THE EFFECT OF IMPREGNATED GLASS FIBERS ON THE FLEXURAL STRENGTH OF ACRYLIC AND COMPOSITE RESIN: AN IN-VITRO STUDY

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THE EFFECT OF IMPREGNATED GLASS FIBERS ON THE FLEXURAL STRENGTH OF ACRYLIC AND COMPOSITE RESIN: AN IN-VITRO STUDY

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Objective: The aim of this in-vitro study is to compare flexural strength of polymethyl methacrylate (PMMA) and bis-acryl composite (BAC) resin material reinforced with impregnated glass fibers.

Materials and Methods: Two groups of rectangular test specimens (n=20) were fabricated. One group contained PMMA acrylic and the other contained bis-acryl composite resin material. The experimental groups contained impregnated glass fiber reinforcement and the non-reinforced group served as the control. Flexural strength of the specimens was measured by a universal testing machine until fracture. The mean flexural strength (N) was compared by a two way ANOVA test and followed by a simple main effect, using a significance level of 0.05.

Results: For reinforced groups, the mean flexural strength of PMMA resin increased from 349.4N (+/- 23.4) to 613.6N (+/-54.2). For BAC resin, the mean flexural strength increased from 513.6N (+/-103.1) to 603.5N (+/-50.5). Reinforced PMMA resin was highly significant ($p<0.001$) compared to BAC resin ($p=0.150$). At the non-reinforced control groups, the flexural strength BAC resin was significantly higher than PMMA resin group ($p=0.036$).

Conclusion: Although impregnated glass fiber increased the flexural strength of both PMMA and BAC groups, it was significantly higher for PMMA resin. At the non-reinforced control groups, the flexural strength of BAC resin was significantly higher than PMMA.

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INTRODUCTION

Provisional restorations, or interim restorations, are widely used in dentistry today. Provisional fixed restorations provide a protective coverage for teeth while the permanent restoration is being fabricated. The fabrication of an ideal provisional restoration is crucial for a successful outcome and a happy patient (Shillingburg, 1997). The term provisional, interim or transitional restoration have routinely been used interchangeably in the literature; however, the term “temporary” is controversial and is considered inappropriate by some, as it may be interpreted as one of lesser importance or value (Driscoll, 2005). Dr. Rosenstiel states that a definitive restoration may be placed as quickly as two weeks after tooth preparation and that the provisional restoration must satisfy important needs of the patient and dentist. The role of a provisional restoration in prosthodontics must satisfy many requirements for an optimal interim restoration, including: biological considerations, mechanical properties and esthetics principals.

Biologically, a provisional fixed restoration must provide pulpal protection by preventing the conduction of temperatures through the outer surface of the enamel into inter-pulpal tissues (Powers, 2006). The margins of the provisional restoration must be adapted to the surrounding tooth structure and prevent any leakage of saliva. They also promote guided tissue healing by providing a matrix for surrounding gingival tissue. Provisional restorations provide tooth stability and prevent the prepared tooth from extrusion or drift in any direction while providing occlusal function. The restoration must be fabricated with ideal contours and materials. This will allow the patient to easily clean around the restoration and keep the surrounding periodontal tissues healthy and free of any inflammation allowing the ease of final cementation.

Mechanically, a provisional fixed restoration must withstand chewing forces without breakage and must withstand dislodgment. Rosenstiel describes that the strength of a provisional restoration material is one-twentieth that of the final restoration (Rosenstiel, 2006). This makes the restorations very prone to fracture when the patient is functioning on the provisional restoration. This concept is especially important if the span of the temporary is increased. In some instances, the need to replace more than one tooth is needed and a provisional fixed partial denture is fabricated. As the span of the provisional fixed partial increases, the likelihood of the provisional fracturing during chewing is increase dramatically.

Lastly, the esthetic principal of fabricating a provisional restoration is critical for patient satisfaction and esthetic results. This is critical with incisor, canines and sometimes premolars. The provisional restoration is our guide in achieving optimal esthetics in the final restoration. This gives the patient a chance to voice their opinion on the esthetics of the provisional restoration prior to the definitive restoration. Factors such as vertical dimension, masticatory function and speech all influence the esthetics of the restoration. Ideally, provisional's are made from materials that are easy to contour, are color compatible and are translucent in nature (Shillingburg, 1997).

One main concern that needs to be addressed in fabricating provisional restorations is how to reinforce a provisional fixed partial denture. Rosenstiel describes that the strength of a provisional restoration material is one-twentieth that of the final restoration. We also know from basic engineering principals that the longer we span a bridge, the greater the tendency for the bridge to bend and or fracture under excessive vertical forces.

1.0 REVIEW OF THE LITERATURE

1.1 BIOMECHANICS IN RESIN REINFORCEMENT

The concept of reinforcing provisional resins in the past included many different materials including the use of metal, carbon graphite, kevlar and polyethylene glass fibers. The problem with long span provisional's is that as the length of the provisional increases, the possibility of fracture or failure also increases, especially in patients with a history of bruxism or excessive occlusal forces. Biomechanically, bending or deflection varies directly with the cube of the length. For example, if we are replacing two missing teeth with a provisional resin, the resin will bend eight times as much as a single tooth replacement. If we are replacing three teeth with a provisional resin, it will bend twenty seven times as much as a single tooth replacement (Shillingburg, 1997). As we increase the span of our provisional fixed partial denture, we inevitable introduce the possibility of fracturing the resin, the need to re-make the provisional, frustrated patients and disappointing results.

1.2 METAL REINFORCEMENT

Numerous articles have included the use of metals in their provisional prosthesis as a way of strengthening the resin material from fracturing during occlusal forces. The strength and serviceability of any acrylic resin, especially in long span provisional restorations, is determined by the material’s resistance to crack propagations (Gegauff, 1987). Crack propagation is defined as any widening, lengthening or increase in the number of cracks in a specimen being tested after fracture initiation. The idea of strengthening provisional restorations with many different types of organic and inorganic materials is to prevent crack propagation in the core resin material.

In 1989, Zinner *et al.* described that one of the most important uses for fabricating a provisional restorations relates to psychological management of the patient. The patient becomes accustomed to intraoral clinic manipulation and accommodates more readily to changing alterations to arch form, occlusal plane and esthetics that are to be established in the definitive restoration. Many changes are occurring during this transitional period. Esthetics, contours of teeth, function and speech are all changing in an amount of time that can take anywhere from two weeks to two year, depending on the type of treatment.

Zinner further describes two main ways to strengthen provisional restorations. The first method indicated for short term clinical use employs the utilization of zephyr-gold bands or preanneaded stainless steel bands wrapped around the prepared teeth as the metal substructure with an acrylic resin provisional fabricated over the metal bands.

The second method is intended for long term clinical use, or, in patients with a history of bruxing or clenching. The procedure calls for gold or non precious alloy waxed and cast on the stone cast in the laboratory, then fitted to a working model. A heat cured acrylic resin is then veneered on top of the superstructure giving the resin provisional material durability and strength.

Zinner also describes different methods to fabricate provisional fixed prosthodontic restorations: directly, by use of the hybrid technique, or indirectly. The direct method involves fabricating the provisional intraoral or chairside using acrylic resin material or metal bands supported by acrylic resin. The second method is a hybrid technique which involves the combination of intraoral and laboratory work to fabricate a provisional. Lastly, the indirect technique involves the laboratory. The indirect method technique is best because a metal superstructure can be cast directly to the stone cast and a heat processed acrylic resin provisional can then be fabricated onto the metal. The durability of the resin material and strength of the provisional restoration is greatly enhanced with the indirect technique and should be used with any long span provisional restoration and with any patient undergoing an extensive period with interim restorations.

In 1998, Emtiaz and Tarnow looked at processed acrylic resin provisional restoration with lingual cast metal framework as reinforcement. They included modification to the design of the cast metal reinforced processed acrylic resin provisional restoration for extensive, long-term reconstruction with implants, because some of the treatments rendered to patients required temporization for up to two years. This incorporation of metal into their fixed provisional restoration allowed two years of healing without disturbing the surrounding tissue or replacing the provisional restoration. In similar fashion, Caputi *et al.* (2000) describes a method of fabricating a provisional gold-resin restoration through an indirect-direct procedure. These provisional restorations remained in the mouth for a period of twelve months to maintain proper occlusion and function without failure of the provisional restoration.

More recently, Galindo *et al.* (1998) described methods of fabricating provisional's with a metal framework incorporated into the acrylic resin material. Waxed copings were fabricated on the abutment stone cast and the edentulous span was connected with a rectangular wax pattern. The wax pattern was then invested and cast into metal. The metal was opaque for esthetics and a heat cured provisional restoration was processed directly onto the metal framework based on the diagnostic wax up for the final restoration. The addition of metal in these types of provisional restorations helped to reinforce the acrylic resin by incorporating a metal substructure into the resin material, preventing fracture.

1.3 FIBER REINFORCEMENT

In the mid 1990's researchers began to experiment with different types of fibers as a method of improving the fracture strength of provisional restorations. Fiber materials are categorized by fiber type, orientation and whether the resin impregnation of the fiber is performed by the dentist/laboratory technician or by the manufacture. Fiber material included the use of carbon, aramid (kevlar), polyethylene, and glass fibers. Fiber orientation includes unidirectional patterns, where all of the fibers run in parallel, braided and woven patterns. Glass fibers can also be manufactured with or without resin applied to the glass fibers. When manufactured with resin applied, the fibers are said to be impregnated. The most commonly used fibers reinforcement in today's dental application are carbon, polyethylene and glass fibers.

1.3.1 Carbon fiber

Carbon fiber was first created in 1958 when researchers heated stands of rayon until it carbonized. This process, however, only contained about 20% carbon and had very weak physical properties. In the 1960's, the process was modified and contained about 55% carbon fibers and had much better physical properties. Carbon fibers are about 5-10um in diameter and composed of carbon atoms that are bonded together in crystals. The crystals align parallel to the long axis of the fibers giving the fiber very high strength for its relatively small weight. The fibers are then twisted together and woven into fabric. The properties of carbon fibers that make it useful in strengthening provisional restorations are that it has a high flexibility, high tensile strength and low weight.

The first experiment of carbon/graphite reinforcement occurred in 1971. Schreiber evaluated the reinforcement of denture base material using carbon fibers using acrylic resin polymethyl methacrylate (PMMA) reinforced with five different types of carbon fibers and then subjected the specimens to different weight forces, thereby measuring the fracture point. Schreiber concluded that PMMA acrylic resins reinforced with treated carbon fibers had an increase in transverse strength as much as 50%.

In 1991, Larson *et al.* looked at the effect of carbon fiber reinforcement on the strength of provisional crown and fixed partial denture resins. In this study, an instron machine was used to compare the modulus of elasticity of three denture resins reinforced with and without carbon fibers. The results of his experiment concluded that PMMA acrylic resin with carbon fibers exhibited a significantly higher modulus of elasticity of about 89%.

1.3.2 Aramid fibers

Aramid fibers were first introduced by the DuPont Company in 1961. In 1965, kevlar was created from aramid fibers and introduced as a replacement for steel in automotive tires. Kevlar was quickly found to have very important properties including high tensile strength, high modulus of elasticity, low weight, and high fracture toughness. Today, this lightweight and durable material is used anywhere from protective helmets to aerospace engineering and even in dentistry.

In 1985, Mullarky used aramid fibers to strengthen PMMA acrylic resin appliances. He placed very thin woven aramid fibers perpendicular to the expected stress into the processed acrylic appliances. Because aramid fibers were new to dentistry at this time, very little research was done on strengthening acrylic materials with this type of fiber. Mullarky concluded that selective reinforcement of unidirectional aramid fibers can greatly increase the strength and fatigue resistance of PMMA acrylic resin appliances. His study indicated a 200% increase in strength after aramid fiber was incorporated into PMMA acrylic resin. One of the downfalls that Mullarky noted was associated with the esthetics and polishability of the fibers. Because the aramid fibers are dark, they can be visible in clear appliances and are difficult to polish if they are exposed to the surface of the resin.

More recently, Jacob *et al.* (2001) studied the flexural strength of heat polymerized PMMA acrylic resin reinforced with multiple fibers including glass and aramid fibers. The purpose of his study was to determine whether the flexural strength of commercially available PMMA acrylic resin reinforced with different types of fibers could prevent fracture of the material. He concluded that glass fiber reinforcement exhibited better flexural strength than aramid or nylon fibers although all three types of fibers, glass, aramid, and nylon, did improve the flexural strength of conventional PMMA acrylic resin compared to the non reinforced control specimens.

In a similar study, Saygili *et al.* (2003) looked at the effect of placement of glass fibers and aramid fibers on the flexural strength of provisional restorative materials. In this study, PMMA, PEMA and bis-acryl composite provisional material was reinforced with glass and aramid fibers and a three point compression load test was performed. This study concluded that both fibers, glass and aramid, improved the flexural strength. Glass fibers however showed higher transverse strength than the aramid fibers, with a 20-50% greater flexural strength.

1.3.3 Polyethylene fibers

Polyethylene fibers, also known as ultra-high-molecular-weight polyethylene (UHMWPE) Fiber was first introduced in the 1970's. It is synthesized from long chains of ethylene monomers, between 100,000- 200,000 monomer per unit molecule, which are bonded together. The bond that is formed from the synthetic fibers has a strength-to-weight ratio from 10-1,000 times higher than that of steel and 40% higher than aramid (kevlar) fibers.

Polyethylene fibers can also exhibit different fiber orientation. Ribbond® polyethylene fibers exhibit a braided fiber orientation with no additional surface treatment. On the other hand, Contruct® polyethylene fibers exhibit a woven fiber orientation and are additionally surface treated with plasma. The woven polyethylene fibers that undergo plasma treatment create an increased surface area allowing better bonding between the resin matrix and the fibers (Gutteridge 1992, Ladisesky 1993).

In 1995, Dixon *at al*. (1995) looked at light polymerizing provisional restorative material with and without reinforcement fibers. The use of light polymerized resin material was introduced as more esthetic; tooth colored, restorative material, but lacked transfer strength compared to heat processed or autopolymerized PMMA acrylic resin. The investigation studied the effects of rupture and flexural modulus with the use of polyethylene fibers (Ribbond). It was concluded that fiber incorporation did not substantially elevate the modulus of rupture, but did increase the flexural modulus compared to those without fiber. In essence, the polyethylene fibers Ribbond did not increase the transverse strength of the PMMA acrylic resin.

In 2004, Hamza *et al.* studied the effect of fiber reinforcement on fracture toughness and flexural strength of provisional restorative resins. Hamza and his colleagues were studying crack propagation in their models by measuring the fracture toughness. The study compared two different types of restorative resins: PMMA and bis-acryl, and two reinforcement fibers: glass and plasma treated- polyethylene (Construct) fibers. Their conclusion was that surface treated polyethylene fibers and glass fibers were effective methods to increase fracture toughness of provisional resins. Similarly, Chen *et al.* (2009) found that long span fiber-reinforced acrylic resin reinforced with plasma treated- polyethylene fibers Constuct enhanced the flexural strength of PMMA acrylic resins.

These latter experimental studies using surface treated plasma polyethylene fibers demonstrated that the surface texture is very important in increasing the flexural strength of provisional resins. Experiments using plasma treated- polyethylene fibers (Construct) demonstrated an increase in flexural strength compared to experiments without fiber surface treatment (Ribbond). The transverse strength was not improved by addition of polyethylene fibers in the absence of surface treatment because of poor adhesion between the fibers and the polymer matrix (Vallittu 1997). When plasma treated polyethylene fibers are used, a significant increase in strength was shown (Ramos, 1996).

1.4 GLASS FIBER REINFORCEMENT

The first production of glass fiber began with the Owens-Corning Fiberglass Corporation in 1938. The technique of heating glass and drawing glass into fine fibers has been known for hundreds of years; however, machinery at that time was not advanced enough to produced finely textile glass fiber. In 1938, glass fiber was marketed as “fiberglass” and was used as an insulating material. The basis of all commercially available glass fiber is silica. It exists in nature as a polymer of silica and oxygen and can soften at a temperature of 2000 degrees Celsius. As the polymers are being heated and pulled into thin fibers, the silica and oxygen molecules rearrange into more ordered structures giving strength to the glass fibers when they cool.

The first type of glass that was used for fiber was lime glass, also called A-glass. This glass fiber was for used for beverage bottles and food jars. The problem with A-glass was that it was not very resistant to alkali conditions and the glass eventually corroded. In efforts to make a more resistant glass, E-glass was invented using alumino-borosilicate, which is alkali-free. This glass is more resistant to environmental factors and proved to be a more durable glass fiber.

E-glass was the first type of glass used for continuous filament formation and still makes up most of the glass fiber production in the world. E-glass was originally developed as an insulator for electrical wiring. It was later found that E-glass also had good fiber-forming capabilities and physical properties that made it a strong fiber for reinforcement. Today, glass fiber is used in everything from reinforced plastics to tent poles.

Glass fiber was first tested as reinforcement for denture base PMMA as early as the 1960’s (Vallittu, 1996). Since then, many studies have investigated the strength of glass-fiber reinforced resins. Glass fibers can be classified by fiber orientation (unidirectional or braided/woven) and whether resin is impregnated into the fiber. The first generation of glass fibers used in dentistry was not impregnated with resin. It required the dentist or technician to add resin and bonding agent to the fibers by hand. The second generation glass fibers were impregnated with resin onto the glass fibers and can be used directly out of the packaging. These includes the brand EverStick®, StickNET®, Fiberstick® and Fibrenet®, which are available in unidirectional and woven glass forms.

1.5 IMPREGNATED GLASS FIBER REINFORCEMENT

1.5.1 Bonding

Impregnation also known as polymer-fiber composite is a term described by Vallittu in 1993. He states that a polymer-fiber composite occurs when fibers are embedded in a polymer matrix, which binds the fibers and forms a continuous phase surrounding the fibers. The benefit of having a polymer-fiber composite is two parts: it allows transfer of load to the fibers, which are the stronger component of the composite and the polymer matrix, which will help to protect the fiber from the effects of the oral environment.

One of the advantages of using glass fiber as a reinforcement agent in provisional restorations is the ability of the glass fibers to bond to the resin matrix, overcoming one of the problems that Pollack noted in 2011: that the use of embedded wires, pins, nylon and stainless-steel mesh in restorative resins never chemically join to the dental resin. Over time, the composite resin could fracture and expose the fibers of the underlying reinforcing materials. The resin could then break away from the embedded metal or nylon due to lack of chemical integration as well as due to the repeated loading stresses placed on resin during excessive occlusal forces

Vallittu (1998) states that strength of polymers can slightly be enhanced by the use of metal strengtheners; however, the influence of metal strengtheners on the fatigue resistance on dental appliances is minor. Furthermore, the use of PMMA acrylic resin causes inadequate impregnation of reinforcing fibers due to the relative high viscosity of the material with a poor wetting property.

Wetting the fibers with monomer has been a commonly used method to improve bonding properties. Although the monomer increases adhesion of the fibers to the matrix, it may impair other properties because of the residual monomer (Valittu 1999). The impregnation of fibers was developed to overcome this problem as an effective impregnation process allows the resin to come into contact with the surface of every fiber.

Theoretically, by altering the powder/liquid ratio you can create a lower viscous pour stage and improve impregnation of fibers with the resin. However, it was shown that a higher proportion of monomer liquid in the mixture increased polymerization shrinkage and caused slits and voids to form between the reinforcing fibers and the resin, which was shown to decrease the strength of the reinforced resin. Vallittu (1998) also noted that having slits or voids at the junction of the fibers and resin caused an increase in water (absorption, which could possibly cause a decrease in mechanical properties of the composite.

To overcome this problem, Vallittu (1993) experimented with different bonding agents on the adhesion between fiber resins. The aim of his study was to clarify the effects of two different silane bonding compounds on the adhesion of glass, carbon and aramid fibers with the use of PMMA acrylic resin. A weight percentage of fibers were measured and placed longitudinally in the test specimens. The specimens were then tested for fracture loads and scanning electron microscopy (SEM) photos were taken of the fiber surface. The results showed an increase in fracture loads for silane bonded reinforced glass and that silanization of fibers enhanced the adhesion between the fibers and acrylic resin, which were confirmed by SEM photography.

Silanized glass fibers were considered promising new materials because of their good adhesion to the polymer matrix, high esthetic quality and increased strength of the resulting composite. (Vallittu 1993, Solnit 1999, Aydin 2002). Although the glass fibers did increase fracture loads, the glass fibers were not impregnated and the bonding process was still carefully applied by hand.

Second generation glass fibers were first created in 1999 by professor Vallitu. He experimented with a novel way of pre-impregnating bonding material on the surface of fibers to overcome the challenges and technical difficulties with first generation glass fibers. He stated that a major difficulty in using reinforced fibers with acrylic resins, such as powder and liquid resins, had been improper impregnation of the fibers with the resin. One approach to increase the adhesion the fibers to a polymer matrix was to impregnate the fibers prior to application.

The aim of Vallittu's study was to determine the flexural properties of unreinforced heat cured PMMA and bis-acrylic temporary material with those reinforced with impregnated glass fibers. The impregnation of the fibers was also examined by SEM analysis. The experiment concluded that unidirectional impregnated fibers significantly increased the transverse strength and flexural modulus of both polymers. More importantly, both fibers were well impregnated with the resin polymer matrix.

An important quality to impregnated fibers is that it would eliminate the need for dentist or laboratory technicians to apply bonding material to the fibers, a technique-sensitive task, and would also allow for a more uniform and consistent bond between the reinforcing fibers and the acrylic resin. Kolbeck *et al.* (2002) stated that the reinforcing effect of glass fibers was more effective than that of polyethylene fibers, and this was attributed to the difficulty of obtaining good adhesion between polyethylene fibers and the resin matrix.

1.5.2 Strength

Another advantage of using impregnated glass fiber as a reinforcement agent in provisional restorations is the ability to resist fractures of the resin material. Most resins used for provisional restorations are brittle (Gegauff, 1987). Repairing and replacing fractured restorations equates to additional time and cost for both the patient and the clinician. Failure often occurs suddenly and probably as a result of crack propagation from a surface flaw (i.e. lack of fiber impregnation or voids between the reinforcing fiber and the resin). The strength of any acrylic resin, especially long span interim restorations, is determined by the material’s resistance to crack propagation. Crack propagation with these materials occurs because of inadequate transverse strength, impact strength, or fatigue resistance (Donovan 1985, Gegauf 1987, Chee 1988).

Similarly to Vallittu’s (1993) experiment, Hamza *et al.* (2004) evaluated the effect of fiber reinforcement on the fracture toughness and flexural strength of provisional resin. They studied crack propagation by measuring the fracture toughness of the material. They concluded that impregnated fibers were an effective method to increase fracture toughness and flexural strength of provisional resins. Impregnated glass fibers increased the fracture toughness of

PMMA acrylic resin by 119% and bis-acryl resin by 49%. This article also indicated that impregnated glass fibers are better at reinforcing PMMA acrylic resin than bis-acryl resins.

In 2005, Vallittu again experimented with glass fiber reinforcement on the flexural strength of provisional FPD’s. The purpose of the study was to compare the flexural strength of traditional metal wires to impregnated glass fibers. He found that the fatigue resistance of glass fiber reinforced polymers was considerably higher than those reinforced with conventional metal wires. The article concluded that the use of glass fiber reinforcement in a provisional FPD considerably increased the fracture toughness of PMMA acrylic resin by about 33%.

More recently, Geerts *et at*. (2008) studied the effect of different reinforcements on the fracture toughness of materials for interim restorations. The purpose of the article was to compare the fracture toughness of PMMA resin and bis-acryl resin reinforced with glass fiber and also conventional steel wire and polyethylene fibers. The specimens were all subjected to a three point bending analyses. Of the three reinforcing materials, glass fiber produced the highest fracture toughness for PMMA and bis-acryl resin increasing it 38% and 34%, respectfully, slightly better for PMMA acrylic resins.

1.5.3 Esthetics

The use of impregnated glass fibers in provisional restorations provides better overall esthetics and is much easier to handle compared to conventional materials like metal wires, carbon, aramid and polyethylene fibers. Provisional restorations, especially in anterior restorations, must not only be esthetically pleasing but also serves the function of assessing esthetic and phonetics values of the planned fixed prosthesis (Burns, 2003). It is important that provisional restorations maintain their form and contours during this trial period without having to fix or replace a provisional restoration, which only adds time and cost to you and your patient.

Metal wire used for reinforcing resin material presents an esthetic challenge in fabricating provisional's in the anterior area and should be limited to posterior teeth. The dark color of the metal can cause the metal wire to “show through” the resin and alter the original color of the resin. Also, the incorporation of metal wires can weaken the surrounding resin due to the thickness of the wire and the decrease in resin bulk of the restoration. Furthermore, the incorporation of metal wires or metal casting as a reinforced provisional ads expense and laboratory time, and should be limited to posterior teeth. Glass fibers, on the other hand, is a more translucent material compared to metal which improves the overall esthetics.

Although carbon fiber is a lighter and thinner reinforcing material for provisional restoration, it still presents esthetic challenges. Early work in by Schreiber (1971) regarding the use of carbon fiber reinforcement stated that the problems he noted with the use of carbon fibers were the black color of the material which caused discoloration in the denture base. Similarly, Vallittu (1997) stated that the aesthetic problems caused by the black color of the carbon fiber can be avoided if glass fiber is used as the reinforcement material instead. Other authors have also stated that the black color of the carbon fibers limits their use to non esthetic areas (Yazdanie 1985, Larson 1991).

Another technical challenge with the use of carbon fibers was the placement of fibers into the resin matrix. Ideally, fibers placed perpendicular to the direction of applied stress produced the most favorable combination of increased resistance to bending and flexural fatigue. It has been shown that the placement of properly oriented fibers that are well centered within the resin was technically difficult (DeBoer, 1984).

Similar to carbon fibers, polyethylene fibers are not translucent in nature and must be incorporated deep within the resin matrix to “hide” the fibers. In anterior provisional restorations, care must be taken to place the fibers away from the anterior portion of the resin matrix for esthetic reasons. Another technical issue with polyethylene fibers is that it tends to fray when adjustments are made to it with acrylic burs. The frayed ends will leave fibers exposed on the surface which can make it difficult to hide and repair in anterior cases. Major difficulties in using fibers with polymer resin and the difficult handing of the fibers due to fraying and spreading of the fibers limits use to undesired regions of the denture (Vallittu 2005).

A technical challenge with the use of any first generation reinforcing glass fiber was that the operator or technician had to apply a silane coupling agent (bonding agent) on the fiber prior to embedding it in the resin matrix. Bonding agent was applied to create a bond between the glass fibers and the resin material as the material set. The bonding agent has to be meticulous applied with gloved hands as to not contaminate the glass fiber surface. Operator error in the application of bonding agent on the fibers can create voids or flaws in the fiber resin affecting the overall strength. Most of the problems with first generation glass fibers were caused by inadequate adhesion between the polyethylene fibers and the polymers (Vallittu 1997, 2005).

Garoushi *et al.* (2007) stated that impregnated glass fibers have good esthetic qualities compared to carbon or aramid fibers. Impregnated fibers are translucent in nature allowing more light to pass through the fibers. This provides an esthetic benefit when choosing to reinforce anterior provisional restorations. The impregnated glass fibers are also thinner compared to metal wires, which allow them to be buried closer to the surface of the resin without affect the esthetic outcomes.

This experiment will evaluate the ability to overcome the challenges from mechanical failures that occur with provisional resin materials by utilizing a second generation impregnated glass fiber as reinforcement in PMMA acrylic and bis-acryl composite (BAC) resin.

2.0 STATEMENT OF THE PROBLEM

A problem we encounter with provisional resin restoration is fracturing of the material. Mechanical forces such as excessive occlusal forces, parafunctional habits, clenching/grinding, and bruxing, can all lead to a catastrophic failure of the provisional restoration, especially in a long span design. Failure of a provisional restoration means added expense in fabricating a new provisional, added cost in materials and dissatisfied patients.

The type of material used for fabricating a provisional restoration also plays a role in the strength and the resistance to fracture. There is currently no ideal provisional material used in the market today. Much of what we use at present is based on ease of use and time required for the material to set. Historically, the gold standard material has been polymethyl methacrylate (PMMA) resin. This material has stood the test of time due to its durability and inexpensive cost.

Today, newer provisional materials made from bis-acryl composite (BAC) resin provide improved physical properties over PMMA resins, including the ease of handling due to auto mixing cartridges, less polymerization shrinkage and a decrease in heat released during curing. One problem that we do encounter with composite provisional material is that it's brittle. Some evidence has shown that the more complex the case, especially in multi tooth replacement situations with the requirement of long-term durability, PMMA resin generally has been the material of choice, but very little data supports this.

3.0 OBJECTIVES

The objective on this in- vitro study will be to measure the flexural strength of two provisional resin materials utilizing a second generation impregnated glass fiber as reinforcement. A three point bending analysis using a universal testing machine will be utilized to measure the flexural strength

3.1 SPECIFIC AIMS

1. Determine the flexural strength of polymethyl methacrylate (PMMA) and bis-acryl composite (BAC) resin material and compare the results.
2. Determine if a new commercially available second generation impregnated glass fiber used as reinforcement affects the flexural strength of polymethyl methacrylate (PMMA) and bis-acryl composite (BAC) resin material and compare the results.

4.0 RESEARCH QUESTION

What effect does a new commercially available second generation impregnated glass fiber as reinforcement have on the flexural strength of polymethyl methacrylate (PMMA) and bis-acryl composite (BAC) resin materials? The null hypothesis is that impregnated glass fibers will not increase the flexural strength of the two resin materials.

5.0 MATERIALS AND METHODS

To ensure standardization of all forty specimens, a split metal crown and bridge flask was used (Figure 3). A 6x6x40mm rectangular bar was placed within impression material (Reprosil Vinyl Polysiloxane Impression Material, Putty Base and Catalyst, Dentsply Trubyte) which was contained in a split metal flask. The impression material and rectangular bar were placed within the split brass flask, pressed at 3,000 psi (COE-Bilt, COE Laboratories, Inc., Chicago, USA) for 10 minutes and excess impression material was removed (Figure 4). This created the master mold from which all samples were fabricated.

Within the mold, two lateral stops were prepared with a carbide burr on either end, 1mm from the top and bottom representing occlusal and gingival position. This was done to ensure the two cured impregnate glass fibers would not move during packing and that sufficient resin would surround the cured glass fiber bundles.

The second generation impregnated glass fiber used in this study is marketed as E-Fiber® (E-Fiber, Preat Corporation, Santa Ynez, CA). E-Fiber is prepackaged as a 1.6 x 100mm bundle containing 4,000 individual glass fibers (Figure 5). It is impregnated with both PMMA and Bis-GMA resin (Figure 6). The impregnated E-Fiber bundle was removed from the foil packaging and cut to a length of 42mm to fit into the lateral stops. They were then light cured for 5 minutes within a clear silicone carrier that was provided by the manufacture (Figure 7) under UV light (Triad 2000, visible light cured system, Dentsply Trubyte). Once cured, bonding agent, supplied by the manufacture, was applied to the surface of each cured glass fiber and immediately inserted into their respective occlusal and gingival stops within mold (Figure 8). All of the cured impregnated glass fibers bundles were placed longitudinal within the mold and perpendicular to the loading force.

The five specimens containing polymethyl methacrylate (PMMA) resin (Jet, Tooth Shade Powder and Liquid, Lang Dental Manufacturing Co., Inc) were measured and weighed at a liquid to powder ratio of 2:1. This ratio produced the best pour consistency and working time. The cured impregnated glass fiber bundle was placed into respective occlusal and gingival positions and PMMA resin was carefully poured into the mold. The split metal flask was closed and pressed at 3,000 psi for 10 minutes allowing the PMMA resin to completely cure (Figure 9). Five control specimens were also fabricated containing only PMMA resin with no reinforcing impregnated glass fibers bundle.

Five specimens containing bis-acryl composite (BAC) resin (Integrity, Temporary Crown and Bridge Material, Dentsply Caulk) was provided in a dual barrel auto mixing cartridge. Instructions were followed according to manufactures cartridge dispensing instructions. The cured impregnated glass fiber bundles were placed in their respective occlusal and gingival positions and BAC resin was carefully dispensed into the mould. The split metal flask was closed and pressed at 3,000 psi and cured according to manufacture instructions. The BAC resin samples were additionally cured for 5 minutes under UV-light (Triad 2000, visible light cured system, Densply Trubyte) to ensure complete curing of the BAC resin. Five control specimens were also fabricated containing only BAC resin with no reinforcing impregnated glass fiber bundles.

A total of twenty resin specimens were carefully examined for quality. Any specimens exhibiting voids in the resin or any with glass fiber that shifted during packing were eliminated and replaced with suitable specimens. Twenty resin samples were divided by resin material. The two resin materials were: acrylic (PMMA) and bis-acryl composite (BAC) resin. These two resin materials were then subdivided into two groups; control samples with no glass fiber reinforcement and those with glass fiber reinforcement.

All twenty resin specimens were subjected to a three point bending test utilizing a universal testing machine (Instron, Series 5564). All samples were continually load tested at a crosshead speed of 5mm/min until fracture of the resin samples occurred (Figure 10). This event was defined by a complete fracture of the specimens or a decrease in the flexural strength of 40%, which was pre-programmed into the computer software. The maximum flexural strength, calculated in Newtons (N), for all twenty resin samples was collected by computer software and data was analyzed.

Flexural strength was calculated by the equation: Stress = $3FL / 2bd^2$, where;

F= Load of fracture (N)

L= Length of support

b= Width of sample

d= Thickness of sample

6.0 RESULTS

A 2 x 2 analysis of variance (ANOVA) was performed to evaluate statistically significant differences of maximum load to fracture between groups. This was followed by a test for simple main effects (post hoc), using a significance level (p-value) of 0.05. The means, standard deviation and sample size are presented in Table 1.

No significant main effect occurred between material type ($p= 0.106$). However, a significant main effect occurred between reinforced and non reinforced groups ($p< 0.001$). Resin material by group interaction was significant ($p= .028$). Line graph representing mean flexural strength of PMMA and BAC resin material is shown in figure 1.

For PMMA resin, the difference between control and glass fiber reinforcement groups was highly significant ($p< 0.001$). For BAC resin, the difference between control and glass fiber reinforcement was not statistically significant ($p= 0.159$). Bar graph representing mean flexural strength of PMMA and BAC resin material is shown in figure 2.

The difference at control groups between PMMA and BAC resin material was significant ($p= 0.036$). The difference at glass fiber reinforced groups between PMMA and BAC resin material was not significant ($p=0.559$).

Table 1: Materials and groups with means, standard deviations and sample sizes.

Material	*Group*	*Mean (N)*	*Std. Deviation (N)*	*N*
PMMA	Control	394.4	23.4	5
	Glass Fiber	613.6	54.2	5
	Total	504.0	122.0	10
BAC	Control	513.6	103.1	5
	Glass Fiber	593.4	50.5	5
	Total	553.5	87.4	10
Total	Control	454.0	94.4	10
	Glass Fiber	603.5	50.5	10
	Total	528.8	106.4	20

7.0 DISCUSSION

The purpose of this in vitro study was to assess the influence of impregnated glass fibers as a reinforcing agent on the flexural strength of two commonly used provisional resin materials. A three point bending analysis utilizing a universal testing machine was employed to measure the flexural strength between the two resins and to compare how the addition of impregnated glass fibers affects the flexural strength. The data rejected the null hypothesis for PMMA resin but supported the null hypothesis for BAC resin.

To ensure standardization of all forty samples it was important to fabricate a custom mold held within a split metal flask from which all samples were fabricated. Studies have indicated that the position, quantity, direction and degree of adhesion between the fibers and polymer matrix affect the degree of reinforcement (Samadzadeh 1997, Vallittu 1999, Nohrstrom 2000, Kanie 2000).

To control the position of the glass fiber, slots were created in the lateral portion of the mold to prevent movement of the glass fibers while incorporating and pressing the resin material. The placement of the fibers within the body of the resin is crucial in stabilizing the resin material against occlusal loads. In this experiment, two reinforcing fibers were incorporated on the occusal and gingival positions to provide optimal reinforcing strength from resin fracture. This experiment was modeled by a previous study by Nohrstrom *et al.* (2000), where he found that placement of glass fibers on the occlusal and gingival positions produced the highest fracture force for reinforced glass fiber resin.

Each glass fiber bundle came prepackaged by the manufacture measuring 1.6mm x100mm and containing 4,000 glass fiber strands. This provided a consistent quantity of fiber in each reinforced resin group and eliminated any quantity variable in the experiment. The cured glass fiber bundles were placed parallel to the specimen and perpendicular to the load force. This has been shown to provide the best orientation in strengthening the resin polymer. This orientation is analogous to fibers on a tree trunk. Fibers in a tree run parallel to the trunk which helps to reinforce the tree from splitting during lateral movements, such as those imposed from wind.

Adhesion of the glass fiber to the resin polymer matrix was provided by an impregnated surface on the fiber bundle, which was prepackaged by the manufacture. The impregnated surface contained both PMMA and bis-acryl resin incorporation within the fiber bundles. Bonding agent was applied to the surface of the glass fiber bundle and cured prior to the application of resin, as recommended by the manufacture.

Flexural strength is defined as a materials ability to resist deformation under load. It is measured as the highest stress experienced within the material at its moment of rupture. Strength is given as a general mechanical term, but what we are really measuring are stresses within the resin. In a three point bending analysis, the resin samples underwent compression forces on the occlusal side and tension forces on the gingival side.

All of the sample groups underwent a three point bending analysis with a continual crosshead speed of 5mm per minute. Failure of the samples was noted as a complete fracture of the resin or a drop in the mean flexural strength of 40%, which was accurately measured by preprogrammed these parameters into the Instron machine’s computer software. One very important observation is that complete resin fracture was never seen with any of the reinforced glass fiber resins groups, but did occur with all the non-reinforced control resin groups (Figure 11). The reinforced glass fiber groups seem to prevent crack propagation and strengthen both PMMA and BAC resin materials from completely fracturing under force (Figure 12). This supports previous articles that impregnated glass fibers bond to the resin matrix and strengthen the resin from fracturing. The reinforced glass fiber samples never separated or frayed from the resin matrix under force; further proof that the impregnated glass fibers bonded to the resin matrix

For PMMA acrylic resin with glass fiber, the mean fracture force increased from 394.4N to 613.6N, an increase of 56%. The BAC resin with glass fiber had an increase in the mean fracture force from 513.7N to 593.4N, an increase of 16%. The use of glass fiber for both PMMA and BAC resin material increased the mean fracture force. However, the statistical data indicated that only PMMA resin with glass fiber was statistically significant ($p<0.05$). Although BAC resin with glass fiber did increase the mean fracture force, it was not statistically significant.

The use of second generation glass fiber as a reinforcing agent to enhance the mechanical properties (fracture strength, fracture toughness, flexural strength) of provisional resin material is in agreement with previous studies (Vallittu 1999, 2005, Hamza, 2004, 2006, Geerts, 2008, Chen 2009). Although some of these authors had different methods of calculating the effects of glass fiber as reinforcing agent in resin material, the general conclusions noted were that second generation glass fibers do help to reinforce the mechanical properties of provisional resin material from failures.

For the control non reinforced resin groups, BAC resin demonstrated an increased mean fracture force compared to PMMA acrylic. BAC resin mean fracture force was 513.7N compared to PMMA acrylic which had a mean fracture force of 394.4N. The results also indicated that resin material by group interaction was significant ($p=0.028$) and the difference at the control groups between PMMA and BAC material was significant ($p<0 .05$). These finding are in agreement with previous studies (Haselton 2002, Lang 2003, Nejatidanesh 2009).

One possibility as to why BAC resin with glass fiber did not produce clinically significant results could be result of the chipping of the composite material that occurred on the tension side of the specimens while undergoing load testing (Figure 13). This was evident in all BAC resin specimens with glass fiber reinforcement. As the load was been applied to the compression side of the specimen, the tension side was being pulled apart and the composite material began to chip and fracture causing a decrease in the amount of load being applied and an overall decrease in mean fracture force for each sample. It is important to note that chipping or fracturing of the resin material was only seen in the BAC resin with glass fiber reinforcement group.

One limitation of this study was that no aging or thermal cycling of resin materials occurred. This process could more accurately interpret true oral conditions and affect the mechanical properties of resin materials.

8.0 SUMMARY

Dental professionals fabricate provisional resin restorations on a daily basis. One factor that we tend to overlook when fabricating provisional restorations is the psychological aspect that the provisional may have on the patient which is esthetics, comfort and function. A properly fabricated provisional restoration may be one of most important factors for the patient and possibly the difference between satisfied patients that is willing to undergo treatment to one that forgoes all treatment.

Strengthening a provisional restoration with the incorporation of second generation impregnated glass fiber incorporated within resin material serves an important role from the clinical perspective. This reinforced resin prevents failures of provisional's and eliminates the need for remakes which, most importantly, keeps patients happy and enhances their interest in undergoing complete treatment.

The present study found that the use of second generation glass fiber as a reinforcing agent increased the mean fracture force of PMMA resin from 394.4N to 613.6N, an increase of 56%. The BAC resin with glass fiber increased the mean fracture force from 513.7N to 593.4N, an increase of 16%. Further analysis of the data indicated that only PMMA resin with glass fiber reinforcement was statistically significant. Although BAC resin with glass fiber did increase the mean fracture force, it was not statistically significant.

9.0 CONCLUSION

Based on the results of this investigation, the following conclusions can be made:

1. Although second generation impregnated glass fiber increased the flexural strength of both PMMA and BAC resin, it was not statistically significant in the BAC resin group ($p>0.05$) but was highly significant in the PMMA resin group ($p<0.05$).

2. At the non-reinforced control groups, the flexural strength of BAC resin was significantly higher than PMMA resin group ($p<0.05$).

APPENDIX A

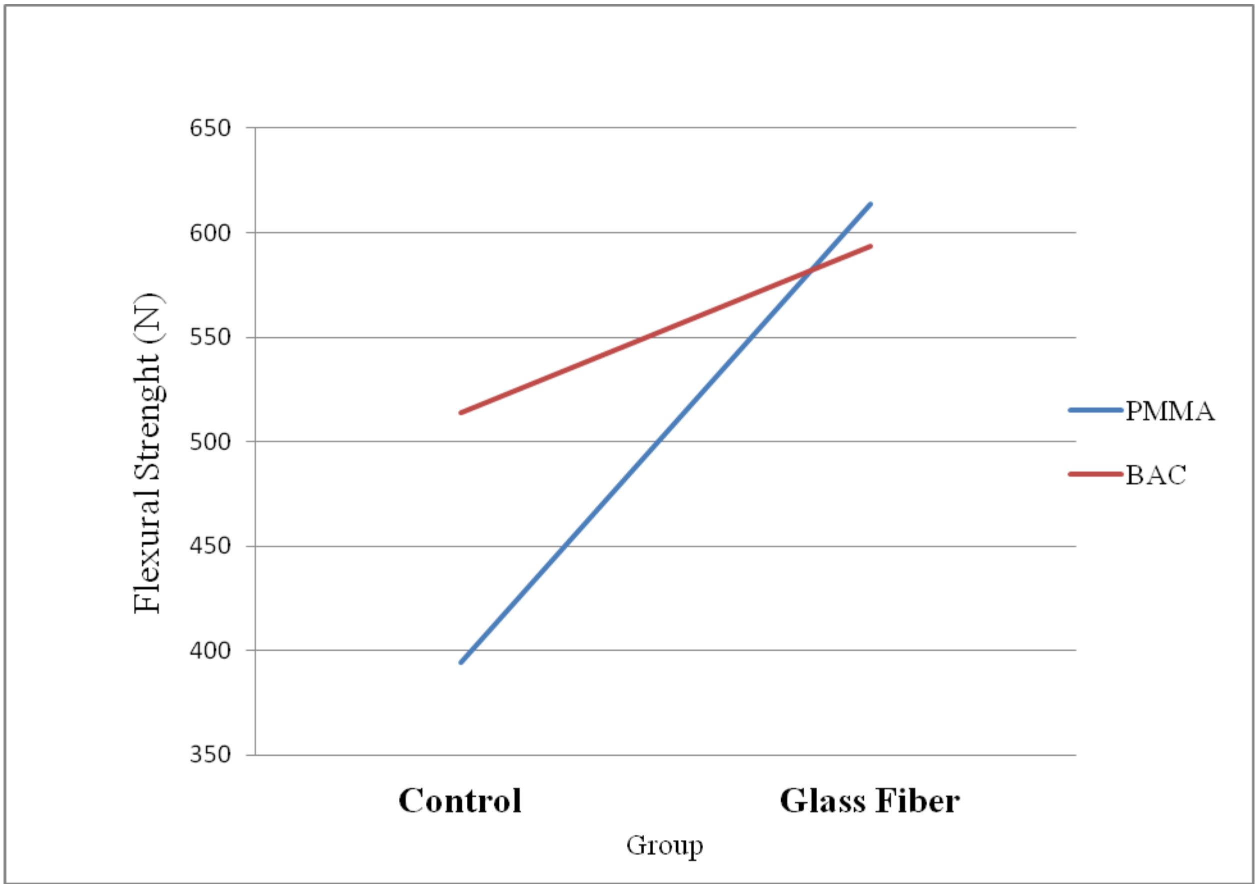

Figure 1: Line graph of mean flexural strength in Newton's (N) for PMMA and BAC resin material without glass fiber reinforcement and with glass fiber reinforcement

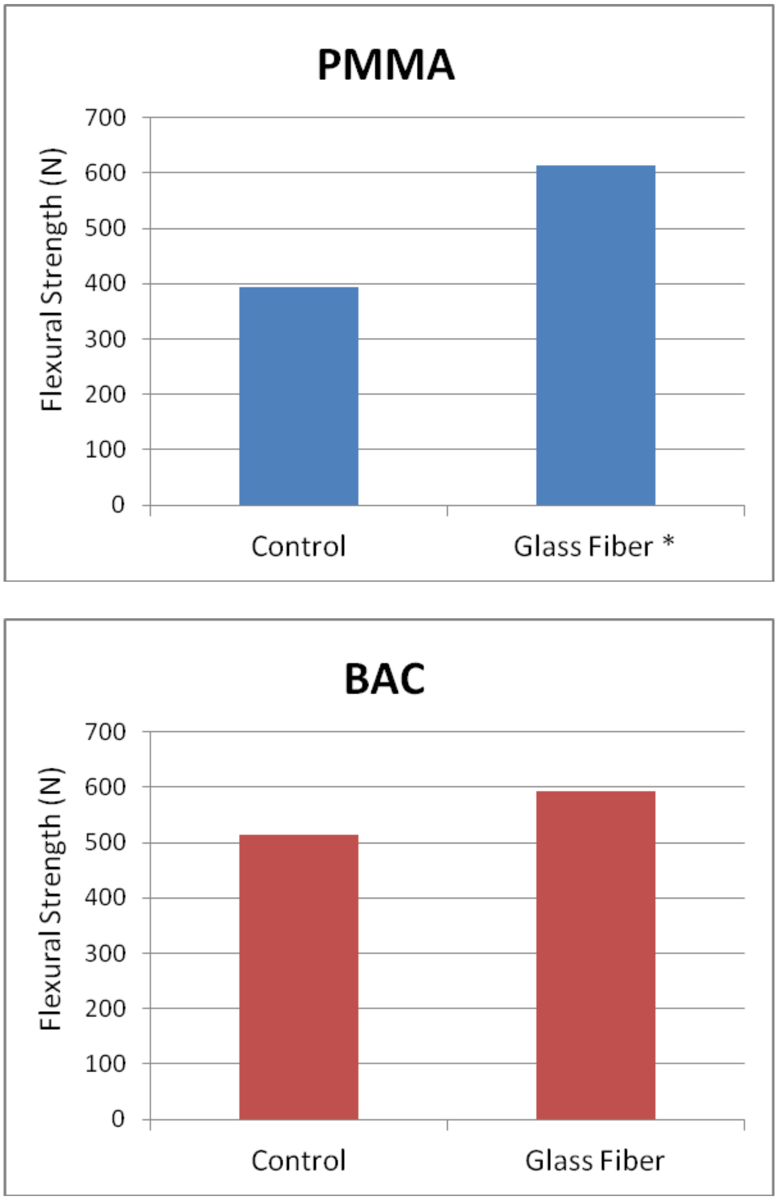

Figure 2: Bar graph of mean flexural strength for PMMA and BAC resin. Asterisk indicates clinically significant value ($p < 0.05$)

Figure 3: Split metal flask

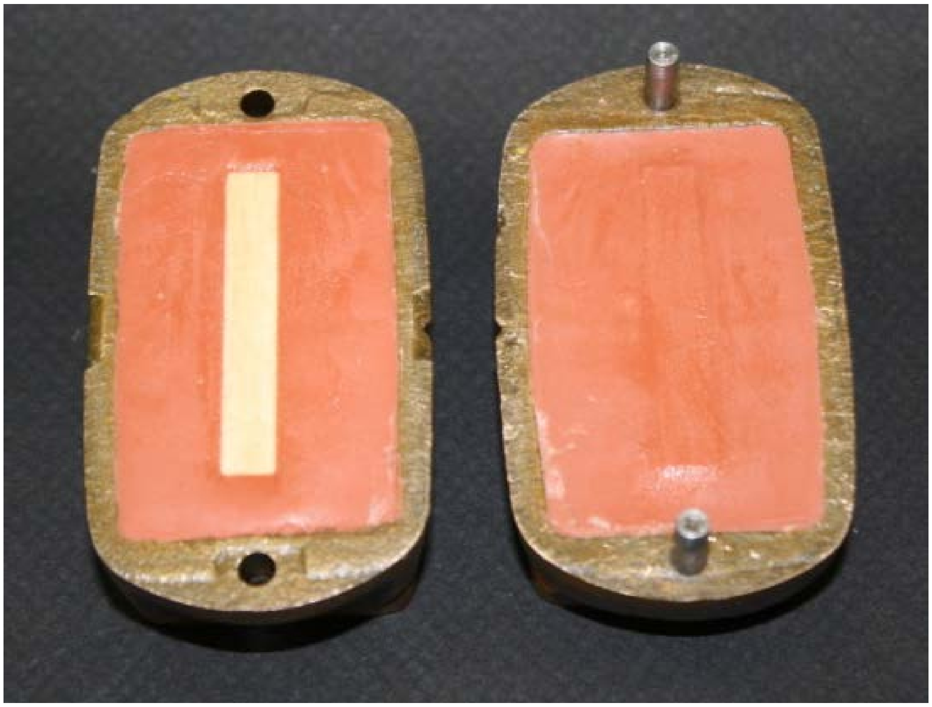

Figure 4: Split metal flask with PVS impression material and rectangular bar

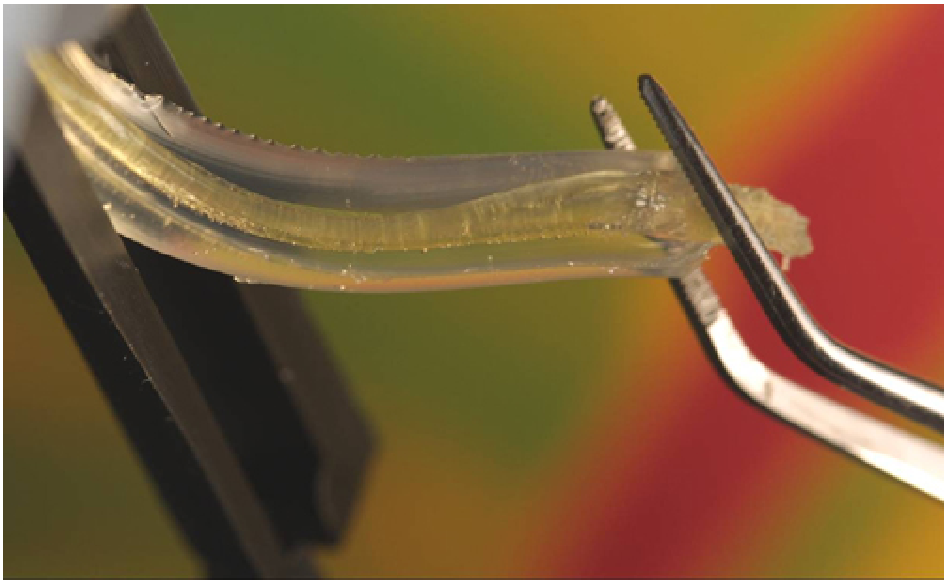

Figure 5: Impregnated glass fiber

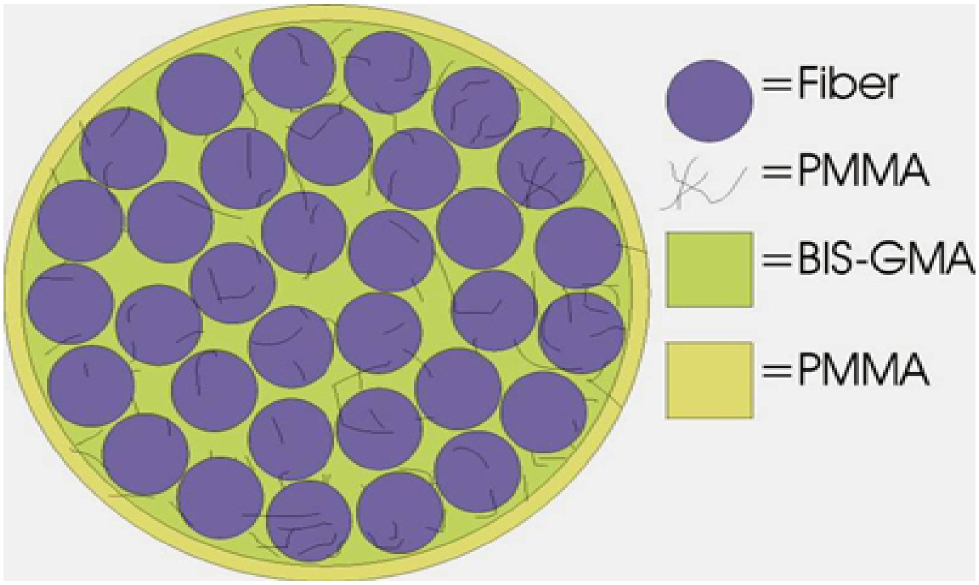

Figure 6: Cross sectional view of impregnated glass fibers

Figure 7: Impregnated glass fiber with clear silicone matrix

Figure 8: Impregnated glass fiber positioned within lateral slots

Figure 9: Resin incorporation at 3,000

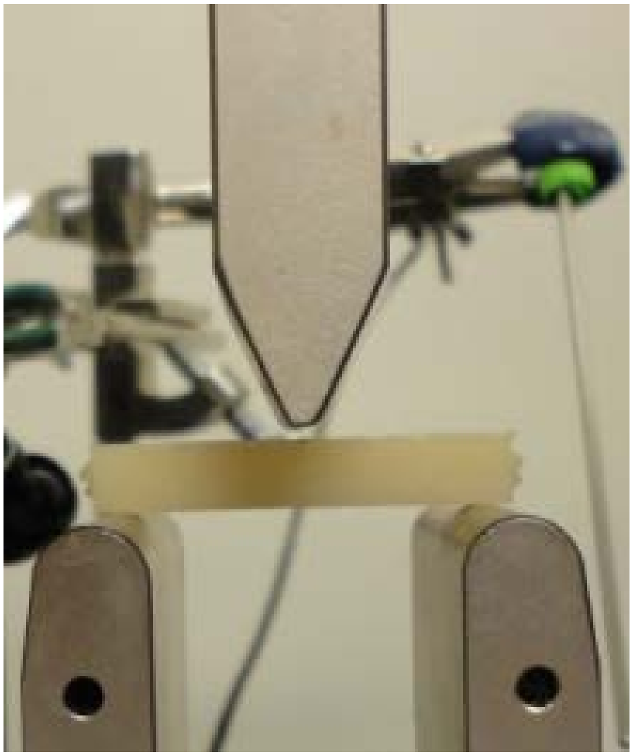

Figure 10: Three point bending with universal testing machine

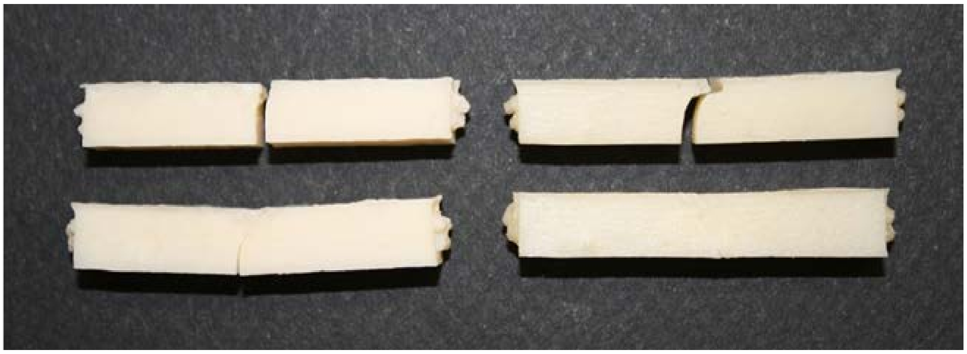

Figure 11: PMMA (left) and BAC resin (right) with control samples (top) and glass fiber reinforcement (bottom)

Figure 12: PMMA resin with impregnated glass fiber reinforcement

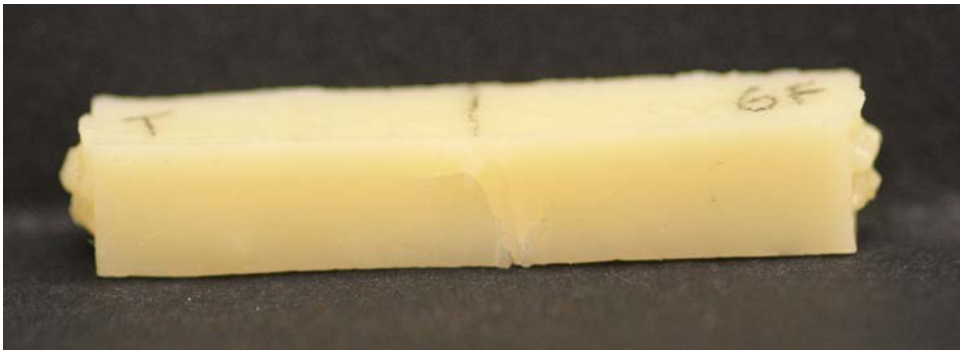

Figure 13: BAC resin with fractures and chipping on the tension side

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