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Fiber-Reinforced Composites in Operative Dentistry (A Literature Review)

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Abstract
Fiber-based composite materials have gotten a lot of interest because of their strength, toughness, corrosion resistance, and lightweight.

By functionally modifying the fiber components, fiber-based composite materials can preserve their original qualities while enhancing or overcoming the drawbacks of any single material.

Composites constructed from modified fibers are highly suited for usage in a range of industries, including aerospace, high-rise construction, bridge and highway building, and maritime infrastructure, because of their excellent mechanical qualities, impact resistance, wear resistance, and fire resistance.

Offering a solid scientific basis for the synthesis of fiber-based composites and their practical applications is the aim of this research.

Introduction:

Common composite materials made of a polymer matrix and extremely thin fiber reinforcement are known as fiber-reinforced composites (FRCs). To give reinforcement, these fibers were added to the composite resin mixture (1, 2). The fibers are held together

and given workability by the polymeric matrix, which is composed of polymerized monomers. Compressive strength, inter-laminar shear and in-plate shear properties, matrix-fiber interaction, and composite defects can all be impacted by the matrix. Several techniques, such as injection molding, have been used to create polymers reinforced with fibers and particles. (3), compressive molding (4), hydrostatic extrusion, and self-reinforced (die-drawing) (5). FRC technology was first developed in dentistry in the 1960s for reinforcing acrylic denture bases. Although it enhanced mechanical qualities, clinical acceptance was low due to decreased fiber volume and insufficient fiber wetting, which resulted in voids in the FRC structure. These issues were solved in the late 1980s when dental researchers created complete resin impregnation of the fiber (6, 7). Polyethylene, glass, polypropylene, carbon, and aramid fibers are the most often used reinforcement fibers in dental applications. The matrix is made of epoxy resin, which keeps the reinforcement secure and gives rigidity and strength to the prosthesis. They have numerous applications in various branches of dentistry. In order to prevent fractures and partially strengthen the weak tooth from the inside, fiber reinforcement might be used. The effectiveness of fiber reinforcement is influenced by a number of elements, including the resins that are employed, the length of the fibers, their orientation, their position, and their adherence to the polymer matrix. (8). The fiber fillers' reinforcing effect is based on stress transmission from the polymer matrix to the fibers. Individual fibers, on the other hand, operate as crack stoppers. Stress must be transferred from the polymer matrix to the fibers. Only if the fiber length is equal to or larger than the critical fiber length is this feasible. Between.5 and 1.6 mm are the key fiber lengths of E-glass with a bis-GMA polymer matrix (8). Furthermore, it is understood that a structure's mechanical properties are influenced by the placement and orientation of reinforcement within the structure (8).

Classification of fibers
The fibers could be classified according to the material into:

1. Glass fibers composed of glass interlaced filaments with minimal extensibility and high tensile strength. They are ideally suited for dental applications with high aesthetic standards due to their clear appearance, however, they do not adhere well to resinous matrix (9). Glass fibers provide a number of benefits, including low cost, great chemical resistance, strong tensile strength, and superior insulating properties. Glass fibers' disadvantages include their high density, limited fatigue resistance, low tensile modulus, and greater sensitivity to wear. (10). They are marketed in a variety of grades depending on the chemical composition of glass.

a.Glass A—or Alkali glass was widely used as a starting material when making glass fiber. The dentistry industry is less interested in this glass because of its poor chemical resistance to water and strength, despite the fact that it is inexpensive and helpful as a filler for plastics.
b.Glass C—or These fibers are employed in the creation of surface layers to provide additional chemical protection over E glass because they have strong corrosion resistance.
c. Glass E— The most popular type of glass fiber used in dentistry is electric glass, which excels in both electrical and mechanical properties. These fibers stand out thanks to their strong water resistance. This grade's primary drawback is the presence of volatile substances like fluorine.
d. Glass R— A reinforcement glass consisting of calcium alumino silicates that is utilized when more strength and acid corrosion resistance are required.
e. Glass S— This glass has a high degree of flexibility and strength. However, due to the manufacturing methods, it is highly expensive. Glass S has extremely few uses and is mostly employed in the aerospace industry.

2. Carbon fibers They prevent composite materials from fatigue fracture and toughen them, but they possess a dark color which is esthetically unpleasant (11).

3. Kevlar fibers are an aromatic polyamide descended from nylon polyamide. They improve the impact resistance of composite

materials. However, because they are unattractive, their application is limited. (11).

4. Vectran fibers are the most recent aromatic polyester-based synthetic fibers. They have high abrasion and impact resistance, but they are expensive and difficult to manage (11).

5. Organic fibers
Organic polymers can be produced chemically or biologically to make organic textiles. Organic fibers include polyester, acrylic, nylon, and polypropylene in addition to high-performance fibers such aramid fibers, UHMWPE fibers, polyparaphenylene benzobisoxazole (PBO fibers), polybenzimidazole (PBI fibers), polyphenylene pyridoimidazole (M5), and polyimide (PI) fibers.

a.Aramid fibers.
Aramid fibers and carbon fibers both possess low density, high stiffness, high strength, and high specific modulus. It is clear that aramid fiber is an incredibly attractive organic fiber since the axial properties of advanced composite materials reinforced with aramid fiber are comparable to those of composite materials reinforced with inorganic fiber. Due to aramid fibers' high crystallinity, significant surface inertness, and poor off-axis strength, the majority of industrial composite resins do not react to them in a way that takes full advantage of their advantages. The interaction of mechanical interlocking, polarity matching, and chemical bonding at the fiber/polymer contact has a significant impact on the outcome. Van der Waals force/electrostatic contact, an increase in surface area, and chemical connections between the fibers and resin can all help in this interaction.

b.Polyethylene fibers
Polyethylene fibers improve the flexural strength, modulus elasticity, and impact resistance of composite materials. Polyethylene fibers merge almost entirely into a resinous matrix, unlike carbon and Kevlar fibers, giving them the most aesthetically attractive reinforcement for composite goods (11).

Factors influencing the mechanical properties and reinforcing capacity of FRC
A. Aspect ratio
The aspect ratio is the ratio of fiber length to fiber diameter. This ratio is significant since it affects the FRC's tensile strength, flexural modulus, and reinforcing capacity. A FRC must have an aspect ratio of 30-94 in order to properly transfer stress from the fibers to the resin matrix. (12).

B. Critical fiber length
Critical fiber length is the minimum fiber length needed for the fiber reinforced composite to be reinforcing (12). The length of the reinforcing fibers must be equal to or greater than the critical fiber length (Lc) in order to ensure that the stress is passed between the fibers. Continuous fibers have a length that is obviously greater than Lc, whereas discontinuous fibers have a length that is less than Lc. The matrix deforms around fibers that are considerably shorter than Lc, resulting in very little stress transfer and almost no reinforcing (13). This critical length, which in glass systems is typically between 50 and 150 times the diameter, is the minimal fiber length that permits tensile failure of the fiber while minimizing the likelihood of shear failure in the matrix or at the interface (14).

C. Fiber Loading (Volumetric Fraction) within the Restoration
By increasing the amount of fibers in the polymer matrix, the fracture resistance of the restoration is increased. It's vital in the clinical situation to establish a balance between enhancing this element and keeping enough area for the overlaying composite. This is necessary in order to execute necessary shape and finishing adjustments while retaining perfect aesthetics. Finishing must be done with care because exposing the fiber reinforcement may cause the resin fiber interface to erode, leading the restoration to fail prematurely. (15). The quantity of fibers used to reinforce a material can significantly affect the material's mechanical characteristics. In dentistry, the volume percentage of fiber is typically kept low since it must be coated with a layer of unfilled polymer, whereas GFRCs typically have a large volume fraction of fiber at around 60 vol.%. (16). The specimen with 7.6 weight

percent glass fibers exhibited very little matrix and a cluster of fibers that was probably brought on by overloading, according to Callaghan et al.'s examination of the GFRC's wear behavior. When there is a lot of glass fiber present, fiber fracture might happen. The amount of fibers in the matrix should range between 2.0 to 7.6 weight percent to offer the optimum wear resistance, bonding, and fracture risk (17).

D. Water sorption

Sorption and solubility can have negative repercussions in a dental FRC. Over time, mechanical characteristics may decrease as a result of water absorption. This happens as a result of the fibers degrading hydrolytically or the matrix and fiber bond breaking (18). All mechanical metrics, including wear resistance, flexural strength, tensile strength, and modulus of elasticity, have been found to be adversely affected by water absorption (19, 20). Concern has been expressed concerning the decreased service life of these materials due to the detrimental impact that water sorption has on the mechanical properties of FRCs. (21). Water sorption can have a negative impact on the characteristics of FRC materials, but it can also be advantageous. According to McCabe et al., water sorption expansion can aid to reduce strains from polymerization shrinkage on the restoration interphase(7, 22).

E. Fiber Architectures and Orientations

Glass fibers can be mixed in a variety of ways, including unidirectional fiber laminates, discontinuous short and long fiber (bidirectional) injection molding, and textile textiles (woven, knitted, and braided fabrics) laminates. Numerous applications benefit from the anisotropic (different properties in different directions) qualities of unidirectional continuous fibers. There are many different types of bidirectional fabrics, such as linen and twill weave. In randomly (chopped) oriented fibers, isotropic properties, or characteristics, exist. These are attributes that are the same in two dimensions but vary in the third, orthogonal direction. Fiber weaving serves as an example of bidirectional polymer reinforcement. When tension is applied perpendicular to the path of the fiber, unidirectional glass fiber is more powerful than bidirectional glass fiber. however, the

strength of unidirectional longitudinal GFRC materials declines when tension is applied at an angle to the direction of the fiber. The chopped fibers or whiskers were all considerably smaller than the composite specimen's size and were distributed unevenly throughout the matrix. Hybrid fiber composites are made by combining two or more different types of fiber (23).

Prior research on GFRC orientation has mostly focused on the impact of the directionality (i.e., random or longitudinal orientation) of the fiber reinforcement. (24). It is well known that glass fibers experience strength strengthening when they are orientated with their long axis perpendicular to an applied force. On the other hand, failures caused by forces perpendicular to the long axis of the fibers usually involve the matrix with little real reinforcement. Occasionally, utilizing design techniques that give multi-directional reinforcement, it is possible to lessen the unidirectional fiber reinforcement's very anisotropic behavior (25). The effectiveness of the reinforcement of FRC, loaded at different levels, is described by the Krenchel factor (K). (26). If the fibers are unidirectional (all aligned in the same direction; see Fig. 1A), the maximal reinforcement level for cracks perpendicular to the fiber direction in FRC is K=1 (100%). However, anisotropy causes K=0 in other loading directions (see Fig. 1D). The effectiveness is reduced for K=0.5 if the fibers are bidirectional (positioned perpendicular to one another), leading to equal reinforcement in both directions as well as other orthotropic properties (see Fig. 1C). In contrast to three-dimensional structures, where reinforcing efficacy is lower (K=0.20), SFRC reinforced with randomly oriented fibers have a terialsarecon strained within planes (K=0.38) (see Fig. 1C) (26). However, neither the direction of the stress nor the resulting crack affects this reinforcement. Alterations in fiber orientation may result with the installation of SFRC in a cavity, and these alterations may have a clinical impact on fiber alignment. Anisotropic reinforcement might come from the fibers being rearranged from a random orientation to a planar orientation, for instance, as a result of the restorative technique. The fiber length and cavity size have an impact on how the fibers are arranged. Anisotropic properties result

from the organization of the fibers in the cavity plane when cavities are narrower than the fiber length during composite implantation. Shorter fibers facilitate multidirectional fiber configurations that produce isotropic properties. On the other hand, longer millimeter-scale fibers can take on a planar orientation, providing anisotropic reinforcement (27). Fig.1 The effectiveness of multiple fiber orientations in terms of crack propagation (Krenchel's factor K).

A: Unidirectional fiber orientation with a reinforcing capacity of 1.0; B: Bidirectional fiber orientation with a reinforcing capacity of 0.5; for a fracture perpendicular to the fibers. For a fracture parallel to the fibers, D: Unidirectional fiber orientation has a reinforcing capacity of 0.0, and C: Random fiber orientation has a reinforcing capacity of 0.2 in three dimensions.

When compared to unidirectional fiber, the multidirectional reinforcement, however, is accompanied by a loss of strength in either direction (28). The center of a composite specimen has traditionally been filled with glass fiber reinforcement (GFR). The orientation of the fibers within the polymer matrix has an impact on the mechanical characteristics of GFRC as well. The strongest and stiffest component was made of continuous unidirectional fibers, but only in the direction of the fiber itself. As a result, the composite also has orthotropic mechanical properties, and unlike woven fibers, which reinforce the polymer in two directions, the reinforcing effect of unidirectional fibers is anisotropic. When fibers are randomly oriented, their mechanical properties are isotropic, the same in all directions.

Lower wear volumes and rates were demonstrated by longer fibers in a composite. This is acceptable given that fibers shorter than the crucial length might not have allowed the full potential of the GFRC to be fulfilled. The critical length of glass fiber is influenced by both the fiber's strength and the interfacial shear strength. Additionally, short fibers can readily cluster together and weaken the composite (17). Theoretically, stress transfer from the polymer matrix to the fibers and individual fiber behavior as crack stoppers both influence the reinforcing effect of fiber fillers. It's conceivable that the

strength of continuous unidirectional GFRC can be found in the 3 mm parallel fibers (28). The maximum reinforcement level for cracks perpendicular to the fiber direction in FRC is K=1 (100%) if the fibers are unidirectional (all aligned in the same direction; see Fig. 1A).However, in other loading directions, anisotropy results in K=0 (see Fig. 1D). (17, 29). The ultimate strength and fracture resistance of GFRC were frequently boosted by prolonging the glass fibers, according to research by Xu et al (30). Clinically significant, these traits would affect how long a restoration would endure. The orientation of the glass fibers affects the composite's thermal performance. There is a distinct thermal coefficient that applies depending on the direction of the fiber. For instance, this may have a clinically significant effect on the bond strength of the veneering composite to the GFRC framework of the fixed partial denture and the bond strength of the GFRC appliance to the tooth material. (23).

Linear shrinkage strain is influenced by fiber orientation. Continuous unidirectional GFRC materials had negligible shrinkage strain along the fiber, but the majority of the shrinkage occurred in the direction orthogonal to the fiber direction. Similar to continuous unidirectional GFRCs, the bidirectional GFRC showed very little decreasing strain in either direction. In comparison to bidirectional GFRC, the polymerization shrinkage of GFRC with randomly oriented fibers was a little higher. Utilizing short strands also has the benefit of minimizing shrinking (31).

Dentin and enamel adhesion both depend on fiber direction. Tezvergil et al. claim that randomly arranged fibers have the strongest shear connection to enamel. Contrarily, bidirectional fibers give dentin the strongest shear bond possible (29).

F. Impregnation of fiber with polymer matrix
When the load can be transferred from the matrix to the reinforcing phase, as is often the case with dental composites, only then is GFRC beneficial. This is only achievable when the fiber is tightly bound to the matrix. (32). The degree of GFRC impregnation used in dental applications affects how FRC behaves. The GFRC's capacity to sustain its own weight is diminished by gaps between the matrix and the fiber caused by inadequate impregnation (33). Additionally, the flexural

strength and modulus of GFRC are notably different from the values that theory predicts. Another problem brought on by incorrect impregnation is water sorption. Water can enter the laminate through fractures and crevices, weakening the binding and perhaps causing the GFRC polysiloxane network to hydrolyze (34, 35).

Additionally, it causes discoloration because oral bacteria can enter the GFRC holes due to insufficient filling. Additionally, these holes act as spaces for the storage of oxygen, which enables oxygen to stop the radical polymerization of the acrylic resin in the GFRC. If the fibers are pre-impregnated with polymers, monomers, or a combination of the two, the GFRC can be totally impregnated. The degree of the fiber's impregnation and the polymerized GFRC's adhesive properties are both impacted by pre-impregnation. If the fibers are pre-impregnated with light polymerizable bifunctional acrylate or methacrylate monomers, the polymer matrix is highly cross-linked in nature. The inter-diffusion of the new resin's monomers and free radical polymerization serve as the foundation for the relationship.

The GFRC substrate and resin can be joined using unreacted carbon-carbon double bonds of functional groups on the surface of the polymer matrix. Free radical polymerization is unlikely to link the polymer since there aren't enough unreacted carbon-carbon double bonds on its surface (36, 37). The inter-diffusion of monomers to the substrate is another alternative for fusing new resin to the antiquated composite substrate. When using a partially cross-linked polymer as the substrate, bonding based on monomer inter-diffusion is conceivable.. (38), and The linear phases of the substrate, such as the semi-interpenetrated polymer network (semi-IPN), can be dissolved by the new resin's monomers. In the semi-IPN polymer, there is no chemical link between the linear phases and the cross-linked polymer network. The independence of the semi-IPN polymer is necessary for good bonding based on monomer interdiffusion. If there are GFRC structures in the oral cavity that need to be repaired or if polymerized GFRC work developed in a lab is finally cemented to the tooth structure using composite luting cement or low-viscosity light-curing adhesive resins, this may occur. The innovative GFR's pre-

impregnation matrix contains linear polymer phases, which should make it easier to use the IPN bonding mechanism to connect the old FRC framework substrate to the new composite resin. Semi-IPN, which includes both linear and cross-linked polymers but is not chemically coupled as a single network, has been used in dentistry. Detachable dentistry, acrylic resin polymer teeth, and denture base polymers have all benefited from its use (38, 39).

G. Effect of contents

The amount of alkali, earth-alkali ions in the glass fiber is crucial because boron oxide combines with the oxide ions in the water to leach off the glass' surface. By destroying the network that sustains it, the leaching of the glass-forming chemical weakens the glass. Six to nine weight percent of the fibers in e-glass are made of B_2O_3 (40, 41). By treating the glass fiber appropriately, the deterioration of the glass surface can be reduced. To solve this issue, Preimpregnated (Pre-preg) GFRC was utilized. They don't require moistening before use because the matrix has already been infused into them. Contrarily, impregnated fibers are glass fibers that have been coated with a highly porous PMMA polymer matrix. These fibers must be soaked in a resin that doesn't contain any solvents or in a resin mixture that is both liquid and powder. (42).

H. Adhesion of fiber to polymer matrix

It was possible to create strong adhesion between glass fiber and polymer matrix with the aid of a silane coupling agent. A silanol group has been found to condense with an inorganic molecule, such as glass fiber, improving bonding strength and decreasing water sorption (43, 44). To increase their adherence, it was recommended that an IPN layer be created between the matrix and the glass fiber. Sizing linear polymers that were partially or totally dissolved by matrix bi or multifunctional acrylate monomers resulted in the IPN structure (45). The degree to which the glass fiber attaches to the resin matrix determines how strong the composite will be; if this adherence is inadequate, the glass fiber will behave as an inclusion in the matrix and weaken the composite. The degree of adhesion between the GFRC and other polymer matrix is one of the key problems with clinical lifespan because of the large differences in deformation behavior between

GFRC and other composites, which cause significant stress to collect around the bi-material interface (46, 47). Van der Waals forces, chemical bonds, electrostatic attraction, and mechanical interlocking are a few examples of interfacial forces that hold two components together. The degree of bonding, viscosity, chemical composition, and mechanical characteristics of the substrates that are joined all have an effect on how strong the adhesion connection (48). Since any estimation of adhesion strength necessitates measuring a fracture stress, the stress distribution over the entire adhesion joint must be in good shap (49). It is expected that the interfacial bonding between GFRC and particle filled composite (PFC) is based on the resin and will not be altered by the addition of the filler if the higher viscosity of the PFC does not hinder wetting of the GFRC surface. Since it is frequently reinforced with unidirectional aligned fibers in dentistry, its response is primarily orthotropic. The most sensitive aspect of their mechanical response is often their interfacial/inter-laminar shear strength. The real relationship between PFC and GFRC under examination may consist of a combination of chemical and mechanical interlocking (50). Mechanical interlocking has no effect on the creation of an adhesive bond because of the flat surface of the cured GFRC and the fact that adhesion strength increases with filler loading.

Clinical Applications of FRC
Periodontal splinting/post trauma splints
Direct splinting and tooth stabilization used to necessitate the use of pins, wires, or mesh grids, as well as adhesive materials. Only the restorative resin is mechanically bound around these materials. As a result, stress may accumulate and shear planes may emerge, leading to composite failure and fracture. The difficulties associated with prior types of reinforcing were overcome with the introduction of polyethylene woven ribbon strands. Ribbond sticks well to restorative materials. In contrast, a specific fiber network efficiently transfers the forces operating on it. Another advantage is that the method is quick and easy to use, with no requirement for laboratory work. It is an aesthetic material that can be light-cured due to its translucency (51).

Immediate replacement transitional and long-term provisional bridges
Children and adolescents who have lost teeth due to trauma can utilize an FRC prosthesis to replace missing teeth. It is less intrusive and more affordable than alternative metal-free tooth replacement choices than traditional fixed partial dentures. A functional and esthetic replacement for a lost tooth may be possible using polyethylene FRC fixed partial dentures (FPDs), according to a preliminary retrospective clinical investigation by Piovesan et al. (52).
A functional survival rate of 95% following a 4.3-year follow-up period was found in another investigation. Since it can restore adequate function and aesthetics by restoring missing teeth and tissues until a permanent replacement can be found, this method may also be regarded as an interim treatment for young patients. The patient's own teeth, an acrylic tooth, or a composite resin can all be used to create a pontic (11).

Space maintainer
To prevent malocclusion brought on by early primary tooth loss, a variety of space maintainers can be employed. If worn improperly, removable appliances might cause treatment outcomes that are not adequate. They can also be destroyed or lost. Fixed appliances are less painful for young patients when they are properly made, and they also don't harm the oral tissue as much. As a fixed space maintainer, a polyethylene fiber reinforced composite offers many benefits. FRC has a stunning aesthetic, is simple to use, can be installed in a single appointment without the need for laboratory services, presents no danger of injury to the teeth that serve as abutments, and is simple to maintain. (11).

Endodontic Post-Core
The technique has the following benefits in addition to reducing the risk of root fracture. There is no need to remove a tooth during endodontic therapy when compared to prefabricated posts. This preserves the tooth's inherent toughness. No longer is an option root perforation. It provides mechanical retention and adapts to the undercuts and curves of the canal because it was constructed while the Ribbond was malleable. There are no stress concentrations at the tooth-post

contact (51). Posts and cores with ribboned edges are passive and retentive. Additionally, natural light may pass through teeth and crowns because to the transparent fibers used in Ribbond, which take on the color of the composite. This yields a stunning aesthetic outcome. (53). Gutta percha is withdrawn from the canal using a solvent, rotary instruments, or heated instruments until the required length for the post is achieved; at least 4 to 5 mm of gutta percha should be left in place to protect the apical seal. The second step is to choose a fiber and determine its length. The fiber used is determined by the width of the root canal. The length of the post space is measured using a periodontal probe. This measurement is multiplied by two, and the projected core length is added to determine the needed fiber length. Cut two pieces of fiber using the special scissor.

To regulate polymerization in the deep regions of the canal, the root canal is following treated with a dual cure sticky resin. After that, the root canal gap is filled with a dual-cure resin cement. A piece of reinforcement fiber covered with glue is wrapped and compressed into the canal space using an endodontic plugger. Then, at an angle to the first, a second piece is condensed into the canal area. The excess glue is scraped away, and the free ends of the fibers are twisted and inserted into the canal. The entire fiber resin post is then cured for 20 seconds. The core is finished with a hybrid composite resin (54). Commercial fiber reinforced composites (FRCs) used in dentistry mentioned in Fig. 2.

Polyethylene Ribbond Fiber

Plasma-treated fibers known as Leno woven ultra-high-molecular-weight polyethylene (LWUHMWPE) have been commercially marketed since 1992. LWUHMWPE fiber reinforcing ribbon systems have been devised in an attempt to boost the toughness of composite resins, hence increasing both durability and damage tolerance (55, 56). These fibers are significantly more resistant to breaking than fiberglass and must be cut using specially designed scissors (53). The open and lace-like architecture of the leno woven ribbon allows it to conform precisely to the curves of the teeth and dental arch yet having almost no memory. The material's densely packed network of locked nodal

connections reduces the possibility of fabric architecture damage by preventing fiber moving during modification and correction prior to polymerization. The material has a three-dimensional structure due to the leno weave or triaxial braid.

These characteristics allow for mechanical interlocking of the resin and composite resin in several planes, allowing for a large processing window (57). Ribboned fibers absorb water quickly as a result of the "gas-plasma" treatment to which they are subjected. This treatment decreases fiber surface tension, ensuring a strong chemical bond with the composites. Ribbond is an aesthetically attractive, biocompatible, translucent, practically colorless material that disappears through the composite or acrylic. Ribboned fibers are also five times stronger than iron (11). Ribbond may be employed in a variety of applications due to its unique mix of strength, aesthetics, and bondability. Ribbond is a versatile substance that attaches to both composite and acrylic.

Ribbond-THM still retains the same crack-preventing leno-weave as Original Ribbond despite being more useful, simpler to apply, and producing thinner results. Thinner Ribbond THM fits the teeth more accurately than Original Ribbond, has less memory, and holds its position better before curing. Ribboned-THM is simpler for composites to cover and has less fiber show-through. Ribboned-THM is simpler for composites to cover and has less fiber show-through. Ribbond-THM is designed for applications where thinness and high modulus are crucial criteria. These make use of endodontic posts and cores, orthodontic retainers, short span anterior bridges, and periodontal splints. (58, 59). The interfacial tensions created along the hollow walls are modified by the polyethylene fiber's increased elasticity and lower flexural modulus. (60).

When compared to restorations without LWUHMWPE fibers, Sengun and colleagues found that fiber-reinforced restorations had a fail-safe mechanism. (61). Because fractures typically happen above the cementoenamel junction (CEJ), catastrophic failures are prevented and the remaining tooth structure is repairable.

Family of Ribbond Fibers

Ribbond has a family of fibers appropriate for many applications in dental practice as a result of the increasing need for fibers with enhanced simplicity of application and decreased failure possibilities. Ribbond comes in numerous varieties, including Ribbond THM, Ribbond original, Ribbond Triaxial, and ultra-high-molecular-weight polyethylene.

1.Ribbond Original: Ribbond is a multi-purpose fiber reinforcement that was first presented in 1991. It has a thickness of 0.35 mm and is available in widths of 2mm, 3mm, 4mm, and 9mm. Original Ribbond is the material of choice when final breaking strength is the most crucial consideration. Provisional bridges, composite bridges, and detachable prosthesis strengthening are examples of these. (53).

2.Ribbond-THM (thinner higher modulus): Ribbond-THM was created in 2001 and has more flexural strength than ordinary Ribbond due to thinner fibers with a higher thread count and is only 0.18 mm thick for fixed orthodontic retainers. Although Ribbond-THM is more practical, easier to apply, and produces thinner results than Original Ribbond, it still has the same crack-preventing leno-weave. Thinner Ribbond THM has less memory than Original Ribbond, fits the teeth more precisely, and maintains its position better before curing. Ribboned-THM has less fiber show-through and is easier for composites to cover. Ribboned-THM has less fiber show-through and is easier for composites to cover. Ribbond-THM is intended for applications where important requirements include thinness and high modulus. These utilize short span anterior bridges, endodontic posts and cores, orthodontic retainers, and periodontal splints. (53).

3.Ribbond Triaxial: In contrast to other Ribbond products, Ribbond Triaxial has a different orientation for its fibers. It is a triaxial, double-layered ribbon made up of braided and unidirectional strands. In comparison to current Ribbond products, this patented design offers much higher multidirectional fracture toughness and modulus of elasticity. For bridges, endodontic restorations, and other uses requiring high durability, fracture toughness, and elastic modulus, ribboned triaxial is the ideal material. Ribbond-Triaxial has an additional benefit for these applications in that it only needs a single layer to be placed inside the pontic region and successfully maintains its shape during polymerization. Ribboned-triaxial frequently requires pretreatment because to its thickness (0.5 mm) (53).

4.Ribbond Ultra: It was introduced in 2013, is the thinnest of all ribbond fiber reinforcing ribbons (0.12 mm thick), and is more adaptable than ribboned THM. It also has the highest flexural modulus. Because of its flatter surface against the teeth, the bond line to the teeth is smaller. The widths offered for fixed orthodontic retainers are 2mm, 3mm, 4mm, and 1mm.

Advantages of Ribbond

Because the fiber is made of multidirectional threads and locked nodal crossings, occlusal forces are dispersed over a larger region of the tooth restorative composite. Due to the nature of the fibers, they also act as a crack-stopping mechanism. The locked stitch interlaced fibers change the direction of the strain and stop it from spreading quickly. Polyethylene fiber has a varied effect on the interfacial tensions created adjacent to hollow walls due to its higher elasticity and lower flexural modulus. Sengun and colleagues found that compared to restorations without them, those reinforced with LWUHMWPE fibers have a fail-safe mechanism. The majority of fractures occur above the cementoenamel junction (CEJ), making it possible to recover any residual tooth structure and prevent catastrophic failures can be avoided (62).

Disadvantages of Ribbond

Fiber insertion is an expensive, time-consuming, and technique-specific procedure. As a result, a clinical approach must be optimized because the effectiveness of fiber implantation is based on the fiber's complete integration and impregnation into the resin (63).

Wallpapering Technique

Using closely matched and overlapped Leno woven ultra-high molecular weight

polyethylene (LWUHMWPE) ribbons to cover cavity walls is referred to as "wallpapering". For success, the ribbons must be as closely matched and polymerized to the shapes of the remaining tooth substrate as is practical. A more durable "bond zone" is produced by the resulting thin bond line between the fibers and the tooth structure. The snug fit of the fibers to the tooth structure decreases the composite volume between the fiber and tooth and protects the remaining weaker walls from polymerization shrinkage and occlusal load stress, which reduces the likelihood of defects and voids forming. The appropriate width and length of the fibers to fit inside the cavity are chosen as part of the preparation for wallpapering. The Ribbond Wetting resin from Ribbond Inc. was used to initially dampen the ribbond fiber segments. Before applying a thin layer of sticky flowable composite (Ribbond Securing Composite, Ribbond Inc.), the excess adhesive is removed, and the fibers are C-shaped before beingput into the cavity. Because they are bondable reinforcing fibers, they can be fitted tightly to the remaining tooth structure. One further piece of Ribbond may be put 1.5 mm below the occlusal surface to ensure an extra energy-absorbing and dispersing mechanism if there are apparent fissures, a structurally unsound pulp chamber floor, or patients. with paraphrasing (64) (65).

EverStick fiber
EverStick's fiber reinforcements are made of silanated glass fibers embedded in a matrix of a thermoplastic polymer and a light-curing resin. The advantages of minimally invasive dentistry are addressed by everStick solutions, which prolong the patient's own healthy tooth tissue for as long as is clinically possible. A proper connection between the fibers and the composite is necessary for a successful therapy. The only goods featuring a patented interpenetrating polymer network structure (IPN) are EverStick products. Clinically, this produces exceptional bonding, enabling treatments that are surface-retained to have reliable surface retention and perfect handling features. (GC, India)

Interlig fiber: A composite material with glass fiber reinforcement is called interlig fiber. The interwoven glass strands of Interlig make it simpler for the dentist to use. They perform better in terms of maleability than polyethylene fibers. Interlig can be cut with any cutting tool; special tools are not necessary. No additional glue or resin is needed to impregnate the glass fibers because they are coated with light-cured composite resin. Pre-impregnation facilitates handling and improves glass fiber and composite resin adherence. By pre-impregnating the fibers with an unfilled resin matrix by an immersion process with regulated duration and temperature, the product's mechanical performance is improved. (Angelus,brazil).

Short fiber reinforced composite
Fiber-reinforced composite (FRC) technology has advanced over the course of its well-documented history in industrial use thanks to new treatment possibilities. It has long been understood that combining multiple fiber types with various orientations and lengths can provide devices with high strengths and fracture toughness for use in engineering and architecture. Fiber reinforcement is the material of choice for dental restorations nowadays. Short fiber-reinforced composite (SFRC) (everX Posterior; GC, Tokyo, Japan) was introduced to the market in 2013 with the intention of replicating dentine's stress-absorbing characteristics. The SFRC material is designed to be utilized as a bulk basis for the restoration of both vital and non-vital teeth in high stress locations.
E-glass fibers that are randomly oriented, a resin matrix, and inorganic particle fillers make up its composition. Bisphenol-A-diglycidyl-dimethacrylate (bis GMA), triethylene glycoldi methacrylate, and polymethyl methacrylate are all components of the resin matrix, which together form a semi-interpenetrating polymer network (semi-IPN) matrix that increases the polymer matrix's toughness and offers improved bonding properties for repair (66).

EverX Flow : EverX Posterior has a low aesthetic value due to its high viscosity (5%-15% by weight of 0.017 by 0.8 mm e-glass fibers), hence the company created a flowable

variation in 2019. EverX Flow, the new solution, was developed to assist customers in overcoming issues with workability (low viscosity) and esthetics (dentin color). The flow version has more fibers (by weight, 25% more) than its predecessor since the e-glass fibers are smaller (0.006 by 0.14 mm) in size. It was demonstrated that it has a lower flexural modulus (9.0 GPa) and better fracture toughness (2.8 MPam1/2) than everX Posterior. Even if the stress of its shrinking is greater than that of its predecessor (67).

A short-fiber reinforced flowable composite, or SFRC, is utilized in conjunction with a traditional composite as the enamel layer in bulk-filling and core build-up applications as well as in cases of weaker or damaged tooth structure. EverX Flow's short-fiber component effectively reinforces repairs and has an incredibly high fracture toughness, akin to the idea of iron rebar in construction. EverX Flow is a perfect material to use in weaker or cracked teeth, such as those that have had amalgam removal, because fibers help in the redirection of cracks and the prevention of catastrophic failures (68). Even in upper molars, everX Flow can flow and conform to the cavity floor because to its very thixotropic viscosity. Your restorative treatment is accelerated and made simpler by its ideal consistency. EverX Flow is available in two different hues to satisfy all of your clinical needs. The Bulk shade is perfect for deep cavities or when you want to expedite the healing process because it offers a 5.5mm depth of cure. The ideal choice for producing the best aesthetic effects is the Dentin shade, which has a higher opacity, is appropriate for core build-up, and is more opaque. The cure depth for the Dentin shade is 2.0 mm. GC, Europe

Composition: Bis-EMA, TEGDMA, UDMA, micrometer scale glass fiber filler, Barium glass 70 wt%, 46 vol%.

Conclusions:

Glass fiber reinforcement is being used to create an expanding number of dental materials due to their strength and hardness, which are comparable to tooth tissues, and their visually pleasant look. The focus of this work was on the many types of glass fibers, the variables affecting the characteristics of fiber-reinforced materials, and the characteristics and uses of fiber-reinforced composites. This in-depth investigation showed that fiber reinforcement in dental restorations is effective as long as the composition, orientation, distribution, quantity, length, and adhesion of glass fibers are done correctly in each clinical situation. Last but not least, fibers' purported efficiency as a reinforcing material exceeds its limitations.
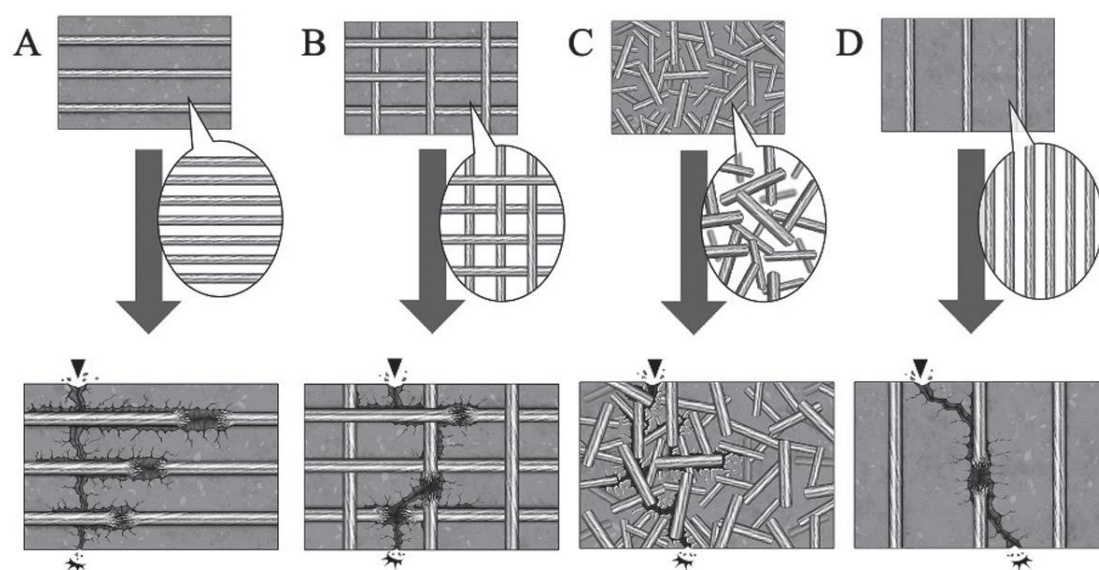

Fig.1 The effectiveness of multiple fiber orientations in terms of crack propagation (Krenchel's factor K).

Brand	Manufacturer	Fiber orientation	Composition
Ribbond	Ribbond Inc, Seattle, WA, USA	Woven	Polyethylene fibers
everStick	Stick Tech Ltd, Turku, Finland	Unidirectional	Pre-impregnated silanized E-glass fibers with Bis-GMA, PMMA
everStick net	Stick Tech Ltd, Turku, Finland	Bidirectional	Pre-impregnated silanized E-glass fiber with Bis-GMA, PMMA
Stick	Stick Tech Ltd, Turku, Finland	Unidirectional	Pre-impregnated silanized E-glass fiber with porous PMMA
Construct	Kerr, Orange, CA, USA	Braided	Polyethylene fibers
Connect	Kerr, Orange, CA, USA	Braided	Polyethylene fibers
Interlig	Angelus, Londrina, Brazil	Braided	Pre-impregnated silanized E-glass fibers with Bis-GMA
DentaPregSplint	ADM a.s., Brno, Czech	Braided	Pre-impregnated silanized E-glass fibers with mixture of dimethacrylete
GLASSSIX Post	Harald Nordin SA, Switzerland	Braided	Pre-impregnated silanized glass fibers with epoxy resin
Vectris	Ivoclar-Vivadent, Schaan, Liechtenstein	Braided	Pre-impregnated silanized R-glass fibers with Bis-GMA, TEGDMA
FiberKor	Jeneric/Pentron, Wallingford, CT,USA	Unidirectional	Silanized S-glass fibers
Estenia C&B EG fiber	Kuarary Medical, Tokyo, Japan	Unidirectional	Pre-impregnated silanized E-glass fibers with TEGDMA
Fiber braided	BTD, Australia	Braided	Polyethylene fibers
Fiber ribbon	Angelus, Londrina, Brazil		Pre-impregnated silanized E-glass fibers with Bis-GMA
Postec	Ivoclar-Vivadent, Schaan, Liechtenstein	Unidirectional	E-glass fibers with mixture of dimethacrylete
UniCore	Ultradent, South Jordan, UT, USA	Unidirectional	E-glass fibers with mixture of dimethacrylete

PMMA, polymethylmethacrylate; Bis-GMA, bisphenol-A-glycidyl dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

Fig.2 Commercial fiber reinforced composites (FRCs) used in dentistry

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