Orthodontic tooth movement is carried out, by engaging successively increasing sizes of archwires in brackets, which are bonded to the teeth. Traditionally, brackets as well as archwires were manufactured with Stainless steel or Chrome-Cobalt alloy. Titanium and its alloys have also found their application in this field. With the steady increase in the number of adults undergoing orthodontic treatment, there has been a corresponding increase in demand for more esthetic orthodontic appliances. Ceramics and polycarbonates have been used to produce tooth colored brackets, and research is under way to produce a suitable archwire material, which will combine esthetics with the required mechanical properties. Fiber-reinforced polymer composites are currently being developed for use as orthodontic archwire materials. By adjusting the ceramic/polymer proportions, these wires can be manufactured in a wide range of clinically relevant levels of elastic stiffness, allowing practitioners to use variable-modulus orthodontic techniques without having to change arch wire materials as treatment progresses. Allergic reactions to nickel, which are a debatable concern for many metallic alloys, are also averted with composite materials. With further developments, in the near future, fiber reinforced composite materials are expected to replace metals as the material of choice for orthodontic arch wires.

Introduction

As is well known, orthodontic appliances are used to move or manipulate certain teeth to correct irregularities in their relationships with surrounding members. This is achieved by the application of force systems, which have their origin in elastically deformed wires that absorb and release energy during loading and unloading.

Traditionally, these wires have been made from metal alloys such as 18-8 stainless steel, Chrome-cobalt -nickel (Elgiloy), and more recently from Titanium containing alloys. Desirable tooth movement can best be achieved by producing an optimal force system, which has the following biomechanical characteristics: Moderate to low force magnitude, which will allow rapid and relatively painless tooth movement, with minimal tissue damage. Constant force level over time, as the appliance experiences de-activation, in order to provide maximum tissue response. Accurate location of the point of application of force. Ability of the appliance to undergo large deflections without deformation.

Historically, the force magnitude applied to teeth has been controlled, by varying the cross-section of the wire used in the appliance. Small wires have been used to achieve large deflections while applying low forces on the teeth. On the other hand, larger wires that fit well into the bracket slots have been used to carry out precise and controlled tooth movement.

Important Properties of Orthodontic Wires:

Elastic Deformation / Springback: It is a measure of the amount of deflection or activation, which the appliance can sustain and still be totally elastic, i.e. recover to its original
shape and position. This feature determines the distance over which an appliance can effectively act, before readjustment is necessary. Appliances with greater spring-back can more readily engage severely malposed teeth. It is fundamentally proportional to the ratio of flexural strength to flexural modulus.

**Stiffness:** It is a primary determinant of the force applied to the teeth. Greater stiffness results in greater force for each unit of activation. It is proportional to the material's flexure modulus, and for isotropic materials, its tensile modulus.

**Resiliency:** Capacity of a material for elastic storage of energy, which depends on the combined effects of stiffness and working range.

**Limitations of contemporary archwire materials:**

**Stainless Steel:** High MOE i.e., high stiffness, Low springback, Nickel content and Unesthetic.

**Nickel Titanium:** Does not withstand cold bending, Cannot be used for fabricating loops, Cannot be welded or soldered and Unesthetic.

**Beta Titanium:** Lacks optimum formability and Unesthetic.

Additionally, metallic orthodontic appliances are a source of interference in NMR imaging, due to their radio-opacity.

**Fiber Reinforced Composites as a Substitute for Metallic Wires**

In the commercial world, reinforcement of polymers with long, continuous fibers has been established as an effective means of developing engineering materials for a wide range of aerospace, automotive, and recreational uses. This is because of their high strength to weight ratio, as compared to other structural materials.

Fiber reinforcement of composite materials has been discussed in the dental literature since the early 1960’s, beginning with reports of polymethyl methacrylate denture resins reinforced with glass fibers, carbon fibers, and aluminum and sapphire whiskers.

Fiber reinforced composite wires for orthodontic purposes are fabricated using a procedure called pultrusion. Fiber bundles are pulled through an extruder, in which they are wetted with a monomer resin. Next, the monomer is cured with heat and pressure, resulting in polymerization. During curing, the wetted fiber is formed into a desired cross-sectional morphology, which may be circular or rectangular. This wire may be also be further shaped into a different morphology by further curing, a process known as beta staging. For this, the monomer should initially only be partially cured.

Goldberg et al. reported the fabrication of fiber reinforced composites, approximately 0.5x2x40 mm long [1]. Kusy et al., 1999, patented a method for pultrusion of fiber reinforced composite wire, using a vertically disposed pultrusion apparatus, and methyl methacrylate resin reinforced with quartz fibers. Curing was achieved by use of ultraviolet radiation [2]. The resultant wire was of a circular cross-section and very thin diameter (0.3-0.6 mm). It was reported to be only 1/4th the weight of a stainless steel wire of the same dimensions, and just as strong.

**Tailoring of Properties of Fiber Reinforced Composite Wires.**

The properties of the composite wire can be customized through the use of various fabricating techniques, which include the orientation of the fibers within the composite material, as well as the percentage of fiber used.

**Orientation of Fibers**

Where continuous fibers are employed, they are usually disposed in a parallel array relative to each other and aligned along the long axis of the wire. These wires can be formulated to exhibit a modulus in the range of 1.5-30 x 106 and greater. It is to be noted that metals are not available in a significant portion of this range of moduli. In addition to the greater range of stiffness values,
the continuous filament material exhibits a larger springback or elastic recovery, permitting active force delivery with greater accuracy.

**Volume Ratio of Fiber to Polymer Matrix**

The volume percent of fiber in each composition may vary within a wide range, extending from as little as 5% to about 75-80%. With increasing amounts of fiber, there will be an increase in the stiffness as well as the yield strength of the material.

An important feature of FRC's is that they can be intentionally designed to be anisotropic in contrast to the nearly isotropic properties of metal alloys. Thus, by altering the materials, the fiber orientation and percentage, it is possible to provide significantly different properties in torsion and flexure. This enables control of the orthodontic force system in all 3 dimensions.

**Advantages of Fiber Reinforced Composite Wires Over Conventional Metal Wires**

Excellent combination of high elastic recovery, high tensile strength and low weight. Excellent formability. Allow for tailoring of flexural and torsional properties. Excellent esthetics because of their translucency. Ability to form wires of different stiffness values for the same cross-section. This would facilitate the practice of Constant Cross-section Orthodontics. Ability to directly bond attachments to these wires, eliminating the need for soldering and electrical resistance welding. Such wires can also be directly bonded to teeth, obviating the need for brackets, in certain situations, e.g. where anchorage from a large number of teeth is required. Incorporation of lubricant materials such as Teflon during manufacture, may also allow control over the frictional characteristics of the wire. This is an important consideration while sliding teeth backwards on the wire, to close extraction spaces. These materials are radiolucent, and do not interfere with nuclear magnetic resonance analysis. Allergic reactions to nickel, which are a concern for many metallic alloys, are averted with composite materials.

**Recent Reports on Fiber Reinforced Composite Archwires:**

Zufall, Kennedy and Kusy compared the frictional characteristics of composite archwires against stainless steel and ceramic brackets [3]. Relative to other frictional studies, the composite archwires had higher kinetic coefficients of friction than stainless steel but lower coefficients than either Nickel-titanium or Beta-Titanium. However, they noted abrasive wear of the composite surface at the archwire-bracket interface, at high forces and angulations. This could potentially lead to release of glass fibers within the oral cavity, which is unacceptable.

Zufall and Kusy studied the suitability of a wear-resistant, low friction, coating for composite archwires to prevent abrasive wear of the archwire [4]. The coating material tested by them was poly (chloro-p-xylylene), which has earlier been used for coating catheters and cardiac pacemakers. Tribological studies showed that the addition of a 10 micron thick layer of Parylene increased the coefficient of kinetic friction by 72%, to 0.43. However, this coating was able to eliminate the abrasive wear and consequent release of glass fibers from the wire, and was thus judged to improve the clinical acceptability of the composite wires.

There has been concern regarding the visco-elastic nature of polymer containing composites, as these materials are often characterized by time-dependent stress-strain behavior. From a clinical perspective, this would cause a decrease in elastic deflection of the archwire, in excess of predicted values, leading to inefficient tooth movement. Zufall and Kusy studied the visco-elastic properties of Bis GMA, TEGDMA composite archwires reinforced with S2 glass, and reported that viscous losses were only 1% of the initial stress, and unrelated to the reinforcement level [5]. They concluded that the composite archwires retained sufficient resilience to function during initial and intermediate stages of orthodontic treatment.

Stress-relaxation is, on the other hand, a highly desirable characteristic for ligature wires, which are used to tie brackets to the archwire, as this result in reduced normal friction between the bracket and wire, facilitating sliding of teeth. Mc Kamey and Kusy reported on the development of a special composite ligature material using n-butyl methacrylate and drawn ultra high molecular weight polyethylene (UHMWPE)
fibers [6]. Tests have shown that such a ligature wire would lose 98% of its ligation force, and thus 98% of its friction, in a few hours. As the esthetics are excellent with these materials, the only hurdle that remains is how best to tie them.

Burstone and Kuhlberg have described the clinical application of a new fiber reinforced composite called "Splint-It" which incorporates S2 glass fibers in a bis GMA matrix [7]. This is available in various configurations such as rope, woven strip and unidirectional strip. These materials are only partly polymerized during manufacture (pre-pregs), which makes them flexible, adaptable and easily contourable over the teeth. Later they are completely polymerized and can be bonded directly to teeth. They can be applied for various purposes such as post treatment retention, as full arches or sectional arches, and to reinforce anchorage by joining teeth together. A particular advantage is that due to direct bondability to teeth, they can obviate the need for brackets in specific situations. In addition, they are highly esthetic, and could thus be an effective alternative to lingual appliances.

**Conclusion**

Fiber reinforced composites are regarded as the last great frontier of orthodontic materials. Due to their excellent esthetics and strength, as well as the ability to customize their properties to the needs of the orthodontist, they are expected to replace metals in orthodontics, just as composites have replaced aluminum in the aircraft industry. No doubt, these materials promise several exciting new possibilities in biomechanics, and could revolutionize the practice of orthodontics.

**References**