancement of the fiber reinforcement and the better understanding of the handling properties, has brought FRC into the arena of dental materials on a large scale.

First off, the FRC were used for reinforcing acrylic base materials of removable dentures.[2] the reinforcing effect of the fibers were found to exceed the effect of that of the conventional metal wire strengtheners.[3] On the successful combination of the fibers with dimethacrylate resins and filler particles of composite, their application began in the field of fixed prosthodontics along with the other fields of dentistry. As reported in the literature, FRC have been used as fixed partial dentures, implant supra-structure, periodontal splints and orthodontic retainers. In restorative dentistry the applications include repairing fractured porcelain veneers, root canal posts, reinforcement of composites. FRC restoration is a tooth conserving technique which is minimally invasive. It is so, because of the adhesive technique clubbed with physical properties of the restoration, along with the orientation of individual fibers and its position. To name a few more advantages of FRC materials are as following:

- Cost effective
- Good esthetics
- Better strength

Structure and properties of Fiber reinforced composites

The reinforcing fibers of FRC are ingrained in a polymer matrix. In comparison to the filler particles of composites used in restorative dentistry, The FRC have high ratio of fillers that reinforce them. In FRC, strength and rigidity are provided by the fibers, whereas the matrix of the polymer holds the fibers and forms a looped phase around the reinforcement. This in turn carries the load to the fibers. For the display of a minimally acceptable mechanical properties, the fibers should adhere well and should be impregnated well enough by the polymer.[4,5] the complete impregnation is important to reach the optimal mechanical properties. Other parameters that affect the reinforcing effect of the fibers are, fiber volume fracture, fiber elongation.

The reinforcement type, orientation and position clearly define the mechanical properties.

Based on the design of the composite, they can be of two types, namely, unidirectional and multidirectional. Unidirectional fibers run parallel and multidirectional fibers are oriented in more than two directions, basically direction. With increase in the fiber volume fraction, there is an increase in the tensile strength of the composite. In dentistry, this concept is more often applicable than that of the total fiber reinforcement. Such a reinforcement is applied to a high stress bearing area where it is placed along with another material to fulfil the hygienic and esthetic demands.

Fiber length and orientation

The orientation of fibers in the direction of the stress provides for the highest reinforcing efficiency. In case of stress application perpendicular to long axis of fibers, there is no reinforcement of the polymer. Direction of the long axis of the fibers are responsible for the mechanical properties. This is called as anisotropicity. Krenchel's factor is used describing the efficiency and the length and orientation dependency of the fibers. The direction and the position of the fibers can be modified, in order to attain reinforcing capability and maximum strength against the stresses. Apart from the mechanical properties, other properties like optical, polymerisation contraction, surface and physical properties, of FRC also depend upon the fiber orientation.

According to the usage of the ratio aspect of the fibers, FRCs can be defined as short discontinuous or long continuous FRCs. Application of long continuous FRC is typically seen in the case of root canal post. Fibres which are short and discontinuous are used to reinforce restorative composites. Despite the fiber volume fraction remaining as same, the mechanical properties of long and short FRC vary from each other. The replacement of continuous unidirectional fibers by the longitudinal orientation of the discontinuous fibers of reduced ratio aspect, result in the decrease in ultimate tensile strength of the composite.[6] Despite this, the material remains anisotropic. But in case of random orientation of short fibers, the material becomes isotropic, along with the decrease in the tensile strength of composite.[7] The type of failure that occurs in the different type of FRCs also vary from each other. In case of discontinuous short FRCs, the failure occurs as following:

- Cracking of polymer matrix
- Fracture of fiber
- Debonding of fiber

The type of failure seen in case of unidirectional continuous FRCs are as following:

- Shera failure
- Transverse failure
- Axial tensile failure

Type of fiber

To develop the strengthening effect in the fibers, compared to the matrix polymer used, their flexural modulus must be greater. Various forms of fibers have been tested and have been found to be useful as reinforcements of dental polymers. Those that are common are glass, carbon or graphite and polyethylene fibers.[8]

The most suitable for clinical use in dentistry, at present, are glass fibers. Some of their advantages are low extensibility, high tensile strength, decreased cost, remarkable compression and impact properties. Due to their transparent appearance, they can be used to meet demands with high cosmetics in case of root canal post in the anterior teeth.

The most essential reason for the high performance of glass fibers is its surface chemistry. The surface chemistry regulates the adhesion to dental polymers through the coupling agents. Glass fibers stretch in a uniform fashion when under stress up to their breaking point. When the tensile load is removed just before the breaking point, it is observed that the fiber returns to its original form.

Their high original strength helps the glass fibers to store and release large amounts of energ. Based on the chemical composition of the glass mass, the glass fibers are classified as following:

A-Alkali glass type
C-Chemically resistant glass type
D-Dielectric glass type
E-Electrical glass type
R-Resistant glass type
S-High strength glass type

The various types of glass fibers, vary in their mechanical and chemical resistant properties. E- glass type is the most commonly used glass fiber in reinforced composites. This consists of calcium alumino-boro-silicate. The technological developments in dental FRC, have produced high flexural strength values (up to 1150 MPa) of the unidirectional E glass fibers. This value is quite comparable to the cast cobalt chromium alloy (1200 MPa).

In case of high performing application, carbon/ graphite fibers have been extensively used in reinforced composites. Carbon fibers have been considered lighter than aluminium, stronger than steel and stiffer than titanium. Generally, carbon/ graphite fibers show very high strength in tension and compression, although their mechanical properties differ along with the composition. In early 1970s, the first dental application of carbon/graphite fibers was seen in PMMA (Poly-Methyl-Methacrylate).

This resulted in an increase of nearly 100 per cent in flex ural strength.The main shortcomings of carbon fibers were the black colour of the fibers, that limited its use in dentistry. Some other drawbacks also included difficulties in manufacturing and handling properties. Most common application is the use of prefabricated posts for root canal.

Among the strongest reinforcing fibers available are the Ultra High Molecular Weight Polyethylene fibers (UHMW). They provide good impact resistance and consists of aligned polymer chains with low modulus of elasticity and density. They are highly suitable for dental application since their colour is white. Due to the complications involved in bonding the fibers to the dental resins, their clinical use remains limited despite the excellent flexural properties.

Bonding properties

FRC composed

FRC Composed of more than one type of material just like all composite materials. The fibers resin matrix and other organic fillers play the role of the bonding substrate. Through silanization, glass and silica fibers can be bonded to dental resins. This contributes towards the bond strength of the composite structure. Silane coupling agents encourage adhesion through the formation of hydrogen bonds with glass surface and covalent bonds with the methacrylate group of the resins.

The polymer matrix, mainly depends upon the resin type system used. Contemporary resin systems are mostly dimethacrylate based. In FRC, both dimethacrylate and epoxy-based matrices have been put to use. Most of the dental FRCs make use of the resin systems based on Bisphenol-A-Glycidyl Dimethacrylate (bis-GMA), Triethylene Glycol Dimethacrylate (TEGDMA) and Urethane Dimethacrylate (UDMA). Highly crossed linked polymer networks are formed by these thermo-setting, multi-functional resins. Therefore, these are poor adhesive substrates in a dental office.[9]

One of the methods to enhanced bonding properties is by altering the components of resin matrix of FRC. This can be done by introduction of a phase with a lower degree of cross-linking polymer chains. A mix of thermoplastic and thermosetting polymer chains, that makes up this multiphasic matrix polymer, can be defined as semi-interpenetrating polymer network (Semi IPN). A combination of thermoplastic and thermoset resins has been developed to make impregnation methods of glass fibers. The addition of linear polymer of PMMA to the matrix results in an increase in the toughness of the material, along with the increase in its surface adhesive properties. It has been demonstrated by several authors that the addition of a semi IPN structure in the composite adhesion. For fabrication of root canal posts and bulk filling composite, FRC uses the semi IPN chemistry.[10]

Applications of FRCs in restoration of endodontically treated teeth

Unidirectional FRCs

A common application of unidirectional FRC in dentistry is a root canal post. During the last decades, the use of FRC root canal posts has rapidly increased. The posts anchor the cores and crowns to the root. Unidirectional FRC can be used individually formed in situ polymerized posts and as prefabricated fully polymerized solid posts. In 1990s, the first prefabricated carbon/graphite FRC post (Composipost, C-post) were introduced. Since then various glass and quartz fibers have come up and have gradually taken the clinical field of prefabricated FRC posts.[11] The early clinical reports of the post showed good survival. But studies with long follow up periods showed some unfavourable outcomes.[12] Requirements for advanced flexural behaviour and high cosmetic demands, led to an increased development of glass FRC posts. It was found out that glass FRC posts showed adequate performance in relatively short time of clinical follow up.

Prefabricated FRC posts

Prefabricated FRC posts form a solid post with a predetermined diameter. In a finally polymerized polymer matrix, these posts consist of continuous unidirectional reinforcing fibers that are of high-volume percentage. Carbon/ graphite or glass (E glass, S glass, quartz/ silica) fibers are used in the posts of prefabricated FRC. The matrix is either of a mixture of epoxy polymer. These matrices have a high degree of conversion and structure which is highly crossed linked. The matrix is usually elastic in nature to which stiffness and strength is contributed by the fibers. The quantity of fibers varies from 65 to 40 volume percentage.[13]

Prefabricated FRC posts have carious advantages over the conventional metallic posts. A suitable elastic modulus is one of the most important benefits of the glass FRC. This property should result in lesser number of root fractures and lesser unfavourable failures. In addition to the previous one, some other advantages that can be numerated are easy build up and removal, good esthetics, especially with prefabricated glass FRC post.[14]

Along with the favourable properties and advantages, there are a few disadvantages of prefabricated FRC posts as well. Due to its preformed shape, the prefabricated FRC posts rarely follow the root canal anatomy. Due to this, there will be a large amount of space which will be filled with resin cement coronally. This also means that there will be an unnecessary amount of dentin removal from the apical aspect. In addition to this, the coronal aspect of the post and core system may not be stiff enough for the resistance of the high stress produced by occlusal loading at the cervical and coronal areas. This results in a post-core system that lacks the sufficient load bearing capacity and a tooth which is restored but will be unable to resist the high stress at the restoration margins, especially at the cervical region. The outcome will be breaking down of the margins due to adhesive failure. The failure will be on the tension side of the restoration and as a result, it will end up in secondary caries. This may be observed in the cases where the restoration lacks a ferrule effect.

The attachment of prefabricated FRC posts to the root canal dentin is through the composite resin luting cements and adhesives. The polymer matrix which is highly cross-linked, is non-reactive. Due to the matrix's high degree of conversion and non-reactivity, the bonding to resin luting cements and core material, becomes difficult. The bond is mainly mechanical in nature, between the composite resin luting cements, composite core material and epoxy-based matrix of certain FRC posts. In order to overcome adhesion problem, some additional features can be included like serrations. This addition to the post increases the mechanical retention of resin of resin cements and core material. But this feature has been of no benefit or has been harmful with respect to the flexural strength of FRC post and its adhesion when the post was of anisotropic nature.[15] Different mechanical and chemical surface treatments have been advocated to improve the bond. Some of these approaches comprises of air- particle abrasion, resin impregnation along with silanization.

Individually formed FRC posts

In order to overcome the limitations of prefabricated FRC posts, new alternatives have been put forward to restore the endodontically treated teeth using a post, in an optimal way. This has given rise to a concept of developing an individually formed FRC post system using different materials. For such a concept, a study used cold-gas plasma treated polyethylene woven fibers. When individual customized FRC posts were compared to prefabricated FRC posts, more favourable fractures and better resistance under loading were reported. A so-called anatomic post with superior fit to the root canal was obtained with a layer of light- curing resin covering the translucent fiber post.[16]

In comparison to prefabricated posts, the individually formed glass FRC post showed significantly higher bond strengths and fatigue resistance. Non-polymerized fiber-resin prepregs, consisting of glass fibers and light curing resin matrix, make up for the individually formed FRC posts along with a semi-IPN polymer matrix. The aim of the custom made FRC post is to fill the root canal space completely, in a cross section with the FRC material. This will be done following the anatomy of the canal and by using minimally invasive preparation method. This method allows the placement of more reinforcing fibers, especially at the cervical parts of the canal. These cervical parts are the regions where high tensile stresses act, so this method results in an increase in the resistance. The ability to place more fibers in the coronal aspect of the root canal enhances the load bearing capacity of the post system. FRC post made using this technique resembles traditional cast post and core design. More dentin can be saved in a structurally compromised tooth by following the anatomy of a modern flared canal preparation along with gradual increase in the thickness in apico-cervical directions.

Added advantage of the individual technique results from the bonding properties. The problems concerned with the adhesion between post and cement are minimized when using the individually formed FRC post which comprises of a semi-IPN polymer matrix between the fibers.[17]

The oxygen inhibition layer dictates as an adhesion promoter for chair-side technique. A non-polymerised surface layer forming occurs as resins are polymerized in the presence of oxygen such as independently shaped root canal posts. This formed layer is known as the oxygen inhibition layer.[18] A durable bond can be formed when the resin cements have the ability to attach to the oxygen inhibition layer.[19]

It has been documented that bonding of the independentl y shaped FRC post to resin cements is strong. When the dimension of the canal orifice is followed by the post closely, there is a decrease in the cement thickness. This reduces the stress due to polymerization contraction in the adhesive layers in between dentin and post.

The highest stress occurs closer to the dentinal walls therefore, the biomechanics of tooth is simulated better when the fibers are placed closely to the walls. In teeth restored with prefabricated FRC posts, the common type of failure that is encountered is adhesive failure and marginal leakage. This occurs especially on the tension side of the tooth where there is a lack of outer ferrule of the restoration. By providing increased stiffness and resistance in the critical cervical area, he individual FRC post decreases the chance of adhesive failures of the restoration. Moreover, a tooth is restored with short and thick individual FRC. This technique provides with advantage from an operative point of view as well. a root canal preparation which is short, consumes less time and also prevents unnecessary hard tissue removal.

The basic need of a sufficient conversion degree of the polymer matrix of attained by using individually formed

FRC post material. When considering fracture load and microleakage, the direct method of polymerizing the individually formed FRC post along with resin cement in the root canal may be superior to the pre-polymerizing.

Short discontinuous FRC in restoring Endodontically treated teeth

Studies and research have shown that fibers can also be used as reinforcements of restorative composites. Some failed attempts have been encountered while reinforcing restorative composites. The failure mostly occurred due to insufficient length of the fibers. Failure of reinforcement for the entire material has occurred due to poor polishing ability of the restoration surface. In order to maintain the applicability for the filling material, fibers should be discontinuous and short. The length of the fibers have to be above critical value. This is necessary for the fibers so that they can provide substantial improvement towards the mechanical and polymerization contraction properties.[20] The fiber length of advanced FRCs should be 50 times more than that of the diameter of the fiber which is also the critical fiber length. The critical fiber length can vary from 750-900μm.

The present trend for using FRC in dental restorations is as a separate base increment. The material gains its strength and toughness when the fibers in the reinforced base increment are longer. In order to attain good esthetics and proper polishability, the base layer is covered with a conventional particulate filler composite (PFC). Superior mechanical strength and fracture toughness are achieved through short FRC base restorations. This also serves as a crack prevention layer by stopping crack propagation by supporting the PFC layer (Particulate Filler Composite). In vitro studies have shown that the use of a bi-layered structure consisting of a fiber reinforced composite sub structure combined with an upper layer of conventional restorative composite increases the fracture load of a restoration.[21] Composite crowns in endodontically treated teeth molars were also significantly reinforced with a short fiber composite core restoration.

In case of molars with adequate amount of tooth structure that have undergone endodontic therapy.

In an endodontically treated teeth, especially molars, in case of presence of adequate amount of coronal dentin, a choice can be made to if post placement can be avoided. A short fiber composite is good enough for restoring the missing coronal dentin.[22] Short FRC transfers the occlusal load equally to the tooth due their adaptation with composite and tooth structure. The fibers also allow the transmission of light, resulting in increased polymerization depth. This feature allows to follow a simple technique for bulk restoration.

This makes the haphazardly directed fibers perpendicular to the axial cavity walls when the material is filled into t he cavity.

An FRC's polymerisation shrinkage is reduced in the dire ction of the fibers ' long axis. The ideal fiber length for a controlled polymerization contraction was 1 to 3 mm. The crack propagation is influenced by the fiber reinforced layer of the restoration. Favourable and repairable fracture behaviour has been demonstrated by the teeth restored with short fiber composite core restoration, when compared with the teeth filled with a particulate filler composite only. Few clinical studies with one year follow up have showed that short FRC when used in endodontically treated teeth is suitable in restoring large coronal defects in both non-vital and vital tooth.

CONCLUSION

The anisoptropic nature of the reinforced composites makes them as the dental material of the new era, serving advantages like being tooth coloured, promotion of use with adhesives and for direct restorative techniques.

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