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Frictional Forces of a Fixed, Esthetic Orthodontic Appliance System

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FRICTIONAL FORCES OF A FIXED, ESTHETIC ORTHODONTIC APPLIANCE SYSTEM

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ABSTRACT

FRICTIONAL FORCES OF A FIXED, ESTHETIC ORTHODONTIC APPLIANCE SYSTEM

By

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Purpose: The demands of an all esthetic fixed orthodontic appliance system are ever increasing in today's world. Frictional values of an esthetic, fixed orthodontic appliance system are needed to evaluate their clinical effectiveness for orthodontic treatment. The aim of this study is to evaluate the frictional values of various esthetic orthodontic archwires ligated to an esthetic orthodontic bracket.

Methods: Three types of stainless steel and nickel titanium alloy (niti) esthetic orthodontic archwires (epoxy, poly, plastic) in four sizes (.016, .018, .017 x .025, .019 x .025 inches) were ligated to both a stainless steel bracket system and a ceramic (esthetic) bracket system and pulled by a Universal testing machine for 90 seconds. Two types of control wires were also tested (stainless steel, niti). Each of these wires was tested 10 times. The mean frictional values were recorded for each wire in pounds. An ANOVA analysis was done to compare frictional differences between the different esthetic fixed bracket systems and a T-test was done to compare the frictional differences between wires tested in stainless steel brackets and those tested in ceramic brackets. Thickness of each of the esthetic archwires was measured with digital calipers and the means recorded.

Results: Of the 14 groups tested using the ANOVA, only 1 was not significant. Of the 13 statistically significant groups, all but 4 of those groups showed that the non-coated archwires systems had increased frictional values. Of the 28 t-tests done to compare frictional differences between archwires tested with stainless steel brackets and those tested with ceramic brackets, 22 were statistically significant. In the 22 significant groups, all but three showed a statistically significant increase in friction in wires tested using ceramic brackets. Of the three types of esthetic archwires measured, the Poly coated archwire had a mean thickness of .001 inches greater than that of the Epoxy and Plastic coated archwires

Conclusions: The non-coated (non-esthetic) archwires had significantly more friction than the coated (esthetic) archwires except for the .016 Niti Plastic Coated Archwire and .018 SS Epoxy Coated Archwire. All rectangular coated archwires had less friction than the non-coated controls. The coated (esthetic) archwires pulled through a ceramic (esthetic) bracket system all had significantly greater friction than those pulled through a stainless steel bracket system except for the .018 Niti Epoxy archwire. The Poly coated archwires had the most friction of the esthetically coated archwires while pulled through a passive arch bracket system. The .001 inch increase in diameter thickness of the Poly coated archwires was most likely the cause of the increased friction.

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CHAPTER 1

INTRODUCTION

Orthodontics is the specialty of dentistry focused on the treatment and correction of malocclusion. Malocclusion (irregular bite) may be the result of tooth irregularity, poor jaw relationships, or a combination of the two. Crowded, irregular and misplaced teeth have been a problem for some individuals since antiquity, and attempts to correct this disorder go back to at least 1000 B.C. They have even discovered primitive orthodontic appliances while sifting through Greek and Etruscan materials (Profitt, 2007 p. 3). The first texts describing orthodontics didn't come until after 1850. It wasn't until the end of the 19th century that crucial advancements were made in orthodontic appliances.

Edward Angle, the "father of modern orthodontics" was a powerful influence in the development of modern orthodontic appliances. Edward Angle developed four major appliance systems. These appliance systems were called the E-arch, pin and tube arch, ribbon arch, and the edgewise appliance. The E-arch consisted of bands on the molar teeth and a heavy labial archwire extended around the arch (Fig 1.1). The end of the wire was threaded, and a small nut placed on the threaded portion of the arch allowed the archwire to be advanced so that arch perimeter increased. Each tooth was simply tied to the advancing archwire. Only tipping of teeth was accomplished with the E-arch. The pin and tube appliance was developed to help precisely position teeth. The pin and tube appliance required a high amount of craftsmanship and was not very practical for clinical use. It is said that only Angle himself and one of his students ever mastered this appliance (Profitt, 2007, p. 408). The ribbon arch was a modification of the pin and tube appliance (Fig 1.2). Each tooth had a vertically positioned rectangular slot behind the tube. A ribbon arch was placed into the rectangular slot and held in with a pin. The spring qualities of this appliance were good but it did not allow the proper forces necessary for adequate root positioning. The edgewise appliance was probably the most important orthodontic appliance design that Angle developed (Fig 1.3). In this appliance, Angle oriented the slot from vertical to horizontal and inserted a rectangular wire 90 degrees to the orientation it had with the ribbon arch. This appliance finally allowed for excellent torque control and proper root positioning. The edgewise appliance was developed in 1928 and was the mainstay of multi-banded fixed appliance therapy (Profitt, 2007 p 408).

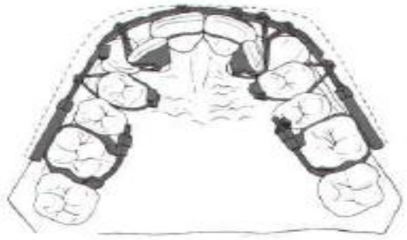


Figure 1.1 E-Arch (Profitt, 2007, p. 408)

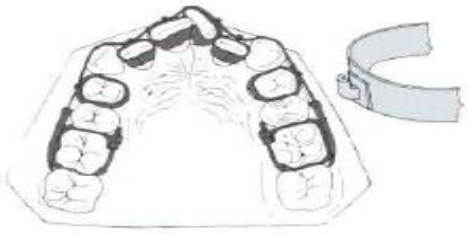


Figure 1.2 Ribbon Arch (Profitt, 2007, p. 408)

Figure 1.3 Edgewise Appliance (Profitt, 2007, p. 409)

With the development of the edgewise appliance, the use of precious metals proved ineffective in the performance of some stabilizing procedures. The precious metals were too flexible and lacked the necessary stiffness to move teeth into their proper position. At around the same time as the development of the edgewise appliance, stainless steel archwire was fabricated. This wire alloy, with chromium and nickel in its metallurgy, was touted as superior to its precious-metal predecessors because of its higher strengths, greater elastic modulus, ductility, and corrosion resistance in the oral environment (Nikolai, 1997). By the 1950's, stainless steel alloys were used for most orthodontic wires. The 1950's also brought about the development of Elgiloy wire. This cobalt-chromium alloy had similar characteristics to stainless steel but had the added benefit of being hardened by heat treatment. In the 1960's, a nickel titanium alloy proved to be an effective alloy as an orthodontic archwire. In the 1980's, beta-titanium alloy (TMA) was also developed. Current developments are being made in the manufacturing of esthetic archwires. Development of a clinically effective composite archwire is being researched and tested. Esthetically coated metallic archwires are currently the only esthetic orthodontic archwires available for clinical use.

Advancements and improvements of orthodontic brackets are also being made. Up until the 1980's, banding was the most common way to secure a bracket to a tooth. With a band on every tooth, an orthodontic patient had a mouth full of metal. With the development of bonding the bracket to the enamel of the tooth, bands were not needed as often and less metal was visible. The last two decades have brought about the development of a more esthetic bracket. Ceramic and plastic brackets have been developed to make orthodontic appliances look less conspicuous. Stainless steel brackets continue to have the best mechanical properties of all the different types of brackets but more and more people are seeking out the "camouflaged" look of a tooth colored bracket.

Purpose of the Study

The field of orthodontics is moving towards an all esthetic fixed appliance system with little, if any, showing of metallic components. The most recent developments of esthetic appliances in orthodontics are the archwires. Coated metallic archwires are currently the only practical esthetic orthodontic archwire available for clinical use. Very little research has been done on the properties of these coated orthodontic archwires. Most of the research testing done on the modern, coated archwires are being done in conjunction with the more conventional stainless steel (non-esthetic) brackets and elastomeric ligature ties. If patients are looking for an "all esthetic" appliance system, more testing should be done using esthetic brackets (ceramic brackets) in conjunction with the newly designed esthetic archwires.

The frictional properties of a fixed orthodontic appliance system are extremely important for orthodontists. Movement of one object contacting another cause's friction at the interfaces and produces a resistance to the direction of movement. Tying an orthodontic archwire into a bracket slot produces a force between the bracket, archwire, and tie. Much of the force produced is conveyed as friction. Too much friction between an archwire, bracket, and tie can delay or even prevent necessary orthodontic tooth movement. Knowing the frictional properties of orthodontic appliances is crucial to the success of orthodontic treatment. Research has been done to test the friction of various orthodontic archwires tied into various bracket designs. Most of this research has been done on stainless steel, nickel titanium and TMA materials while few projects include the newly designed "esthetic" orthodontic archwires. More frictional testing needs to be done on these modern "esthetic" orthodontic archwires used in conjunction with other esthetically looking brackets.

The purpose of this research is to test the frictional values of a modern "ALL" esthetic fixed orthodontic appliance system. An "All" esthetic orthodontic appliance system would include tooth colored brackets and coated (esthetic) wires. Frictional forces of various modern esthetic archwires, ligated to esthetic brackets with elastomeric (plastic) rings, will be measured and compared to each other. Nickel titanium and Stainless steel wires will also be tested as controls and a comparison to the frictional values of the esthetic archwire systems will be made.

Definition of Terms

Fixed Appliance System: An appliance that is attached to the teeth by cement or an adhesive material

Esthetic Brackets: An orthodontic bracket designed to be tooth colored in appearance.

Esthetic Archwires: An orthodontic archwire designed to be tooth colored in appearance

Elastomeric ties (O-rings): Circular plastic rings designed to attach an orthodontic archwire into an orthodontic bracket

Resilience: The power or ability of a material to return to its original form, position, etc.., after being bent or stretched.

Stiffness: The rigidity of an object. The extent to which a material (archwire) resists deformation in response to an applied force

Friction: The force resisting the relative motion of a solid surface, fluid layers, and material elements sliding against each other.

Banding: The cementing of a band around a tooth.

Research Questions

The overall research goal of the study is as follows:

The frictional comparison of multiple types of newly designed esthetic orthodontic archwires, in both Niti and Stainless Steel coated forms, while being pulled through esthetic (ceramic) brackets using a universal testing machine; the frictional similarities or differences between esthetic archwires pulled through stainless steel and Ceramic (esthetic) brackets using a universal testing machine.

The research goal can be addressed by evaluating the following specific questions:

1. What are the frictional differences of the 4 types of niti wires (niti non-coated, niti-epoxy-coated, niti-poly-coated, niti-plastic-coated) after they are ligated with elastomeric O-rings to a stainless steel bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated niti archwire (control) will be higher than the niti-epoxy-coated, niti-poly-coated, and niti-plastic-coated.

2. What are the frictional differences of the 4 types of niti wires (niti non-coated, niti-epoxy-coated, niti-poly-coated, niti-plastic-coated) after they are ligated with elastomeric O-rings to a ceramic (esthetic) bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated niti archwire (controls) will be higher than the niti-epoxy-coated, niti-poly-coated, and niti-plastic-coated archwires.

3. What are the frictional differences of the 4 types of stainless steel wires (stainless steel non-coated, stainless steel epoxy-coated, stainless steel poly-coated, stainless steel plastic-coated) after they are ligated with elastomeric O-rings to a stainless steel bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated stainless steel archwires (controls) will be higher than the stainless steel epoxy-coated, stainless steel poly-coated and stainless steel plastic-coated archwires.

4. What are the frictional differences of the 4 types of stainless steel wires (stainless steel non-coated, stainless steel epoxy-coated, stainless steel poly-coated, stainless steel plastic-coated) after they are ligated with elastomeric O-rings to a ceramic (esthetic) bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated stainless steel archwires (controls) will be higher than the stainless steel epoxy-coated, stainless steel poly-coated, and stainless steel plastic-coated archwires.

5. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of non-coated niti wires after they are ligated with elastomeric O- rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The non-coated niti archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

6. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, 19x.025 inches) of non-coated stainless steel wires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The non-coated stainless steel archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

7. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-epoxy-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-epoxy coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

8. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel epoxy-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel-epoxy coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

9. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-poly-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-poly-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

10. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel poly-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel poly-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

11. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-plastic-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-plastic-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

12. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel plastic-coated archwires after they are ligated with

elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel plastic-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

CHAPTER 2

REVIEW OF THE LITERATURE

Literature review of this topic encompassed both US and European published literature via online databases. Search terms included the following: esthetic archwire, coated archwire, esthetic bracket, ceramic bracket, friction and esthetic archwires, friction and coated archwires, friction and esthetic brackets, friction and ceramic brackets. Searchable databases included: Pubmed, Science Direct, Scopus, Academic Search Premier, Medline, Web of Knowledge, and Cochrane Library. A UNLV library search was also completed on the search terms to locate books regarding this topic. The search terms were also placed into several internet search engines including Google, Yahoo and MSN for further investigation. The search resulted in nineteen articles and three text books related to esthetic orthodontic bracket and esthetic orthodontic archwire and friction.

History and Mechanical Properties of Orthodontic Archwires

Understanding the mechanical properties of a fixed orthodontic appliance system is extremely important. Although this study is intended to measure the frictional values of various esthetic orthodontic archwires, it's still important to understand the mechanical properties of all orthodontic archwires and brackets in order to assess their clinical effectiveness and strengths and weaknesses. The esthetic archwires used in this study are esthetically coated stainless steel and niti wires. An understanding of the properties of these two types of wires is especially essential to the study.

Some of the most important properties to describe in these metallic and non-metallic appliances are their stiffness, springback, formability, working range, and frictional characteristics.

Stainless steel wires are very popular in clinical orthodontics because of their adequate mechanical properties and lower cost. The stainless steel alloys used for orthodontic wires are of the “18-8” austenitic type; containing approximately 18% chromium and 8% nickel (Eliades, 2001. p. 79). The modulus of elasticity of stainless steel archwires tends to be the highest of the orthodontic archwires. This means that stainless steel wires are stiffer and stronger than other archwire alloys of the same size and shape. Most of the time stainless steel archwire is not the wire of choice when orthodontic treatment first begins. A more flexible archwire is usually needed. The springback qualities of stainless steel are also low due to their high modulus of elasticity. One of the best qualities of stainless steel archwires are its ability to be formed. This allows the orthodontist to make bends in the wire when needed. The working range of stainless steel is generally smaller than that of other archwire alloys. This is also due to its higher stiffness and strength characteristics. The frictional qualities of stainless steel are generally the best of all the orthodontic archwires currently available. Numerous studies testing the frictional characteristics of stainless steel archwires have proven it to produce the least amount of friction. The hardness and smoothness of the surface of stainless steel archwires makes it’s coefficient of friction less than that of other archwire alloys. Other qualities of stainless steel are its abilities to be soldered and its high resistance to corrosion.

Elgiloy archwires, also referred to as cobalt-chromium archwires, have similar characteristics as stainless steel archwires. They are made of 40% cobalt, 20% chromium, 15% nickel, 15.8% iron, 7% molybdenum and small amounts of manganese, carbon, and beryllium. Elgiloy has the advantage that it can be supplied in a softer and therefore more formable state, and then can be hardened by heat treatment after being shaped. The heat treatment increases strength significantly (Profitt, 2007, p. 361).

In the late 1960's the Office of the Navy was actively studying new types of alloys that exhibited a shape memory effect (Kusy, 1997). One of these studied alloys happened to be made of 50% nickel and 50% Titanium. They decided to call the alloy Nitinol which stands for 'nickel titanium naval ordnance laboratory'. One decade later, Dr. George Andreasen recognized the potential of its use as an orthodontic archwire (Kusy, 1997). Nitinol has a very low modulus of elasticity which makes it very flexible. It only has about one-fifth of the force delivery as that of stainless steel archwires but still delivers a force great enough for orthodontic tooth movement (O'Brien, 2008. p. 282). It also has a large working range. This means that it can be bent a large amount before permanent deformation occurs. This allows the wire to be placed between two extremely uneven brackets without being permanently deformed. Without permanent deformation, more springback energy is available in the wire to produce force on a tooth and subsequent movement. In 1980, Nickel Titanium was developed in a "superelastic" form. This form of Nitinol has a very large reversible strain and a non-elastic stress-strain or force-deflection curve. This means that over a considerable range of wire deflection, the force produced by the wire hardly varies. This unique force-deflection curve for superelastic niti happens because of a metallic phase transitions that occur in the alloy while being deformed. In the early 1990's, a Niti orthodontic wire alloy with true shape memory at the temperature of the oral environment was introduced (Eliades, 2001, p. 85). This meant that the wire could be easily placed in the brackets and then allowed to heat up by the persons own breath. The heat from the mouth would cause a change in the grain structure to the wire and subsequently revert back to its original pre-formed shape.

Although Nitinol sounds like the perfect orthodontic archwire, there are some flaws associated with it. The formability of Nitinol is very poor. This makes placing bends in Nitinol wire extremely difficult. It also has poor frictional characteristics. Research done on the frictional characteristics of Nitinol conclude that there is an increase in frictional resistance while using Nitinol archwires compared to stainless steel archwire.

In the 1980's, TMA (Titanium Molybdenum Alloy) was introduced into the field of orthodontics as yet another valuable archwire material. TMA, also known as Beta-Titanium, contains 78% titanium, 11% molybdenum, 7% zirconium, and 4% tin. The approximate stiffness of TMA is around half of that of stainless steel. It is about twice as stiff as nickel titanium. The spring-back qualities of TMA also fall in-between the ranges of stainless steel and nickel titanium. In other words, TMA's stiffness, strength, spring-back, working range, and flexibility values fall in-between that of stainless steel and nickel titanium. Its properties can make it a good wire to use in situations where stainless steel may be too stiff and nickel titanium not stiff enough. TMA has excellent formability characteristics due to its bcc metallic structure (Eliades, 2001, p.83). This allows permanent bends to be placed in the archwire when needed. Another advantage of

TMA is that it’s the only orthodontic wire alloy possessing true weldability (Eliades, 2001, p.84). With all the qualities described above about TMA, one would think that this would be the perfect archwire for orthodontists? Although TMA has great orthodontic archwire properties, there are a few setbacks. Of all the orthodontic archwires, it is the most expensive. Expensive enough to make a lot of orthodontist keep it out of their supplies. TMA also has very poor frictional characteristics. Scanning electron microscopy examination of beta-titanium wires has revealed relatively rough surfaces that are attributed to adherence or cold welding by the titanium to the dies or rollers during wire processing. This surface roughness contributes to the high values of archwire-bracket sliding friction measured in the laboratory, along with localized sites of cold welding or adherence by the wire to the bracket slots (Eliades, 2001, p.84).

An “esthetic” archwire is any wire made to look more tooth colored and ultimately “esthetically pleasing”. Composite archwires along with surface coating of metallic archwires are the only current esthetic archwires being studied. Composite archwires can be composed of ceramic fibers that are embedded in a linear or cross-linked poly-metric matrix. The composite archwires can be as strong as the strongest piano wire and can vary in stiffness from that of the most flaccid multi-stranded archwire, to nearly that of a beta-titanium archwire (Kusy, 1997). Hints of experimentation with composite wires have shown that they can be very flexible and highly resilient (Nikolai, 1997). Although not common in the marketplace at this time, composite archwires will most likely capture a significant share of the marketplace in the near future. Esthetically coated archwires are currently the more popular type of esthetic orthodontic archwires available for clinical use. Coatings to archwires of all alloys can be done to produce an esthetic archwire. Most coatings on the archwire are done using ion implantation. The ion implantations can be made of epoxy, Teflon, rhodium, or palladium. Surface coated metallic archwires are new to the marketplace and very few studies have been done to test their mechanical properties. Problems with coating cracking have been noted in the literature. More research needs to be done on the properties of aesthetic archwires before these wires are routinely used in orthodontic practices.

Surface Characteristics of Esthetic Archwires

The surface characteristics of an orthodontic archwire are important for practicing orthodontists to know. Having a good knowledge of these characteristics can help the orthodontist make correct decisions during the course of a patient's treatment. Because there is an increased demand for esthetic fixed orthodontic appliances, more and more orthodontic supply companies are developing esthetic archwires. These newly developed archwires need to be researched and tested to keep the orthodontist informed about their benefits and limitations. The surface characteristics of the archwire can play a huge role in the friction produced during orthodontic tooth movement. The goal of this section is to describe the surface characteristics of the esthetic orthodontic archwire in order to get a better understanding of the possible frictional effects they can have.

Most esthetic orthodontic archwires are composed of a Niti or stainless steel archwire with an "esthetic" coating applied by ion implantation. Ion implantation is the process in which a substrate is refined by ionized atoms, adhering to the high-energy, positively charged radicals of the coating material through negative loading. The radicals penetrate the substrate surface and bind with the substrate. It is thus not a coating but a permanent modification of the surface composition that is produced (Husmann et al., 2002). The ion implantation can increase hardness, reduce flexibility, and improve surface finish (Doshi, 2011). Some reports indicate that the ion implantation fills in the depressions and rough valleys found at the microscopic level of the archwire (Husmann et al., 2002). This ultimately smooth's the surface and can lead to a decrease in friction. Other studies determined the esthetic coating not durable and that the coating tends to split over time (Elayyan et al., 2008). The splitting of the coating can increase the frictional resistance. It seems that surface roughness would play a big role in determining the frictional effects of an archwire. Surprisingly these characteristics don't always coincide with objective values obtained during research experiments. An example of this would be the microscopic examination of the surface of niti and TMA archwire. TMA appeared to have the smoother surface of the two, yet it generated the highest frictional values. There can't be an assumption made that the smoother the archwire appears, the less friction it will have.

History and Mechanical Properties of Orthodontic Brackets

The two major types of brackets used in modern orthodontics are the stainless steel bracket and the ceramic (esthetic) bracket. Stainless steel brackets have been used for decades with high clinical success. Like the stainless steel archwire, stainless steel brackets are strong and have the lowest frictional resistance of all the orthodontic bracket types. Ceramic brackets can be made of either a single-crystal alumina or a poly-crystal alumina. Strength of ceramic brackets can differ based on their single-crystal or poly-crystal structure and the size of their grain structure. The optical properties and strength are inversely related for the poly-crystalline ceramics: the larger the individual grains in the microstructure, the greater is the ceramic translucency. However, when the grain size approaches 30 microns, the material becomes substantially weaker (O'Brien, 2008, p. 151). The single-crystal alumina brackets contain fewer impurities than are found in the poly-crystalline alumina brackets. This gives the single-crystal brackets more clarity but increases the chances of crack propagation and fracture of the bracket. Ceramic brackets are larger than their stainless steel competitor and are more brittle. This makes the debonding (removal) of the ceramic bracket more difficult. The only true benefit of a ceramic bracket over a stainless steel bracket is the esthetically pleasing look it gives to a self-conscious orthodontic patient.

Frictional Factors of Orthodontic Appliances

Friction is defined as the resistance to motion when one object moves tangentially to another (Reicheneder et al., 2007). The first law of friction states that the frictional force is equal to the applied load (N) multiplied by the coefficient of friction (Mu) of the objects (F= N x Mu). Coefficient of friction depends on the relative roughness of the material itself. Interestingly, friction is independent of the apparent area of contact. This is because all surfaces, no matter how smooth, have irregularities that are large on a molecular scale, and real contact occurs only at a limited number of small spots at the peaks of the surface irregulaties (Fig 2.1). These spots, called asperities, carry the entire load between two surfaces (Profitt, 2007 pg. 377).

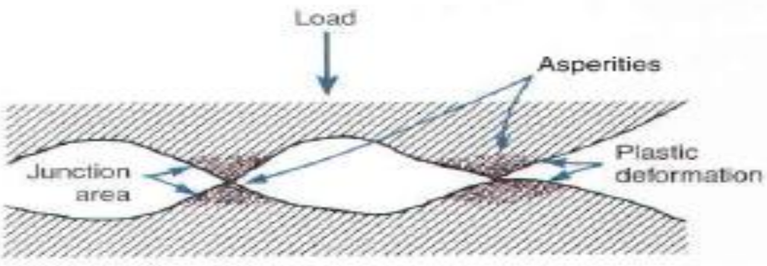


Figure 2.1 Illustration of contacts between surfaces at the asperities

When a tangential force is applied to cause one material to slide past the other, the junctions begin to shear. The coefficient of friction then is proportional to the shear strength of the junctions and is inversely proportional to the yield strength of the materials (because this determines the extent of plastic deformation at the asperities). At low sliding speeds, a “stick-slip” phenomenon may occur as enough force builds up to shear the junctions and a jump occurs, then the surfaces stick again until enough force again builds to break them.

Two other factors can affect the resistance to sliding: the interlocking of surface irregularities, which obviously becomes more important when the asperities are large or pointed; and the extent to which asperities on a harder material plow into the surface of a softer one. Thus the total frictional resistance will be the sum of three components: (1) the force necessary to shear all junctions, (2) the resistance caused by interlocking of roughness, and (3) the plowing component of the total friction force. In practice, if the two materials are relatively smooth and not greatly dissimilar in hardness, friction is largely determined by the shearing component (Profitt, 2007, p. 377).

Frictional Characteristics of Archwires

The increased use of sliding mechanics that followed the development of the pre-adjusted edgewise systems has focused interest on the effect of friction between bracket and archwire and its contribution to the resistance to tooth movement (Reicheneder, 2007). Scientific publications on archwire-bracket friction generally concur that metallic slot in contact with stainless steel archwires experience the least friction, while ceramic slots in contact with nickel-titanium and beta-titanium archwires experience the greatest friction (Eliades, 2001). Stainless steel archwires in contact with stainless steel bracket have essentially equal hardness values. This equality in hardness decreases the friction that can occur when two materials of different hardness's slide past each other. Although Niti has shown to have greater surface roughness, TMA has greater frictional resistance. This is due to the amount of titanium in the wires. It's been proven that as the amount of titanium increases in a material, the coefficient of friction also increases. Beta-ti has 80% titanium whereas niti has 50%. This increased amount of titanium in beta-ti also causes reactivity for the wire to "cold-weld" itself to a steel bracket under some circumstances, making sliding almost impossible.

Frictional Characteristics of Brackets

Ceramic brackets became quite popular in the 1980's because of their improved esthetic look, but problems related to frictional resistance to sliding have limited their use. The ceramic brackets made from polycrystalline ceramic have considerably rougher surfaces than steel brackets. The rough but hard ceramic material is likely to penetrate the surface of even a steel wire during sliding, creating considerable resistance. Although single crystal brackets are quite smooth, these brackets also can damage wires during sliding, and so they also have increased frictional resistance to sliding. Many manufactures are producing ceramic brackets with metal slots to help decrease the frictional resistance to sliding. They are also working on making clinically acceptable composite plastic brackets that are tooth colored. These brackets should have better frictional characteristics than those of ceramics.

CHAPTER 3

METHODOLOGY

Collection of Data

The six groups of esthetic orthodontic archwires tested (Epoxy- Europa 1: G&H wire, Franklin IN; (1)Tooth tone coated Nickel Titanium Wire, (2)Tooth tone coated Stainless Steel Wire. Poly- Bioforce High esthetic Archwire: Dentsply GAC, Bohemia NY; (3) Tooth tone coated Nickel Titanium Wire, (4) Tooth Tone coated Stainless Steel Wire. Ortho Technology: Tampa FL; (5) Tooth tone coated Nickel Titanium Wire, (6) Tooth tone coated Stainless Steel Wire). Four different size archwires (.016 inches, .018 inches, .017 x .025 inches, .019 x .025 inches) were used for groups 1,3 and 5. Three different size archwires (.018 inches, .017 x .025 inches, .019 x .025 inches) were used for groups 2,4 and 6. There were no .016 inch diameter archwires in groups 2,4 and 6 and therefore could not be tested.

The two groups of non-esthetic archwires tested: (1)Nickel Titanium: G&H wire, Franklin IN. (2) Stainless Steel: G&H wire, Franklin IN. The non-coated nickel titanium and stainless steel wires will be used as the controls in this study. Four different size archwires (.016 inches, .018 inches, .017 x .025 inches, .019 x .025 inches) were used for the two non-esthetic archwires.

The two types of bracket tested (Radiance: American Orthodontics, Sheboygan WI; (1) Polycrystaline Ceramic. Mini Masters Series MBT: American Orthodontics, Sheboygan WI; (2) Stainless Steel). The Stainless Steel bracket will be used as the control in this study. The bracket slot dimensions of both brackets tested were 0.022 x 0.028 inches.

Elastomeric ties used to secure the archwires to the bracket systems (polyurethan: 0.045 inch inner diameter, 0.115 inch outer diameter: American Orthodontics, Sheboygam WI).

Each size of the six esthetic archwires and two non-esthetic archires will be tested ten times in each of the two types of bracket systems. This makes 560 total number of tests performed in the study (Fig 3.1 to 3.8). The frictional analysis of the 560 tests were done using the universal testing machine (United Calibration Corp. Huntington Beach, CA) (Fig 3.9). Two experimental models, manufactured out of Stainless Steel, were designed to represent the arc of a preformed archwire manufactured by G&H wire, Franklin IN (Fig 3.10). One experimental model had stainless steel brackets glued, with epoxy, to the outer surface and the other had ceramic brackets fixed in the same manner. The brackets were glued in a position representative of the upper right quadrant of the maxillary arch (Upper right 1st molar, Upper right 2nd premolar, Upper right 1st premolar, Upper right canine, Upper right lateral incisor, Upper right central incisors). The brackets slots were aligned using .021 x .025 stainless steel archwire tied to the bracket. Each bracket was fixed 6mm apart from each other and the upper right central incisor was placed 6mm away from the midline of the steel arc model. Each archwire size was also measured ten times with digital calipers to determine the exact dimensions of each archwire.

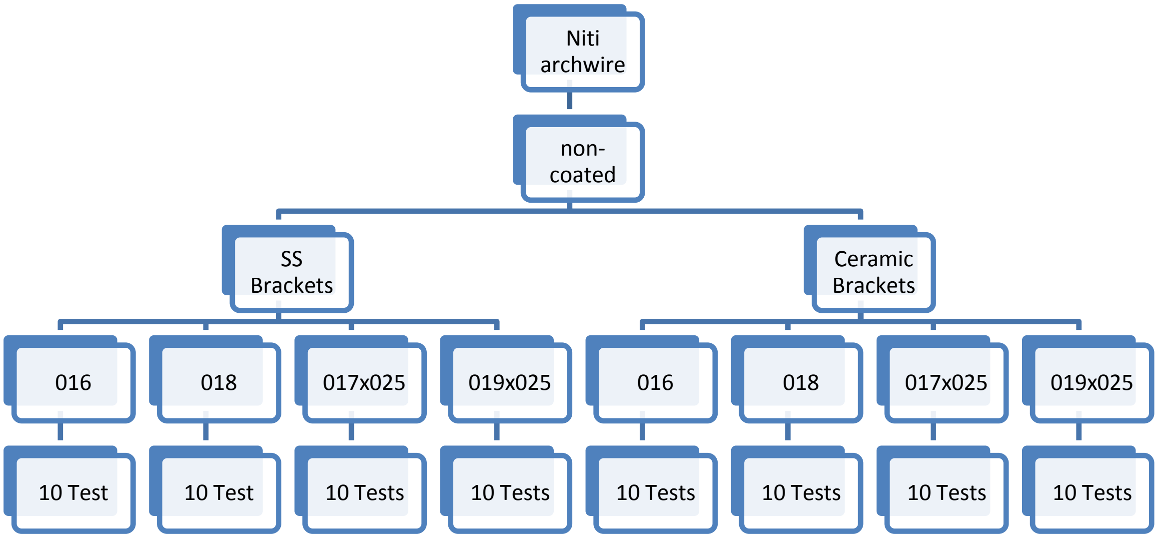


Figure 3.1 Flow Chart of Non-Coated Niti Wires

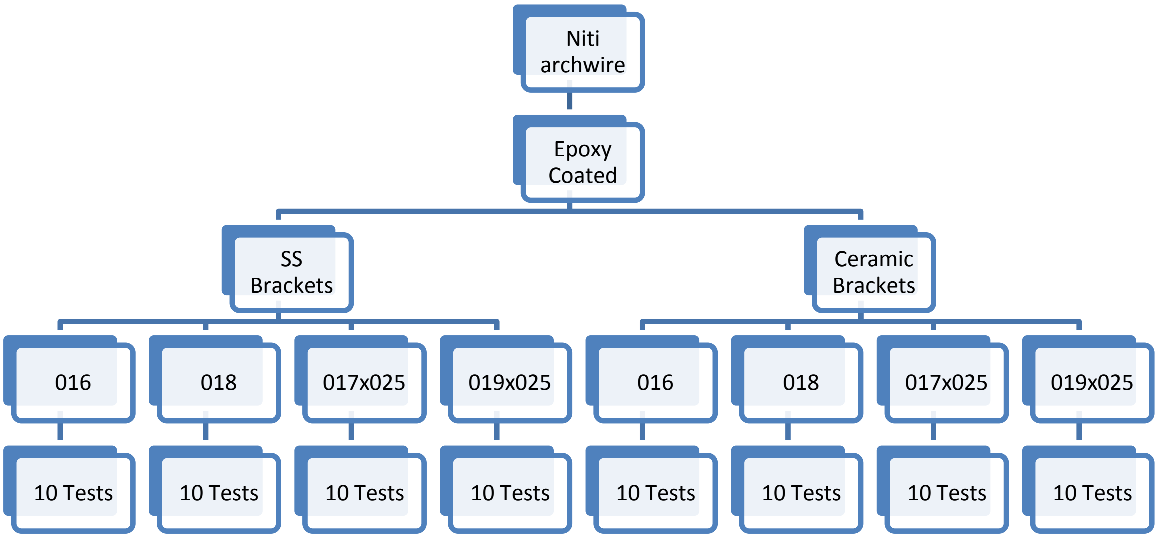


Figure 3.2 Flow Chart of Epoxy-Coated Niti Wires

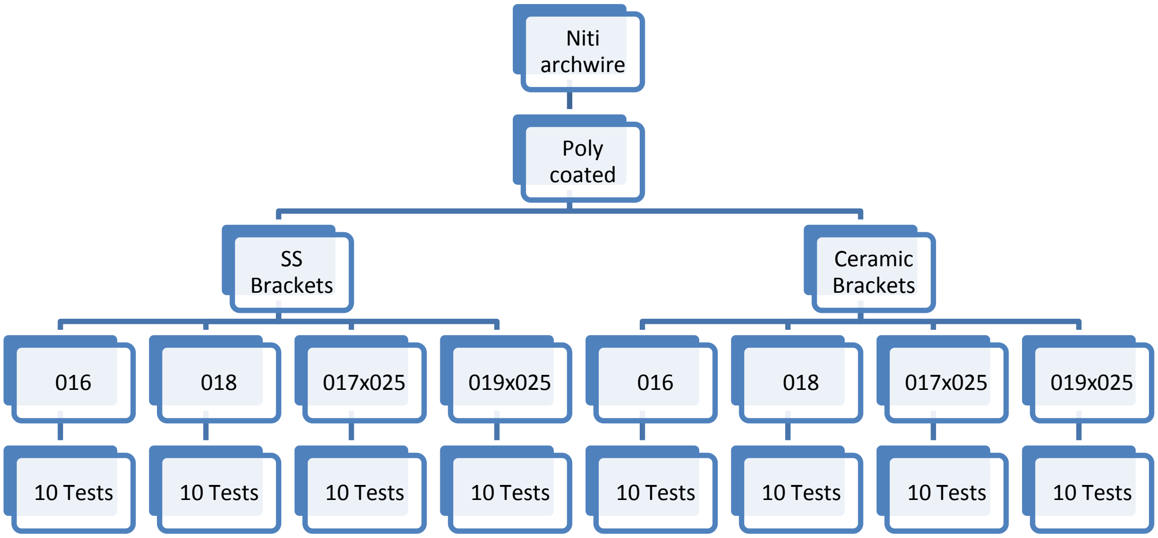


Figure 3.3 Flow Chart of Poly-Coated Niti Wires

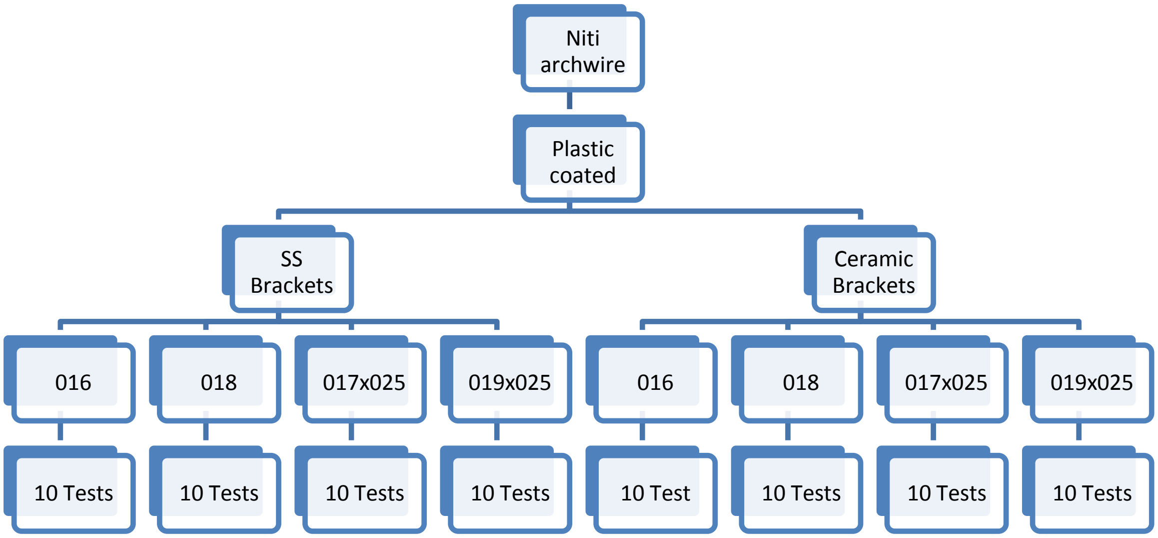


Figure 3.4 Flow Chart of Plastic-Coated Niti Wires

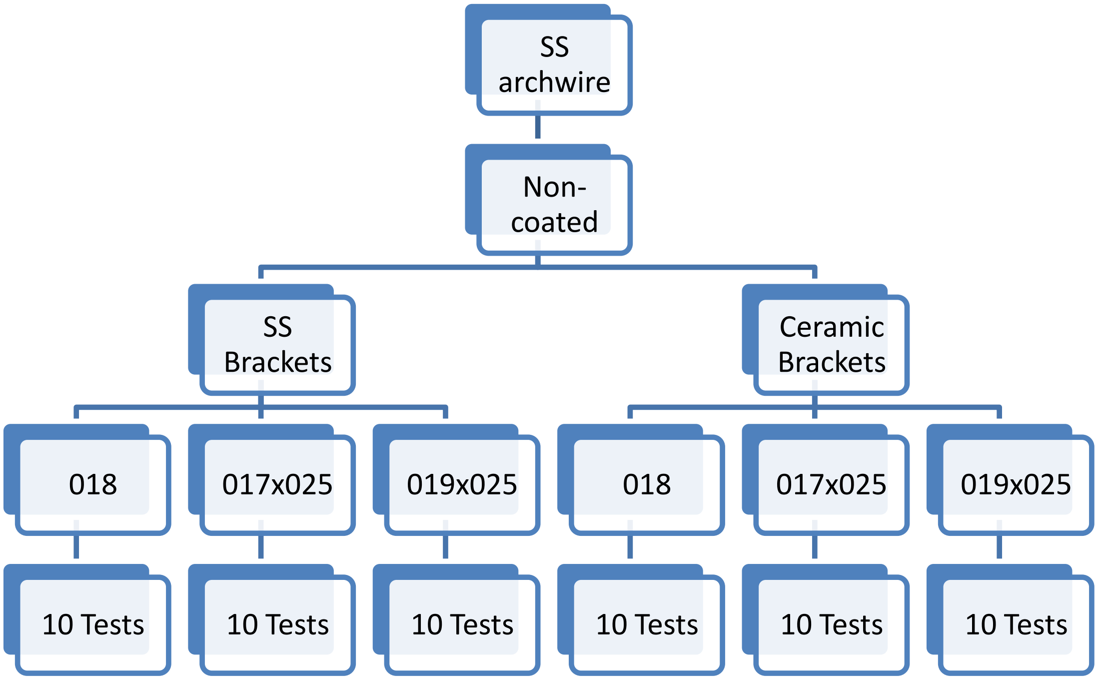


Figure 3.5 Flow Chart of Non-Coated SS Wires

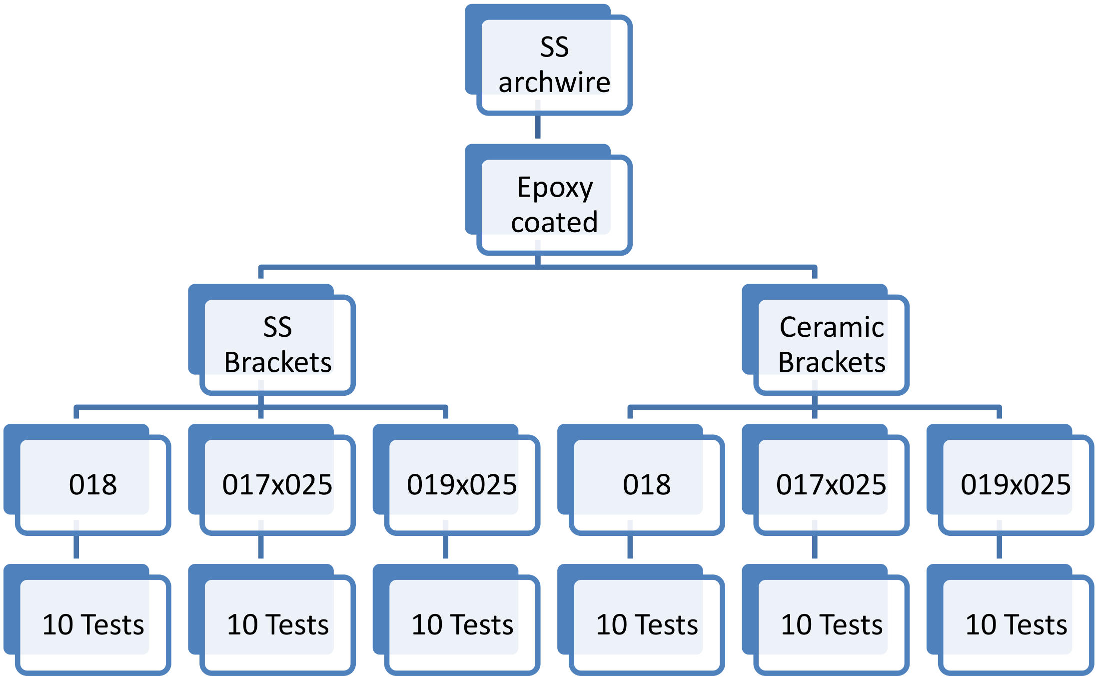


Figure 3.6 Flow Chart of Epoxy-Coated SS Wires

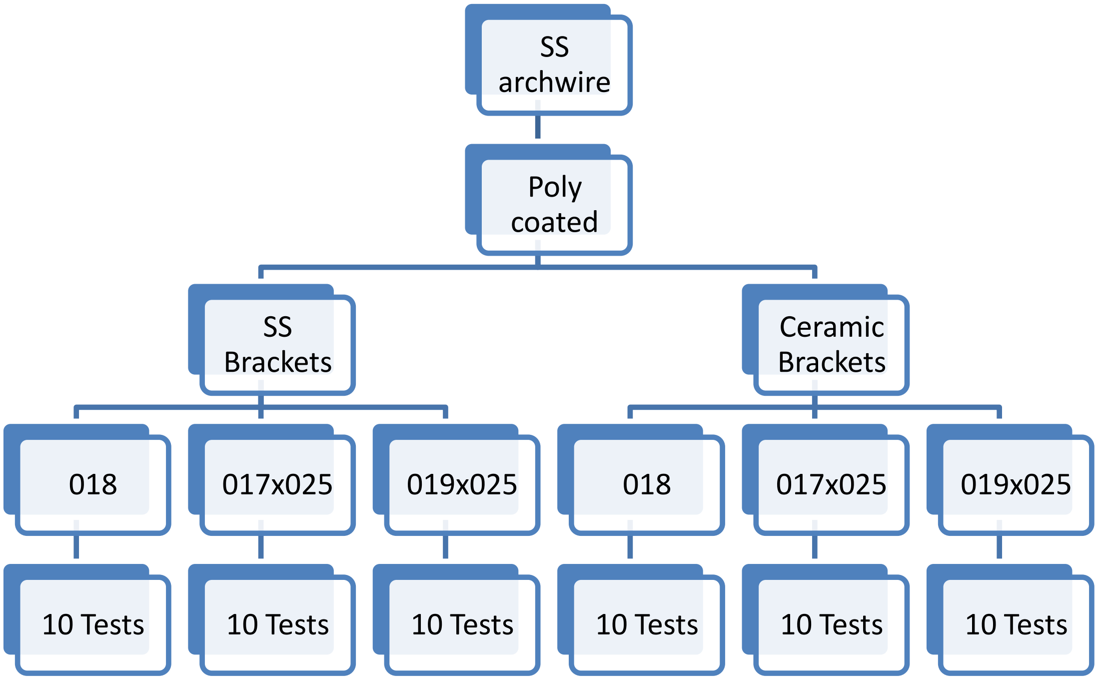


Figure 3.7 Flow Chart of Poly-Coated SS Wires

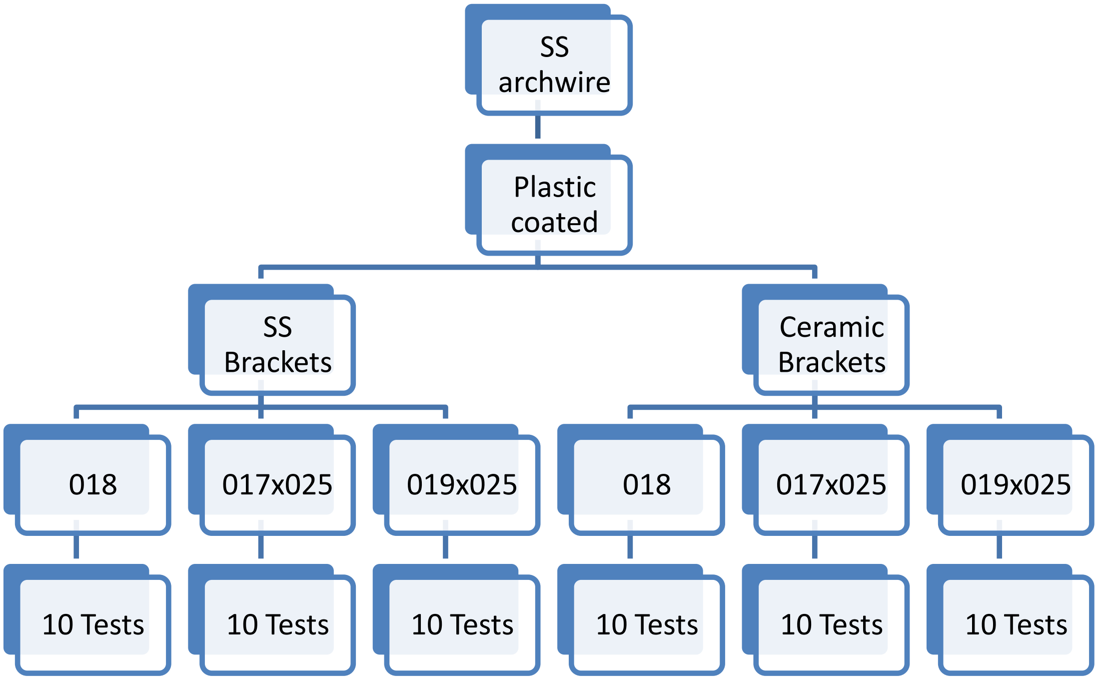


Figure 3.8 Flow Chart of Plastic-Coated SS Wires

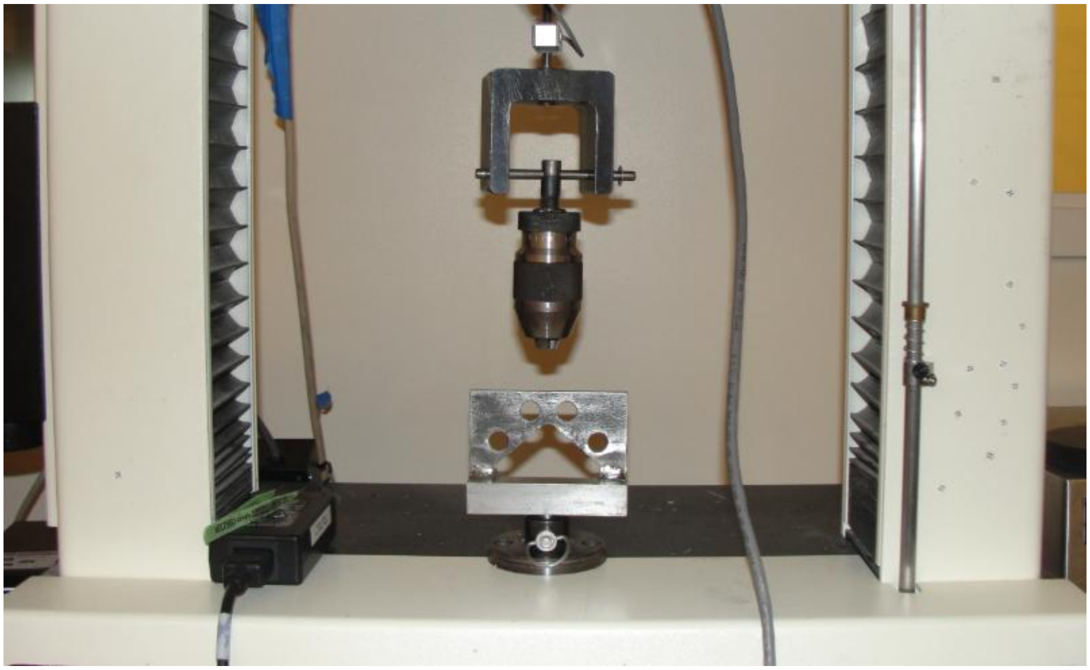


Figure 3.9 Picture of Universal Testing Machine with Set-up

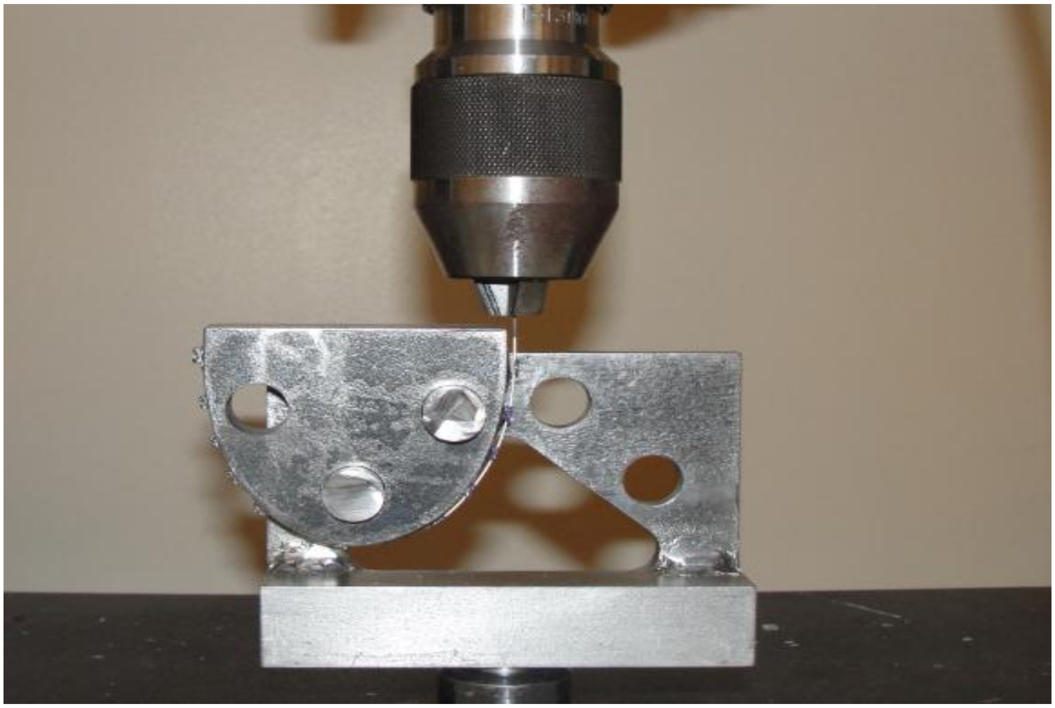


Figure 3.10 Picture of Archwire Engaged in Ceramic Bracket Arc-Form Set Up

To secure the archwire to the brackets, elastomeric ties were wrapped around the bracket wings with the archwire seated in the bottom of the bracket slot. The end of the archwire was positioned at the midline of the model arc fixture. The model arc fixture was then secured to the stabilizing block by placing two steel cylindrical lock joints. The wire exiting from the upper right 1st molar bracket was then locked into a clamp that was connected to the load cell.

To measure frictional forces of the wires sliding in the brackets, the universal testing maching pulled upward on the archwire at 12mm per minute until the archwire reached the mesial end of the lateral bracket. 25-pound capacity force transducer mounted in the universal testing machine continuously recorded frictional values in lbs. and the average frictional force of each wire was recorded after each test. The measurement error of the load cell is 0.1% of its' full scale load or 0.025 pounds. This was repeated 10 times for each archwire size.

Treatment of Data

An Anova (first 14 groups) and t test (last 28 tests) were used to analize the data. The first 8 groups analysed were between niti wires of similar size from the four different archwire types (1 control niti and 3 esthetic niti archwires). Groups 9-14 were frictional differences between stainless steel wires of similar size from the four different archwire types. There were no .016 inch stainless steel esthetic archwires and therefore could not be included in the study (Table 3.1, See Appendix 2). Groups 15-42 were tested with T tests (Table 3.2, See Appendix 3). These tests measured the frictional differences between the same type and size wire pulled through stainless steel brackets and Ceramic brackets.

CHAPTER 4

RESULTS OF THE STUDY

Analysis of Data

The results of the study are listed in the excel worksheet found in Table 4.1-4.2 in Appendix 4 and 5. The average frictional force in pounds is shown for each test in the table. The force readings ranged from approximately 0.5 to 7.8 pounds during all the experiments. The measurement error for the load cell used is ±.025 pounds. This corresponds to approximately a 5% experimental error in the smallest readings and a 0.3% error in the larger readings. The first 14 groups in the study were analyzed using analysis of variance. Groups 15- 42 were analyzed using a T-test. Graphs of the average frictional values of each group are shown in Figures 4.1 to 4.12. Each wire size was measured 10 times with digital calipers and an average measurement was compared to the manufacturers numbers. All measurements of wires were within .001 inches of manufacutres labels. Average of the Poly-coated archwires was .001 inches larger in vertical hight than manufactures indications. Average of the Epoxy and Plastic coated archwires was .001 inches less than the manufactures indications.

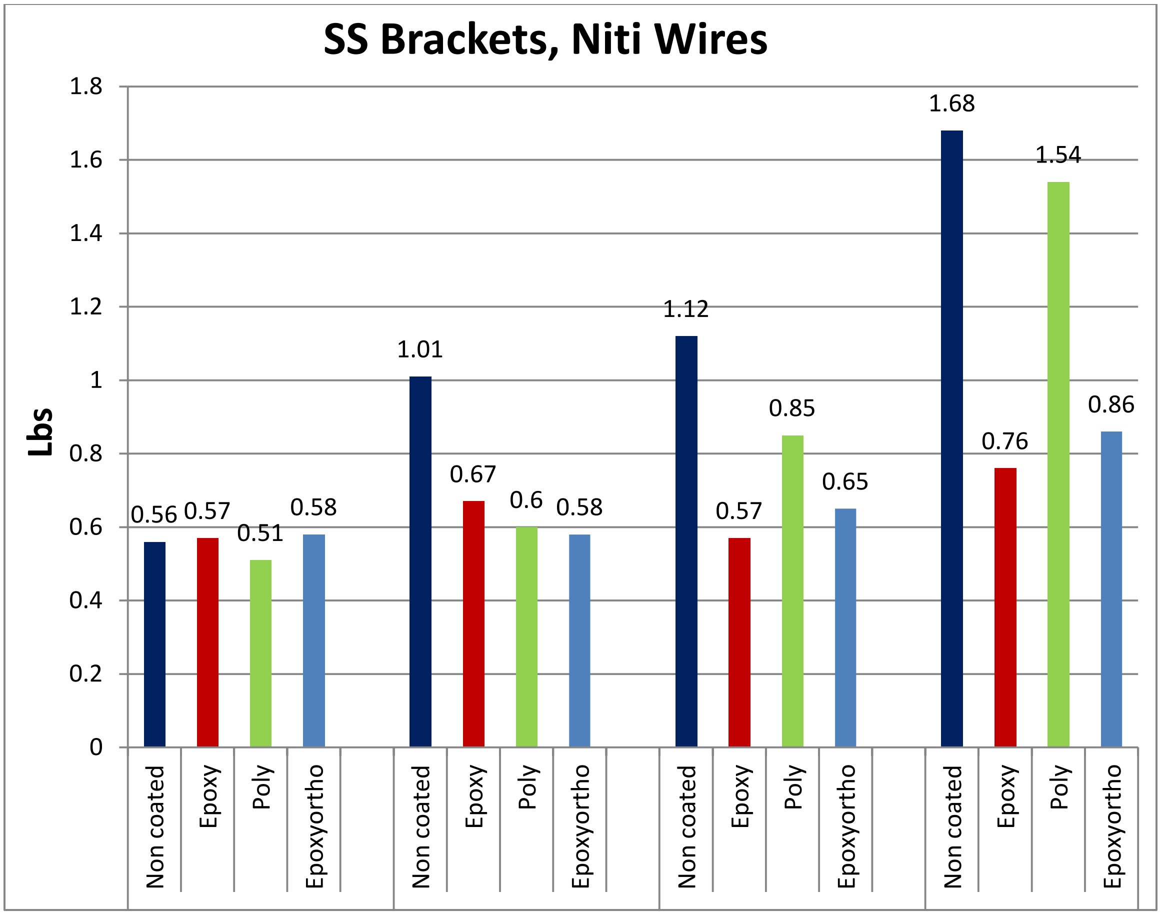


Fig 4.1 Average Frictional Values of Niti Wires Tested in SS Brackets (Groups 1-4)

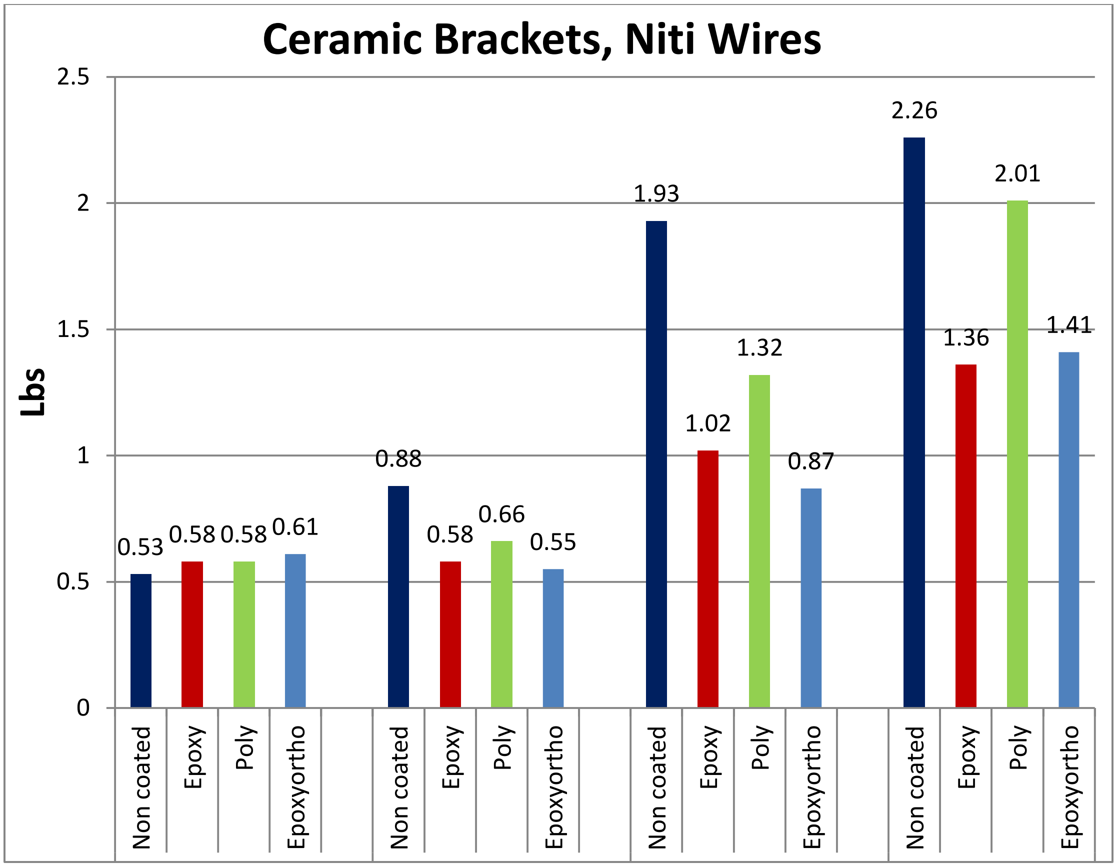


Fig 4.2 Average Frictional Values of Niti Wires Tested in C Brackets (Groups 5-8).

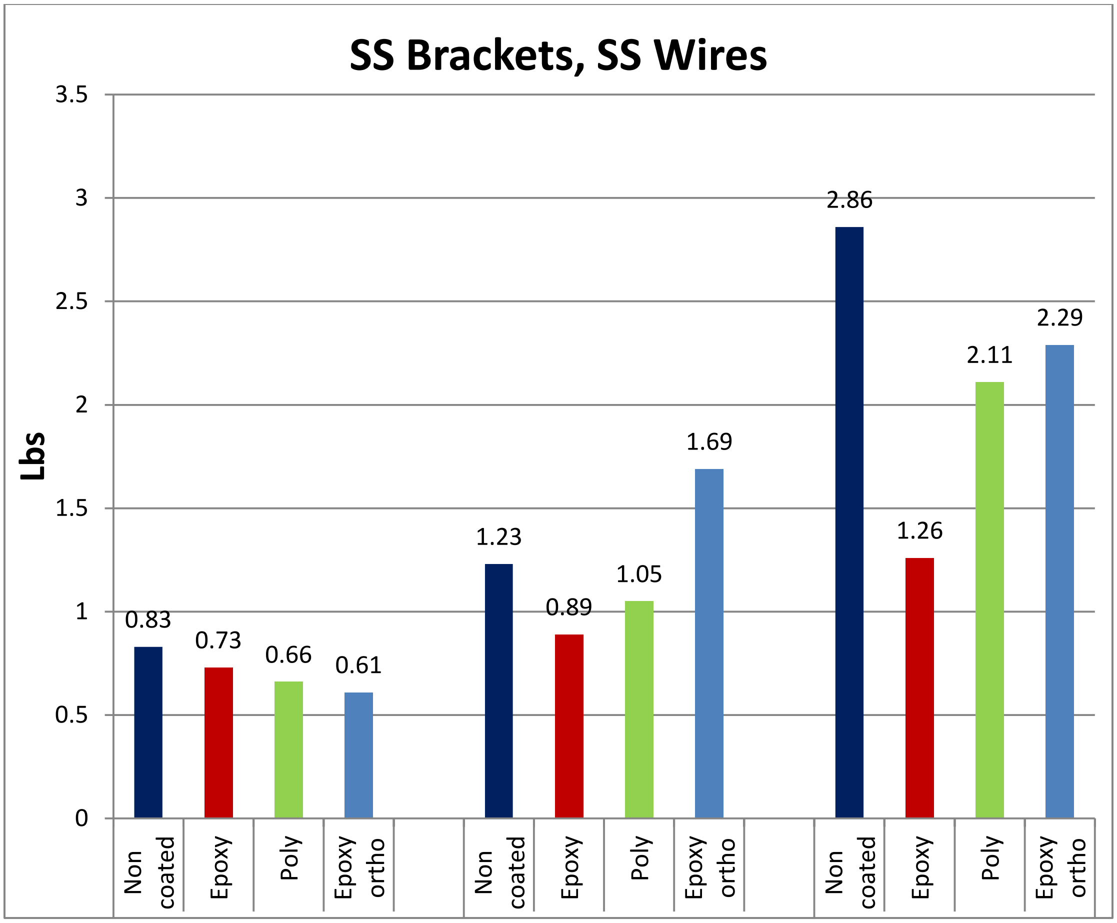


Fig 4.3 Average Frictional Values of Non-Coated SS Wires Tested in SS Brackets

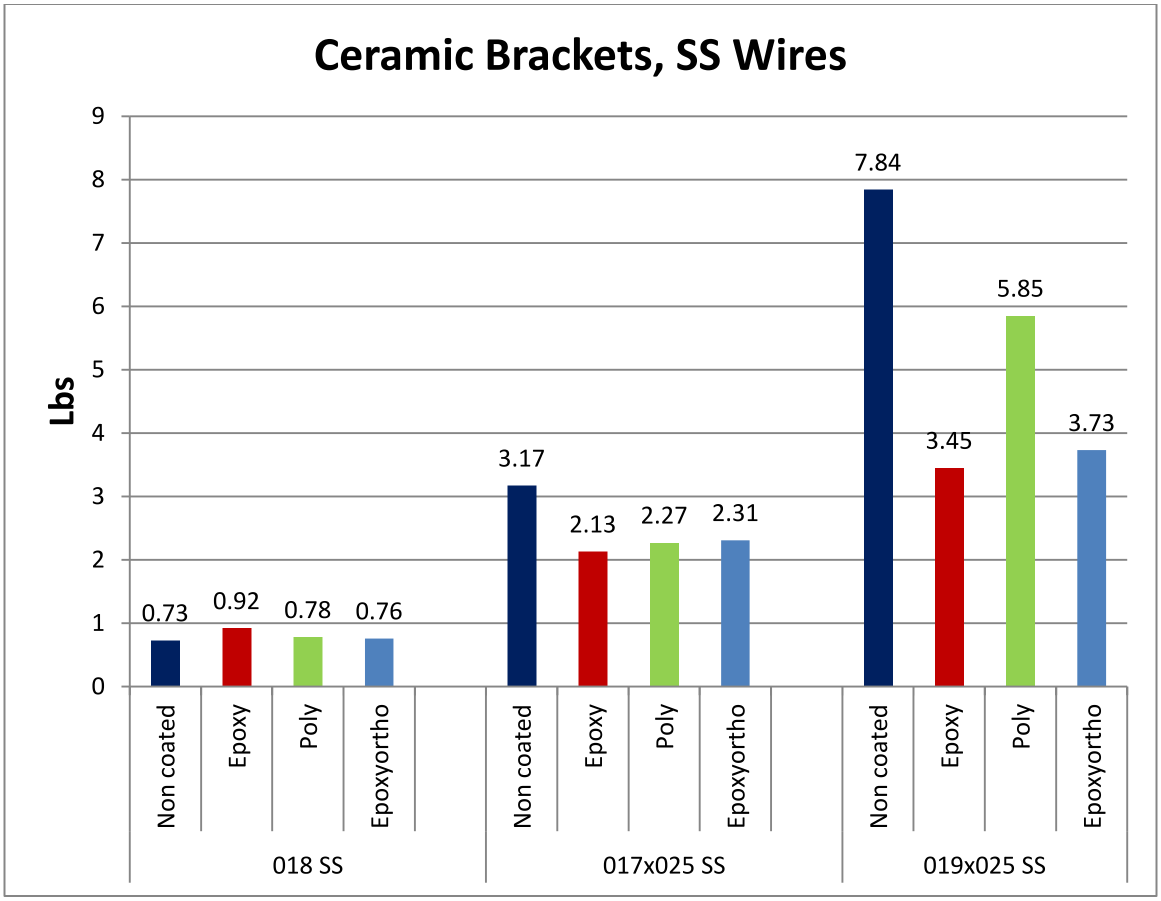


Fig 4.4 Average Frictional Values of Non-Coated SS Wires Tested in C Brackets

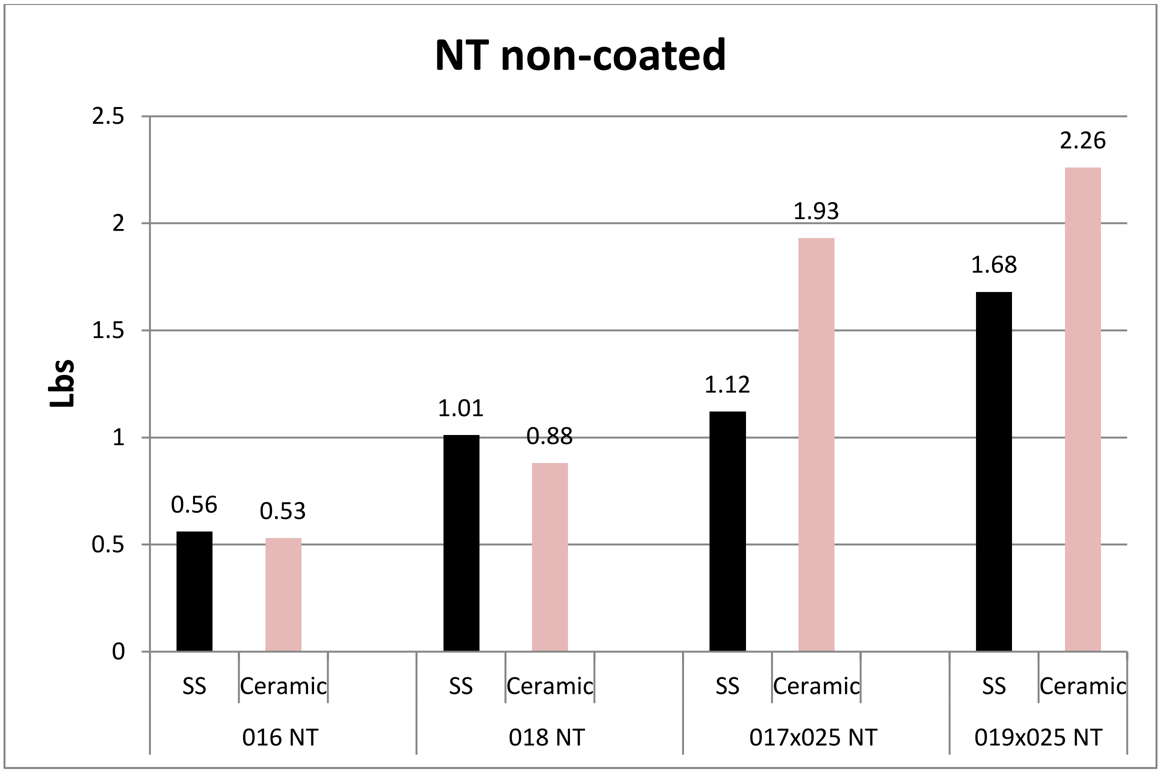
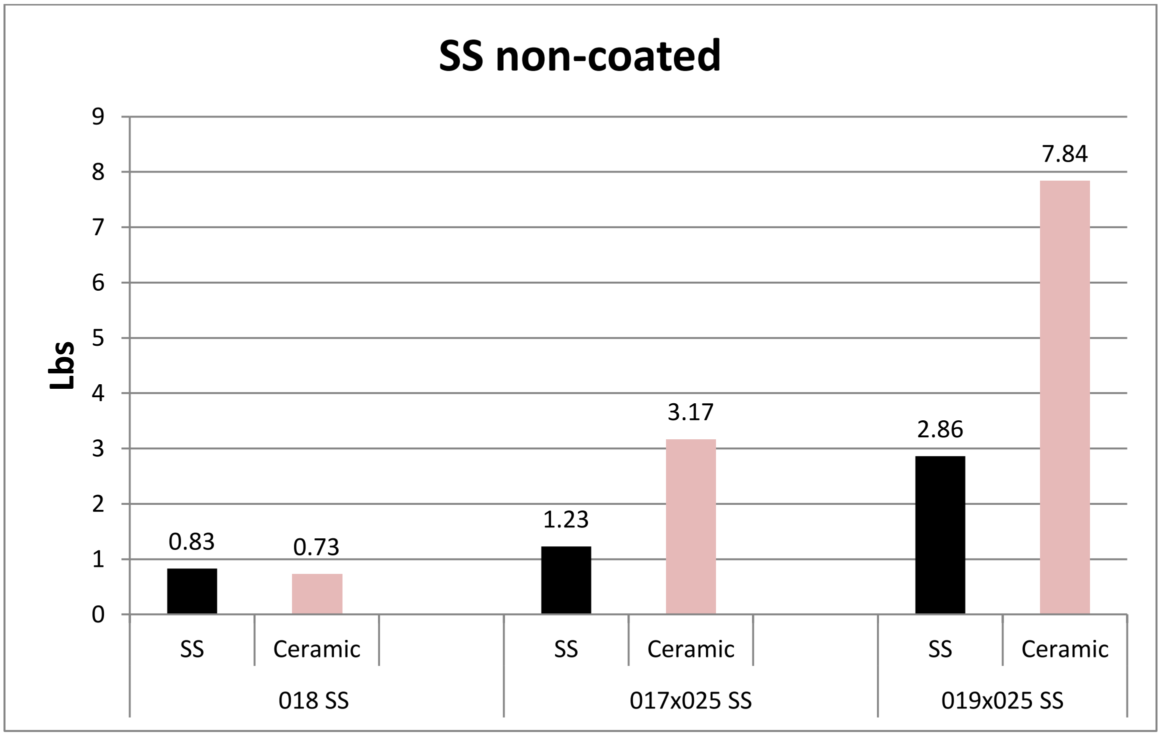


Fig 4.5 (above) Fig 4.6 (below) Average Frictional Values of Niti Wires (groups 15-18) and SS Wires (groups 19-21) Tested in SS and C Brackets.



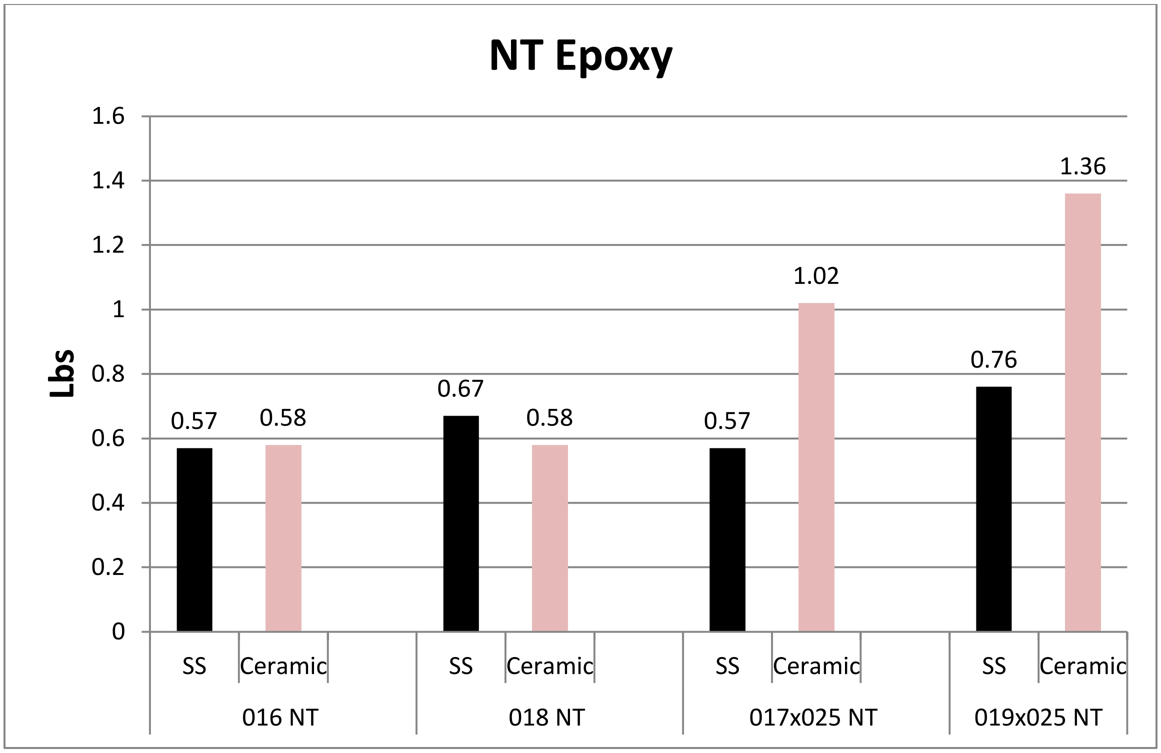
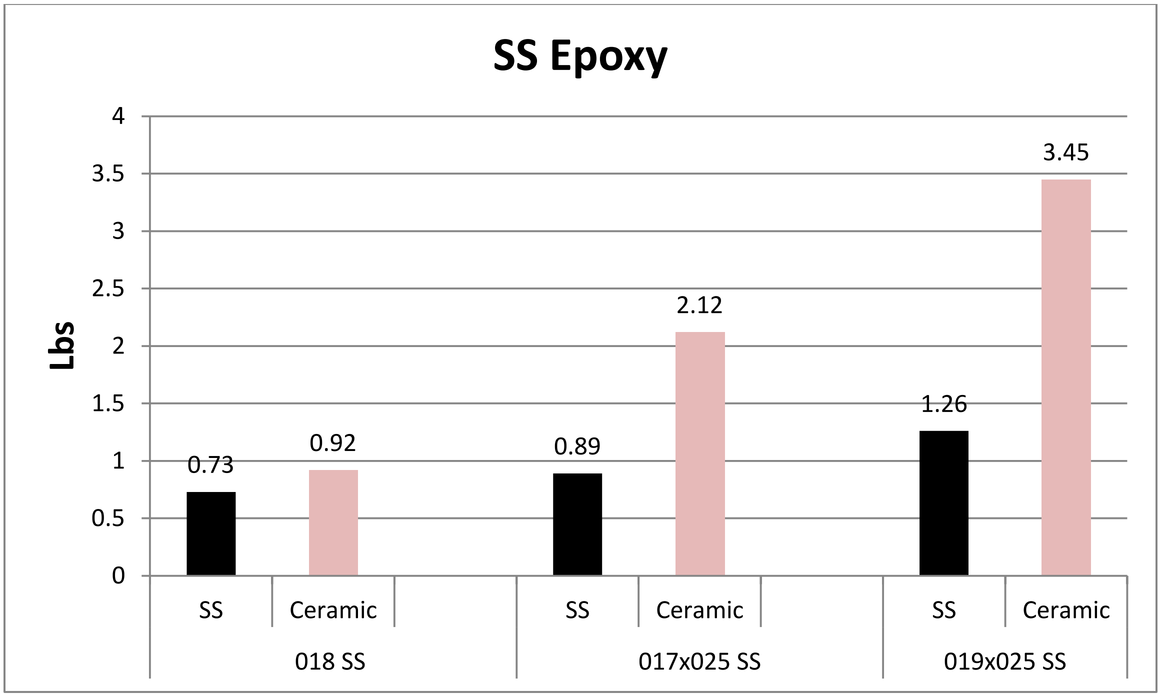


Fig 4.7 (above) Fig 4.8 (below) Average Frictional Values of Epoxy Niti Wires (groups 22-25) and Epoxy SS Wires (groups 26-28) Tested in SS and C Brackets



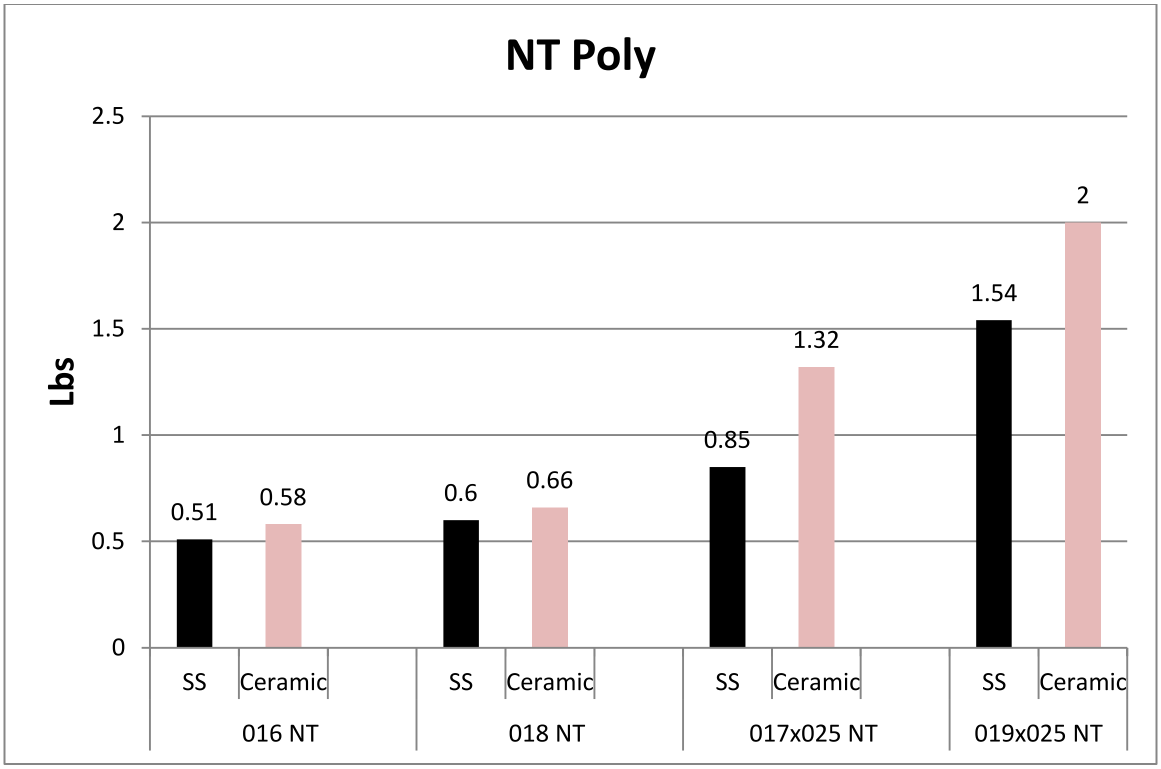
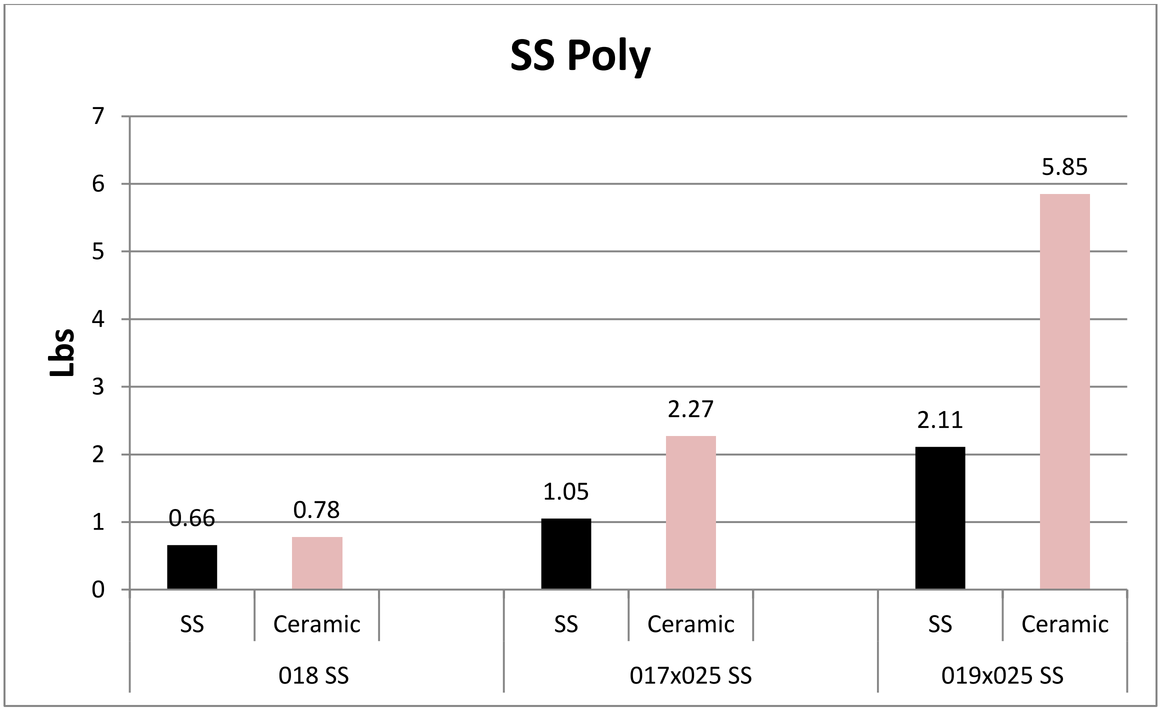


Fig 4.9 (above) Fig 4.10 (below) Average Frictional Values of Poly Niti Wires(groups 29-32) and Poly SS Wires (groups 33-35) Tested in SS and C Brackets



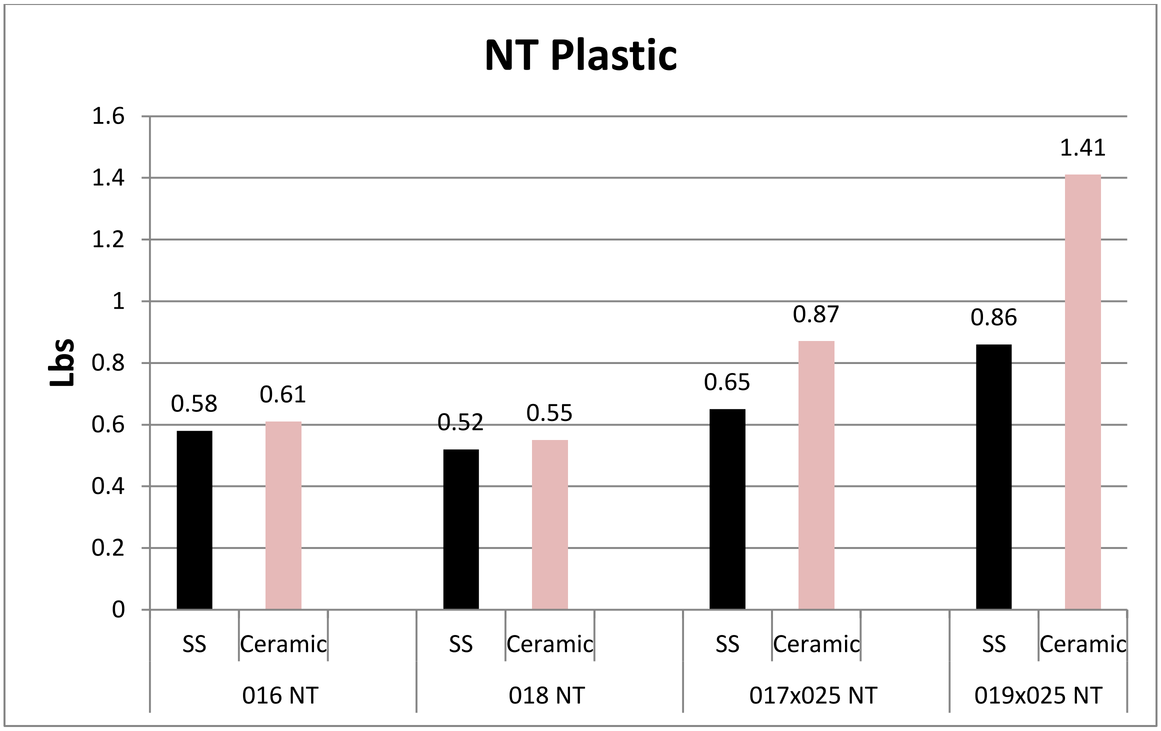
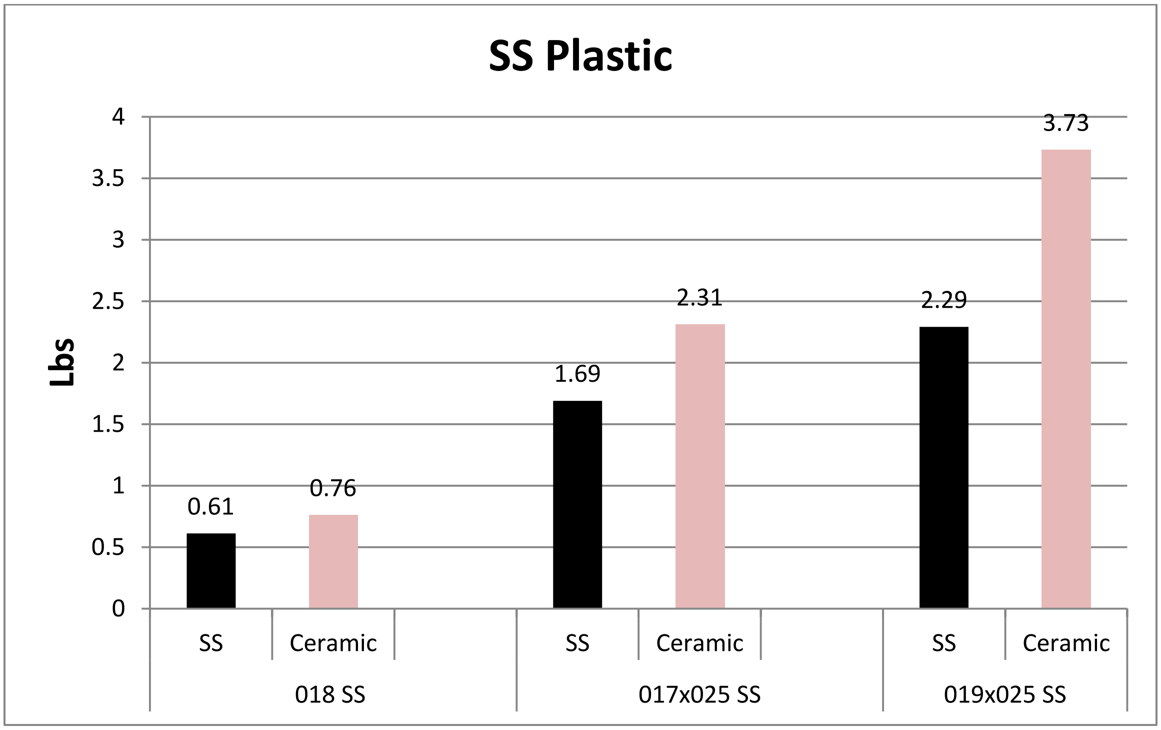


Fig 4.11 (above) Fig 4.12 (below) Average Frictional Values of Plastic Niti Wires (groups 36-39) and Plastic SS Wires (groups 40-42) Tested in SS and C Brackets



Statistical Analysis of Data

The ANOVA Post Hoc Bonferroni test evaluated 14 comparisons. The results of the ANOVA test found significant findings (p value ≤ 0.05) in all group comparisons except the first group. The first group was a comparison of the 4 types of wires (non-coated, epoxy, poly, plastic), size .016, pulled through stainless steel brackets. Of the 13 significant ANOVA groups tested, the non-coated archwire had significantly higher frictional values than the epoxy, poly, and plastic coated archwires in all but groups 4,5,10, and 12. Frictional differences between the coated (esthetic) archwires were as follows:

Group 2: Significant difference between the epoxy and plastic archwires.

Group 3: Significant differences between the epoxy and poly, epoxy and plastic archwires.

Group 4: Significant differences between the epoxy and poly, plastic and poly archwires.

Group 5: No significant difference between the esthetic archwires.

Group 6: Significant difference between poly and plastic archwires.

Group 7: Significant difference between epoxy and poly, plastic and poly archwires.

Group 8: Significant difference between epoxy and poly, plastic and poly archwires.

Group 9: Significant difference between epoxy and plastic archwires.

Group 10: Significant difference between epoxy and plastic archwires.

Group 11: Significant difference between epoxy and plastic archwires.

Group 12: Significant difference between epoxy and poly, epoxy and plastic archwires.

Group 13: No significant differences between the esthetic archwires

Group 14: Significant differences between epoxy and poly, poly and plastic archwires

Groups 15-42 were tested using a T-test. This test was done to compare frictional differences between the wires tested while being pulled through stainless steel brackets and those pulled through ceramic (esthetic) brackets. Of these groups, all were significant except group 15, 22,23,36,37 and 41. Of these non-significant groups, only group 41 was a rectangular archwire (size .017x .025). The other groups, 15,22,23,36, and 37, were either .016 or .018 round archwires. Of the significant groups, all wires pulled through the ceramic (esthetic) brackets had higher frictional values than those pulled through the stainless steel brackets except groups 8, 19, and 23.

CHAPTER 5

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion of Results

From the results of the ANOVA done on the first 14 groups we can see that in 9 of the 13 groups with significant results, the non-coated control wire had more friction than that of the coated archwires. Group 5 (016 niti non-coated archwire) pulled through Ceramic brackets was the only non-coated group that had lower frictional values than the 3 esthetic archwires. The group 5 results showed frictional averages of between .53 (non-coated niti in ceramic brackets) and .61 (epoxy-ortho niti in ceramic brackets) pounds. Although significant, the frictional differences of this group do not vary very much. These results are similar to previous studies done on frictional values of coated archwires. In the majority of studies done, the coated archwires had less friction than those of the non-coated version. This is most likely a result of the epoxy or poly coating placed on the archwire filling in any valleys between the asperities making the surface of the archwire smoother. It should be noted that these esthetic archwires were brand new and none of the coating had fractured off. The comparison of esthetic archwires with the surface coating fractured, indicating wear, and non-coated archwires could result in higher frictional values for the esthetic archwires. Frictional testing of esthetic archwires after clinical use on a live patient would be a good follow up to this study.

Comparison between the 3 esthetic archwires showed significance in all groups but group 13. In 6 of the 13 significant groups, poly coated archwires showed the significantly higher frictional values of the esthetic archwires. 4 groups showed that plastic-coated archwires had the highest frictional value of the three esthetic archwires and only 3 groups showed that the epoxy-coated archwires had a higher value. The .001 inch higher average width dimensions of the Poly-Coated archwires may have played a role in its higher frictional values.

The 28 t-tests were done to compare frictional values between an all esthetic (coated archwires pulled through ceramic) fixed appliance system and a non-esthetic system. As stated earlier, of these 28 groups, 22 were clinically significant. This indicates that coated archwires pulled through ceramic brackets does significantly increase the frictional values in 22 of the 28 groups. Of the 6 non-significant groups, 5 were groups of round archwires. This would indicate that esthetic archwires and non-coated archwire frictional values do not differ significantly in round wires. You could assume that coated and non-coated round archwires pulled through ceramic brackets will give you similar frictional values. Rectangular esthetic archwires, however, will significantly increase your frictional values when pulled through ceramic brackets. Although esthetic archwires pulled through ceramic brackets results in higher frictional values than those pulled through stainless steel brackets, these frictional values are still lower than those of the non-coated archwires.

Limitations of the Study

There are several limitations in this study that are worth mentioning. The testing of the frictional values of the esthetic archwires was done In-vitro rather than in-vivo. In-vivo testing on human subjects could have an effect on the outcome of the frictional values. Factors, such as human saliva, the pressure on teeth during mastication, and wear and tear to the brackets and wires while patients eat, could change the frictional values. From the literature, there are conflicting findings in regards to saliva and friction. Kusy et. al, for example, regarded artificial saliva as inadequate replacement for human saliva and hence such experiments as invalid. Andreasen and Quevedo claimed that saliva played an insignificant role, while ReadWard et al. concluded that the presence of human saliva had inconsistent effects on static friction and sliding mechanics. Baker et al. found that saliva acted as a lubricant, while Stannard et al. and Downing et al. reported that saliva increased friction (Reicheneder et al., 2007). Mastication, tooth to tooth contact, can cause teeth to depress and compress the periodontal ligament. This slight movement of the teeth can have an effect on archwire movement and change frictional values in a positive or negative way. Wear and tear of the brackets and archwires could also affect frictional values. Wearing away of the esthetic coating could increase the amount of asperities and notches in the wire and increase frictional resistance to sliding.

This study was done using stainless steel brackets and ceramic brackets. The same brackets were used for all tests. The wear and tear on the brackets could have had an effect on the outcomes. It was unrealistic to expect to test each archwire with a brand new set of brackets.

It must be noted that only three types of esthetic wires (epoxy, poly, plastic) were used in this study. There are various esthetic archwires made by many other manufacturing companies that were not included in the study. Precaution should be taken to assume that these three esthetic archwires represent all types of esthetic archwires in today’s market. There are also composite archwire currently being developed. These types of archwires should be included in future studies.

Recommendations for Future Research

Recommendations for future research would be to do more in-vivo testing. There are many in-vivo factors, as mentioned previously, that could have a significant effect on the results. Although it would be difficult to measure frictional values of an archwire while ligated to a human subject, it would be possible to test these esthetic archwires, in a similar manner as this study, after first using them to treat human subjects. Another recommendation would be to test more types of esthetic archwires and ceramic brackets. As mentioned previously, only three types of esthetic archwires and one type of ceramic bracket was used in this study.

Hypothesis Evaluation

The research questions, hypothesis and evaluation of the 12 hypotheses are listed below. Statistical significance for determination of rejection or acceptance of the hypothesis will be taken from the 13 accepted ANOVA statistical comparisons and the 22 statistically significant T-tests.

1. What are the frictional differences of the 4 types of niti wires (niti non-coated, niti-epoxy-coated, niti-poly-coated, niti-plastic-coated) after they are ligated with elastomeric O-rings to a stainless steel bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated niti archwire (control) will be higher than the niti-epoxy-coated, niti-poly-coated, and niti-plastic-coated wires.

Of the 4 groups (1-4) tested to prove or disprove the first hypothesis, only the 1st group showed no significant frictional differences and was not in agreement with the hypothesis. Groups 2, 3, and 4 were clinically significant and were accepted by the hypothesis.

2. What are the frictional differences of the 4 types of niti wires (niti non-coated, niti-epoxy-coated, niti-poly-coated, niti-plastic-coated) after they are ligated with elastomeric O-rings to a Ceramic (esthetic) bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated niti archwire (controls) will be higher than the niti-epoxy-coated, niti-poly-coated, and niti-plastic-coated wires.

Of the 4 groups (5-8) in hypothesis #2, the hypothesis was accepted in each of them but group 5. In group 5, the non-coated niti archwire had less friction than all of the esthetic archwires. Therefore the hypothesis was not accepted in group 5.

3. What are the frictional differences of the 4 types of stainless steel wires (stainless steel non-coated, stainless steel epoxy-coated, stainless steel poly-coated, stainless steel-plastic-coated) after they are ligated with elastomeric O- rings to a stainless steel bracket system and pulled using a universal testing machine?

Hypothesis: The friction of the non-coated stainless steel archwires (controls) will be higher than the stainless steel epoxy-coated, stainless steel poly coated, and stainless steel plastic-coated archwires.

Of the 3 groups (9-11) in hypothesis #3, the hypothesis was accepted in groups 9 and 11 but not accepted in group 10. In group 10, the friction of the plastic-coated archwire was significantly greater than the non-coated stainless steel archwire.

4. What are the frictional differences of the 4 types of stainless steel wires (stainless steel non-coated, stainless steel epoxy-coated, stainless steel poly-coated, stainless

steel plastic-coated) after they are ligated with elastomeric O-rings to a ceramic (esthetic) bracket system and pulled using the universal testing machine?

Hypothesis: The friction of the non-coated stainless steel archwires (controls) will be higher than the stainless steel epoxy-coated, stainless steel poly-coated, and stainless steel plastic-coated archwires.

Of the 3 groups (12-14) in hypothesis #4, the hypothesis was accepted in groups 13 and 14 but not accepted in group 12. In group 12, all the coated archwires tested had higher frictional values than the non-coated archwire.

5. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of non-coated niti wires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The non-coated niti archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 4 groups (15-18) in hypothesis #5, the hypothesis was not accepted in group 15 and 16. In these two groups, the friction was greater while being pulled through stainless steel brackets.

6. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, 19x.025 inches) of non-coated stainless steel wires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using the universal testing machine?

Hypothesis: The non-coated stainless steel archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 3 groups (19-21) in hypothesis #6, the hypothesis was accepted in all three. The friction was greater in all three groups while being pulled through a ceramic bracket system.

7. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-epoxy-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-epoxy coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 4 groups (22-25) in hypothesis #7, the hypothesis was accepted in groups 22, 24, and 25. Although the hypothesis was accepted in group 22, the frictional differences between stainless steel brackets and ceramic brackets were not significant. Although the hypothesis was not accepted in group 23, the frictional differences were not significant.

8. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel epoxy-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel epoxy-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 3 groups (26-28) in hypothesis #8, the hypothesis was accepted in all three groups.

9. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-poly-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-poly coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 4 groups (29-32) in hypothesis #9, the hypothesis was accepted in all 4 groups.

10. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel poly-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel poly-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 3 groups (33-35) in hypothesis #10, the hypothesis was accepted in all 3 groups.

11. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of niti-plastic-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The niti-plastic-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 4 groups (36-39) of hypothesis #11, the hypothesis was accepted in groups 38 and 39. The hypothesis was not accepted in groups 36 and 37.

12. What are the frictional differences of the 4 sizes (.016, .018, .017x.025, .019x.025 inches) of stainless steel plastic-coated archwires after they are ligated with elastomeric O-rings to a stainless steel and ceramic bracket system and pulled using a universal testing machine?

Hypothesis: The stainless steel plastic-coated archwires pulled through ceramic brackets will have higher frictional values than those pulled through stainless steel brackets.

Of the 3 groups (40-42) of hypothesis #12, the hypothesis was accepted in groups 40 and 42. The hypothesis was not accepted in group 41.

Conclusions

Analysis of the results of this study yields the following conclusions: These conclusions are based on tests done on a passive, self-designed arch jig.

- The non-coated (non-esthetic) archwires had significantly more friction than the coated (esthetic) archwires accept for the 016 niti Plastic Coated Archwire and 018 ss Epoxy coated archwire
- All rectangular coated archwires showed lower frictional values than the non-coated rectangular archwires
- The coated (esthetic) archwires pulled through a Ceramic (esthetic) bracket system all had significantly greater friction than those pulled through a stainless steel bracket system accept for the 018 niti epoxy archwire.
- The Poly-Coated archwires had the highest friction of the esthetic archwires while tested on a passive self-designed arch jig. These wires had a .001 inch average

width measurement than manufacturers labels. This could have played a role in its increased frictional values.

- In 6 of the 14 ANOVA's, Poly-Coated archwires had the highest friction of the esthetic archwires. In 4 of the 14 ANOVA's, Plastic-Coated archwires had the highest friction of the esthetic archwires. In 4 of the 14 ANOVA's, Epoxy-Coated archwires had the highest friction of the esthetic archwire
- Rectangular coated (esthetic) archwires could decrease frictional values in passive sliding mechanics.

APPENDIX 1

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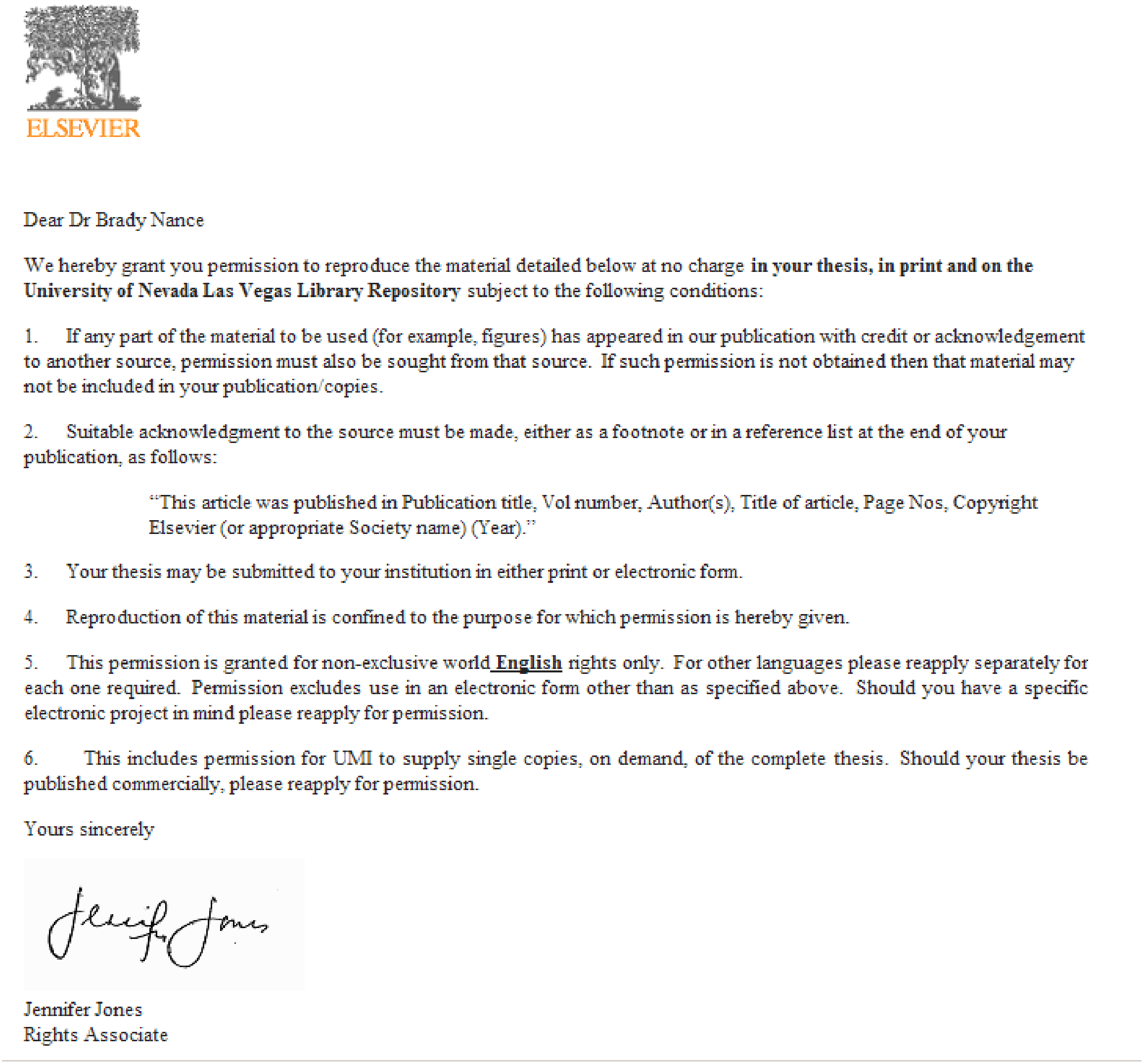

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Yours sincerely

Jennifer Jones
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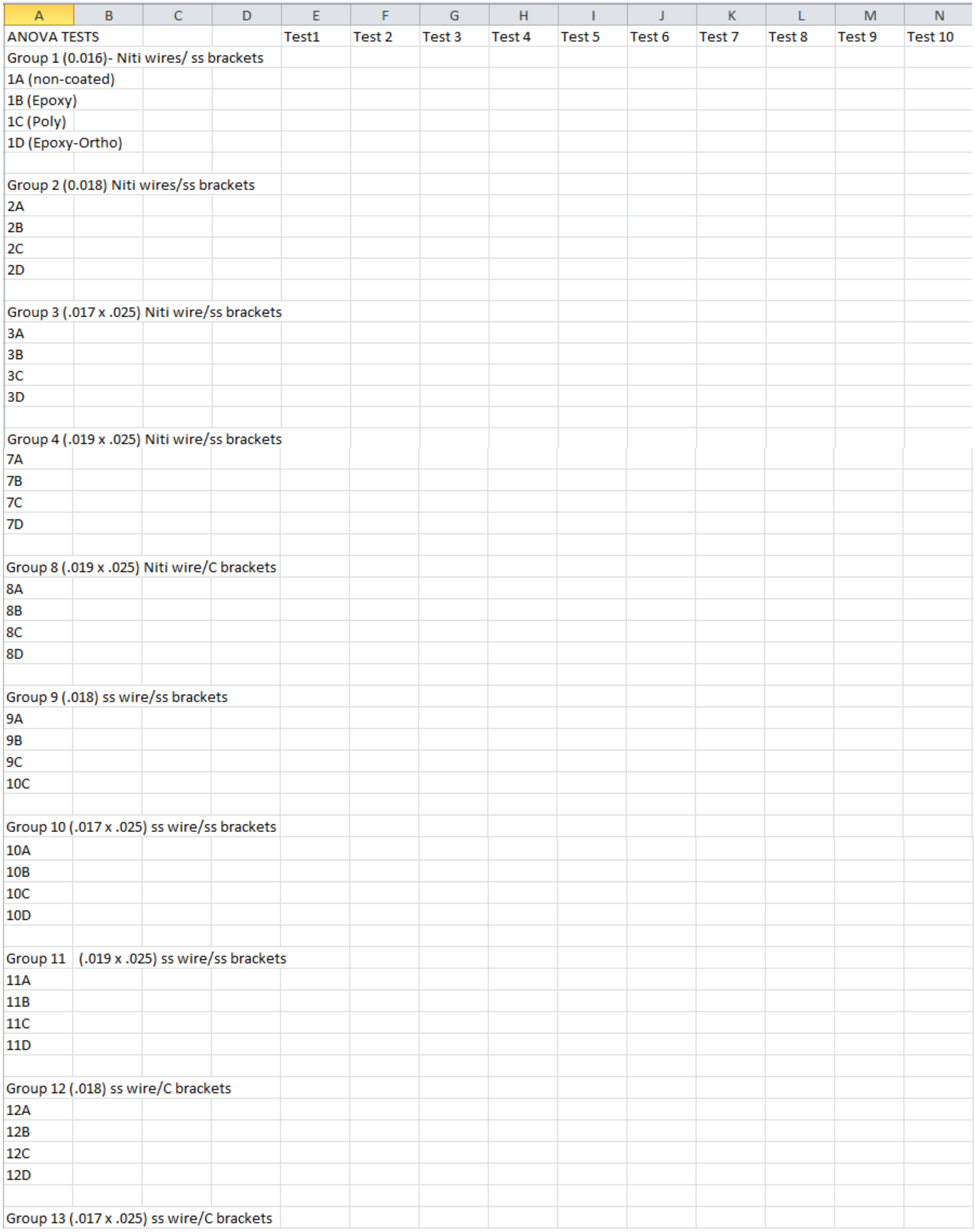
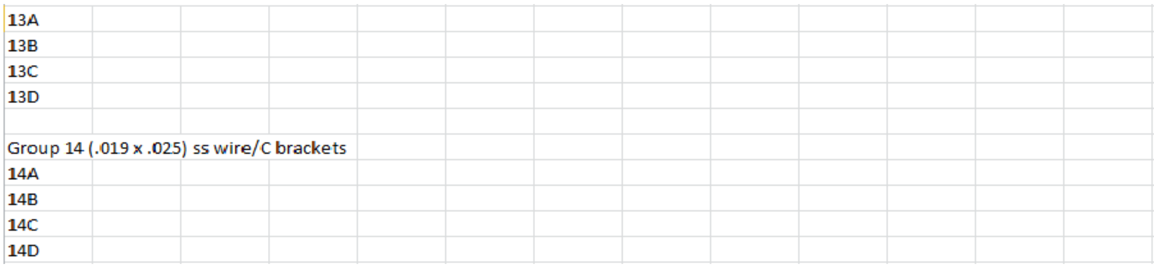
APPENDIX 2

TABLE 3.1 GROUPS 1-14 (ANOVA)



A	B	C	D	E	F	G	H	I	J	K	L	M	N
ANOVA TESTS				Test1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Group 1 (0.016)- Niti wires/ ss brackets													
1A (non-coated)													
1B (Epoxy)													
1C (Poly)													
1D (Epoxy-Ortho)													
Group 2 (0.018) Niti wires/ss brackets													
2A													
2B													
2C													
2D													
Group 3 (.017 x .025) Niti wire/ss brackets													
3A													
3B													
3C													
3D													
Group 4 (.019 x .025) Niti wire/ss brackets													
7A													
7B													
7C													
7D													
Group 8 (.019 x .025) Niti wire/C brackets													
8A													
8B													
8C													
8D													
Group 9 (.018) ss wire/ss brackets													
9A													
9B													
9C													
10C													
Group 10 (.017 x .025) ss wire/ss brackets													
10A													
10B													
10C													
10D													
Group 11 (.019 x .025) ss wire/ss brackets													
11A													
11B													
11C													
11D													
Group 12 (.018) ss wire/C brackets													
12A													
12B													
12C													
12D													
Group 13 (.017 x .025) ss wire/C brackets													

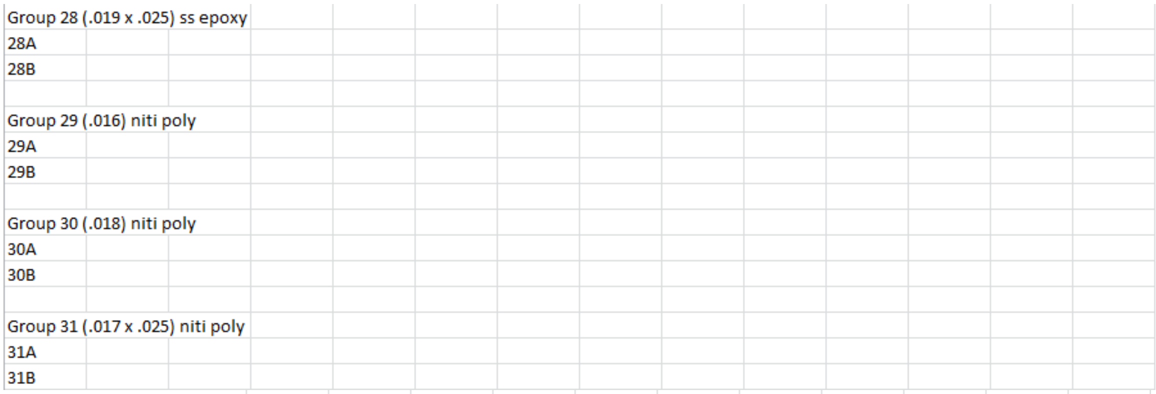


13A												
13B												
13C												
13D												
Group 14 (.019 x .025) ss wire/C brackets												
14A												
14B												
14C												
14D												

APPENDIX 3

TABLE 3.2 GROUPS 15-42 (T-TESTS)

T-TESTS	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Group 15 (.016) niti wire-non coated										
15A (SS brackets)										
15B (Ceramic brackets)										
Group 16 (.018) niti- non coated										
16A										
16B										
Group 17 (.017 x .025) niti- non coated										
17A										
18B										
Group 18 (.019 x .025) niti- non coated										
18A										
18B										
Group 19 (.018) ss wire- non coated										
19A										
19B										
Group 20 (.017 x .025) ss-non coated										
20A										
20B										
Group 21 (.019 x .025) ss-non coated										
21A										
21B										
Group 22 (.016) niti epoxy										
22A										
22B										
Group 23 (.018) niti epoxy										
23A										
23B										
Group 24 (.017 x .025) niti epoxy										
24A										
24B										
Group 25 (.019 x .025) niti epoxy										
25A										
25B										
Group 26 (.018) ss epoxy										
26A										
26B										
Group 27 (.017 x .025) ss epoxy										
27A										
27B										


Group 28 (.019 x .025) ss epoxy
28A
28B

Group 29 (.016) niti poly
29A
29B

Group 30 (.018) niti poly
30A
30B

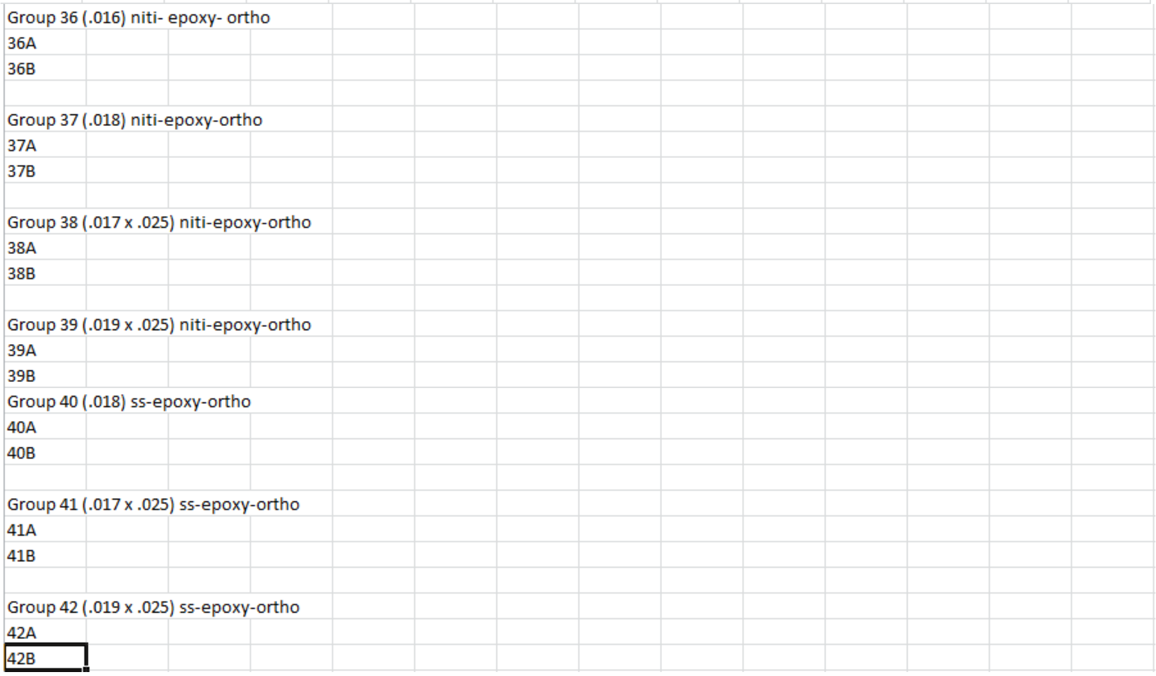
Group 31 (.017 x .025) niti poly
31A
31B


Group 32 (.019 x .025) niti poly
32A
32B

Group 33 (.018) ss poly
33A
33B

Group 34 (.017 x .025) ss poly
34A
34B

Group 35 (.019 x .025) ss poly
35A
35B


Group 36 (.016) niti- epoxy- ortho
36A
36B

Group 37 (.018) niti-epoxy-ortho
37A
37B

Group 38 (.017 x .025) niti-epoxy-ortho
38A
38B

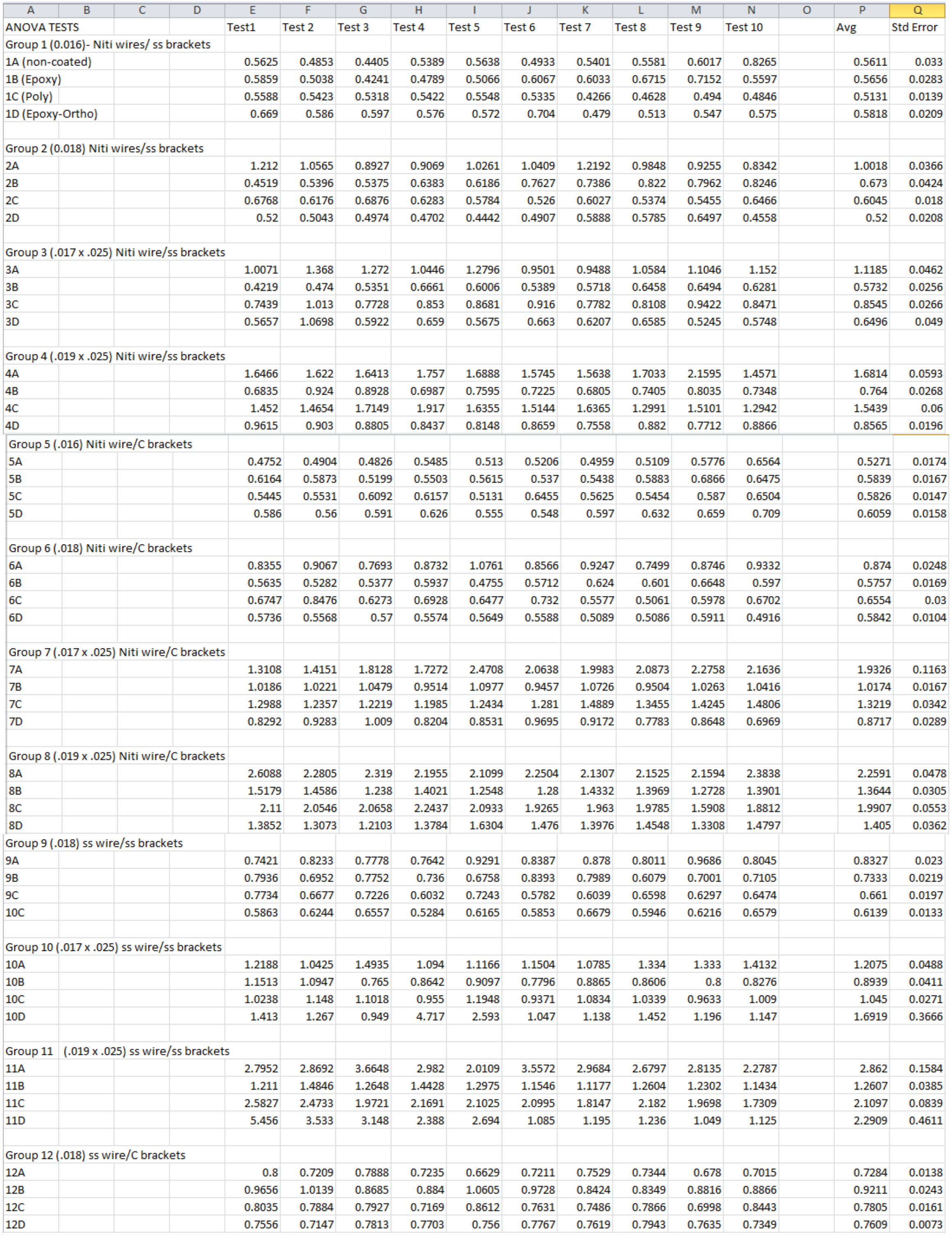
Group 39 (.019 x .025) niti-epoxy-ortho
39A
39B
Group 40 (.018) ss-epoxy-ortho
40A
40B

Group 41 (.017 x .025) ss-epoxy-ortho
41A
41B

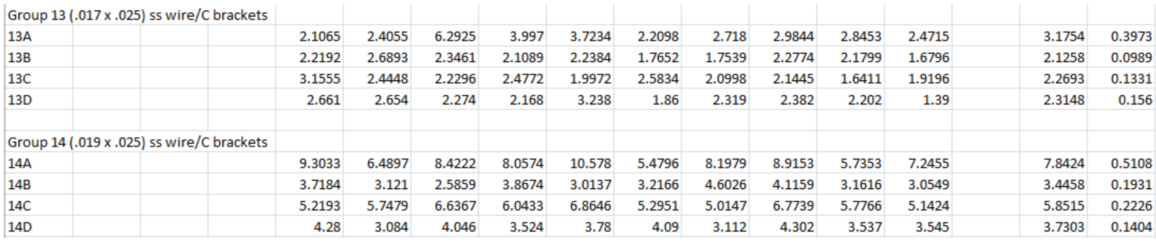
Group 42 (.019 x .025) ss-epoxy-ortho
42A
42B

APPENDIX 4

TABLE 4.1 EXPERIMENTAL DATA OF GROUPS 1-14



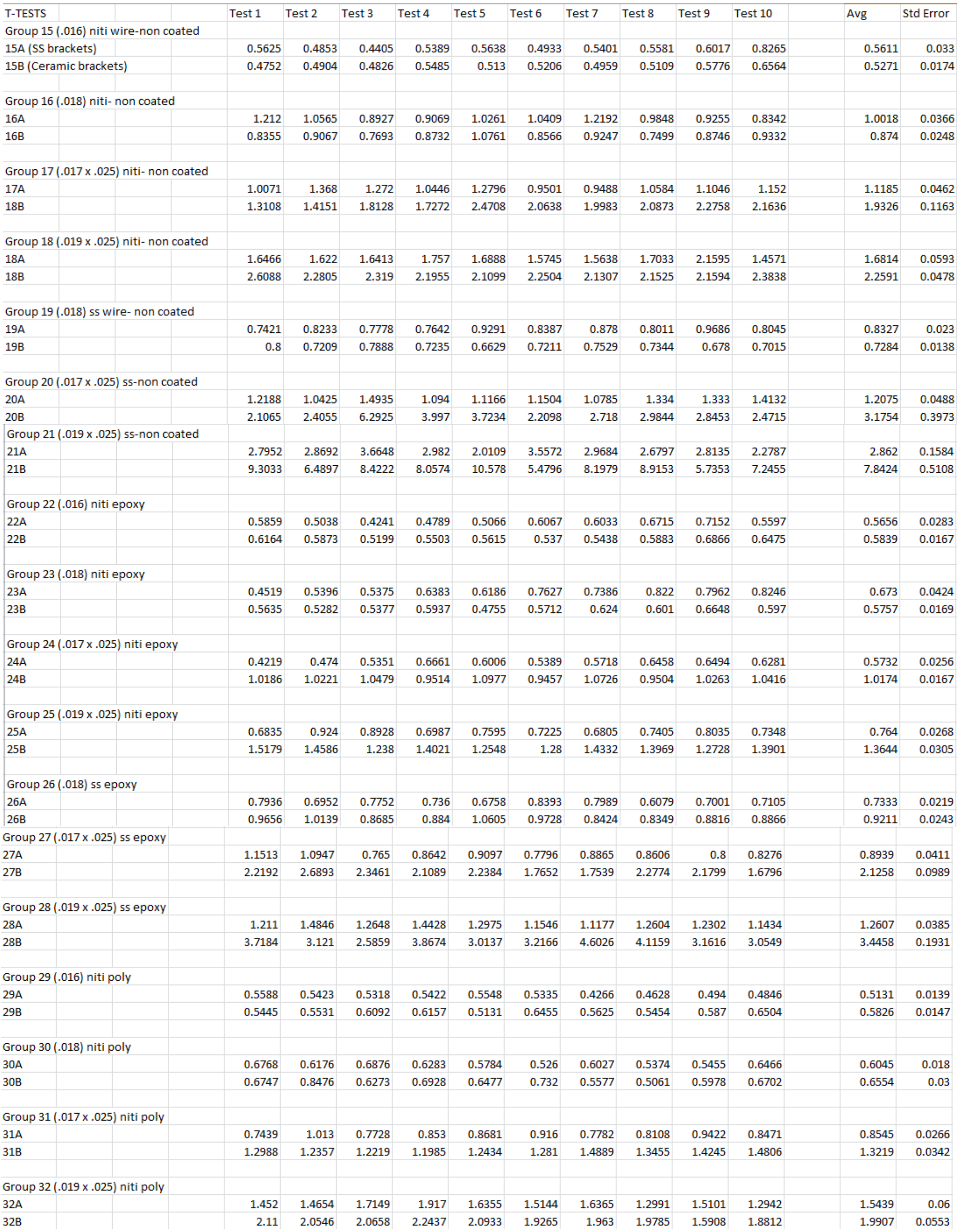
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
ANOVA TESTS				Test1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10		Avg	Std Error
Group 1 (0.016)- Niti wires/ ss brackets																
1A (non-coated)				0.5625	0.4853	0.4405	0.5389	0.5638	0.4933	0.5401	0.5581	0.6017	0.8265		0.5611	0.033
1B (Epoxy)				0.5859	0.5038	0.4241	0.4789	0.5066	0.6067	0.6033	0.6715	0.7152	0.5597		0.5656	0.0283
1C (Poly)				0.5588	0.5423	0.5318	0.5422	0.5548	0.5335	0.4266	0.4628	0.494	0.4846		0.5131	0.0139
1D (Epoxy-Ortho)				0.669	0.586	0.597	0.576	0.572	0.704	0.479	0.513	0.547	0.575		0.5818	0.0209
Group 2 (0.018) Niti wires/ss brackets																
2A				1.212	1.0565	0.8927	0.9069	1.0261	1.0409	1.2192	0.9848	0.9255	0.8342		1.0018	0.0366
2B				0.4519	0.5396	0.5375	0.6383	0.6186	0.7627	0.7386	0.822	0.7962	0.8246		0.673	0.0424
2C				0.6768	0.6176	0.6876	0.6283	0.5784	0.526	0.6027	0.5374	0.5455	0.6466		0.6045	0.018
2D				0.52	0.5043	0.4974	0.4702	0.4442	0.4907	0.5888	0.5785	0.6497	0.4558		0.52	0.0208
Group 3 (.017 x .025) Niti wire/ss brackets																
3A				1.0071	1.368	1.272	1.0446	1.2796	0.9501	0.9488	1.0584	1.1046	1.152		1.1185	0.0462
3B				0.4219	0.474	0.5351	0.6661	0.6006	0.5389	0.5718	0.6458	0.6494	0.6281		0.5732	0.0256
3C				0.7439	1.013	0.7728	0.853	0.8681	0.916	0.7782	0.8108	0.9422	0.8471		0.8545	0.0266
3D				0.5657	1.0698	0.5922	0.659	0.5675	0.663	0.6207	0.6585	0.5245	0.5748		0.6496	0.049
Group 4 (.019 x .025) Niti wire/ss brackets																
4A				1.6466	1.622	1.6413	1.757	1.6888	1.5745	1.5638	1.7033	2.1595	1.4571		1.6814	0.0593
4B				0.6835	0.924	0.8928	0.6987	0.7595	0.7225	0.6805	0.7405	0.8035	0.7348		0.764	0.0268
4C				1.452	1.4654	1.7149	1.917	1.6355	1.5144	1.6365	1.2991	1.5101	1.2942		1.5439	0.06
4D				0.9615	0.903	0.8805	0.8437	0.8148	0.8659	0.7558	0.882	0.7712	0.8866		0.8565	0.0196
Group 5 (.016) Niti wire/C brackets																
5A				0.4752	0.4904	0.4826	0.5485	0.513	0.5206	0.4959	0.5109	0.5776	0.6564		0.5271	0.0174
5B				0.6164	0.5873	0.5199	0.5503	0.5615	0.537	0.5438	0.5883	0.6866	0.6475		0.5839	0.0167
5C				0.5445	0.5531	0.6092	0.6157	0.5131	0.6455	0.5625	0.5454	0.587	0.6504		0.5826	0.0147
5D				0.586	0.56	0.591	0.626	0.555	0.548	0.597	0.632	0.659	0.709		0.6059	0.0158
Group 6 (.018) Niti wire/C brackets																
6A				0.8355	0.9067	0.7693	0.8732	1.0761	0.8566	0.9247	0.7499	0.8746	0.9332		0.874	0.0248
6B				0.5635	0.5282	0.5377	0.5937	0.4755	0.5712	0.624	0.601	0.6648	0.597		0.5757	0.0169
6C				0.6747	0.8476	0.6273	0.6928	0.6477	0.732	0.5577	0.5061	0.5978	0.6702		0.6554	0.03
6D				0.5736	0.5568	0.57	0.5574	0.5649	0.5588	0.5089	0.5086	0.5911	0.4916		0.5842	0.0104
Group 7 (.017 x .025) Niti wire/C brackets																
7A				1.3108	1.4151	1.8128	1.7272	2.4708	2.0638	1.9983	2.0873	2.2758	2.1636		1.9326	0.1163
7B				1.0186	1.0221	1.0479	0.9514	1.0977	0.9457	1.0726	0.9504	1.0263	1.0416		1.0174	0.0167
7C				1.2988	1.2357	1.2219	1.1985	1.2434	1.281	1.4889	1.3455	1.4245	1.4806		1.3219	0.0342
7D				0.8292	0.9283	1.009	0.8204	0.8531	0.9695	0.9172	0.7783	0.8648	0.6969		0.8717	0.0289
Group 8 (.019 x .025) Niti wire/C brackets																
8A				2.6088	2.2805	2.319	2.1955	2.1099	2.2504	2.1307	2.1525	2.1594	2.3838		2.2591	0.0478
8B				1.5179	1.4586	1.238	1.4021	1.2548	1.28	1.4332	1.3969	1.2728	1.3901		1.3644	0.0305
8C				2.11	2.0546	2.0658	2.2437	2.0933	1.9265	1.963	1.9785	1.5908	1.8812		1.9907	0.0553
8D				1.3852	1.3073	1.2103	1.3784	1.6304	1.476	1.3976	1.4548	1.3308	1.4797		1.405	0.0362
Group 9 (.018) ss wire/ss brackets																
9A				0.7421	0.8233	0.7778	0.7642	0.9291	0.8387	0.878	0.8011	0.9686	0.8045		0.8327	0.023
9B				0.7936	0.6952	0.7752	0.736	0.6758	0.8393	0.7989	0.6079	0.7001	0.7105		0.7333	0.0219
9C				0.7734	0.6677	0.7226	0.6032	0.7243	0.5782	0.6039	0.6598	0.6297	0.6474		0.661	0.0197
10C				0.5863	0.6244	0.6557	0.5284	0.6165	0.5853	0.6679	0.5946	0.6216	0.6579		0.6139	0.0133
Group 10 (.017 x .025) ss wire/ss brackets																
10A				1.2188	1.0425	1.4935	1.094	1.1166	1.1504	1.0785	1.334	1.333	1.4132		1.2075	0.0488
10B				1.1513	1.0947	0.765	0.8642	0.9097	0.7796	0.8865	0.8606	0.8	0.8276		0.8939	0.0411
10C				1.0238	1.148	1.1018	0.955	1.1948	0.9371	1.0834	1.0339	0.9633	1.009		1.045	0.0271
10D				1.413	1.267	0.949	4.717	2.593	1.047	1.138	1.452	1.196	1.147		1.6919	0.3666
Group 11	(.019 x .025) ss wire/ss brackets															
11A				2.7952	2.8692	3.6648	2.982	2.0109	3.5572	2.9684	2.6797	2.8135	2.2787		2.862	0.1584
11B				1.211	1.4846	1.2648	1.4428	1.2975	1.1546	1.1177	1.2604	1.2302	1.1434		1.2607	0.0385
11C				2.5827	2.4733	1.9721	2.1691	2.1025	2.0995	1.8147	2.182	1.9698	1.7309		2.1097	0.0839
11D				5.456	3.533	3.148	2.388	2.694	1.085	1.195	1.236	1.049	1.125		2.2909	0.4611
Group 12 (.018) ss wire/C brackets																
12A				0.8	0.7209	0.7888	0.7235	0.6629	0.7211	0.7529	0.7344	0.678	0.7015		0.7284	0.0138
12B				0.9656	1.0139	0.8685	0.884	1.0605	0.9728	0.8424	0.8349	0.8816	0.8866		0.9211	0.0243
12C				0.8035	0.7884	0.7927	0.7169	0.8612	0.7631	0.7486	0.7866	0.6998	0.8443		0.7805	0.0161
12D				0.7556	0.7147	0.7813	0.7703	0.756	0.7767	0.7619	0.7943	0.7635	0.7349		0.7609	0.0073



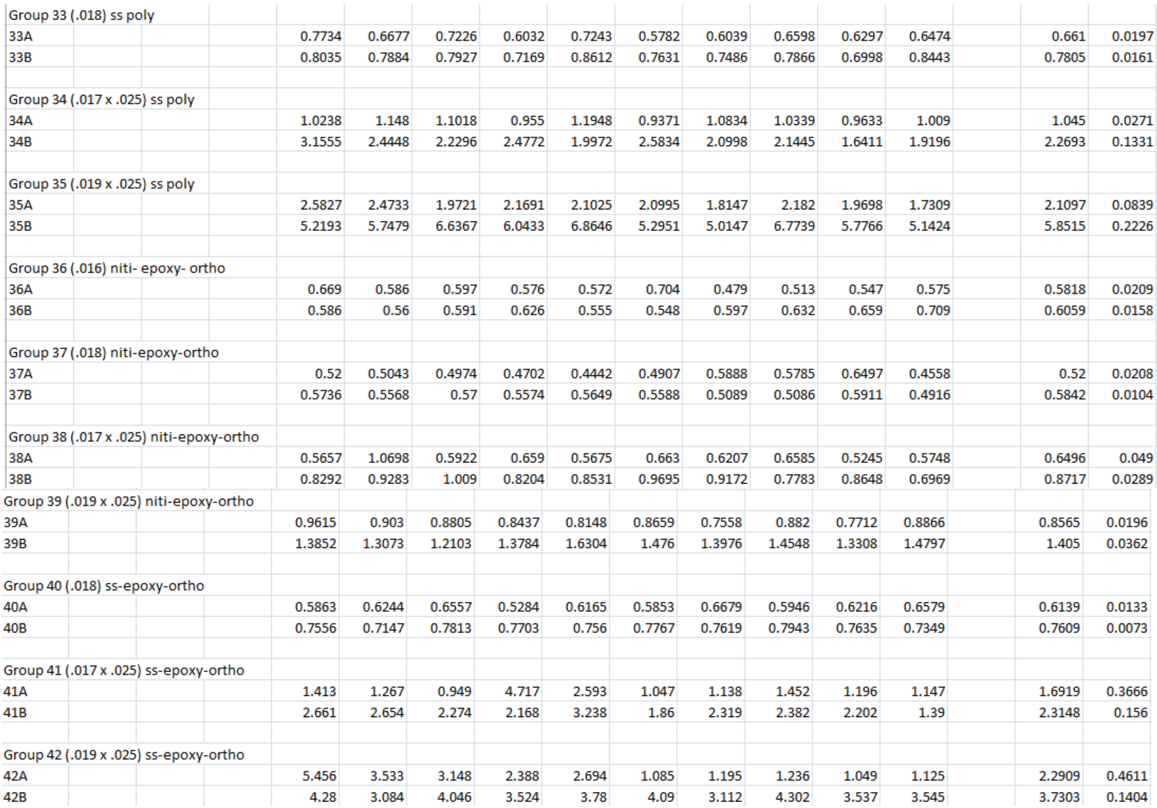
Group 13 (.017 x .025) ss wire/C brackets																
13A				2.1065	2.4055	6.2925	3.997	3.7234	2.2098	2.718	2.9844	2.8453	2.4715		3.1754	0.3973
13B				2.2192	2.6893	2.3461	2.1089	2.2384	1.7652	1.7539	2.2774	2.1799	1.6796		2.1258	0.0989
13C				3.1555	2.4448	2.2296	2.4772	1.9972	2.5834	2.0998	2.1445	1.6411	1.9196		2.2693	0.1331
13D				2.661	2.654	2.274	2.168	3.238	1.86	2.319	2.382	2.202	1.39		2.3148	0.156
Group 14 (.019 x .025) ss wire/C brackets																
14A				9.3033	6.4897	8.4222	8.0574	10.578	5.4796	8.1979	8.9153	5.7353	7.2455		7.8424	0.5108
14B				3.7184	3.121	2.5859	3.8674	3.0137	3.2166	4.6026	4.1159	3.1616	3.0549		3.4458	0.1931
14C				5.2193	5.7479	6.6367	6.0433	6.8646	5.2951	5.0147	6.7739	5.7766	5.1424		5.8515	0.2226
14D				4.28	3.084	4.046	3.524	3.78	4.09	3.112	4.302	3.537	3.545		3.7303	0.1404

APPENDIX 5

TABLE 4.2 EXPERIMENTAL DATA OF GROUPS 15-42



T-TESTS	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg	Std Error
Group 15 (.016) niti wire-non coated												
15A (SS brackets)	0.5625	0.4853	0.4405	0.5389	0.5638	0.4933	0.5401	0.5581	0.6017	0.8265	0.5611	0.033
15B (Ceramic brackets)	0.4752	0.4904	0.4826	0.5485	0.513	0.5206	0.4959	0.5109	0.5776	0.6564	0.5271	0.0174
Group 16 (.018) niti- non coated												
16A	1.212	1.0565	0.8927	0.9069	1.0261	1.0409	1.2192	0.9848	0.9255	0.8342	1.0018	0.0366
16B	0.8355	0.9067	0.7693	0.8732	1.0761	0.8566	0.9247	0.7499	0.8746	0.9332	0.874	0.0248
Group 17 (.017 x .025) niti- non coated												
17A	1.0071	1.368	1.272	1.0446	1.2796	0.9501	0.9488	1.0584	1.1046	1.152	1.1185	0.0462
18B	1.3108	1.4151	1.8128	1.7272	2.4708	2.0638	1.9983	2.0873	2.2758	2.1636	1.9326	0.1163
Group 18 (.019 x .025) niti- non coated												
18A	1.6466	1.622	1.6413	1.757	1.6888	1.5745	1.5638	1.7033	2.1595	1.4571	1.6814	0.0593
18B	2.6088	2.2805	2.319	2.1955	2.1099	2.2504	2.1307	2.1525	2.1594	2.3838	2.2591	0.0478
Group 19 (.018) ss wire- non coated												
19A	0.7421	0.8233	0.7778	0.7642	0.9291	0.8387	0.878	0.8011	0.9686	0.8045	0.8327	0.023
19B	0.8	0.7209	0.7888	0.7235	0.6629	0.7211	0.7529	0.7344	0.678	0.7015	0.7284	0.0138
Group 20 (.017 x .025) ss-non coated												
20A	1.2188	1.0425	1.4935	1.094	1.1166	1.1504	1.0785	1.334	1.333	1.4132	1.2075	0.0488
20B	2.1065	2.4055	6.2925	3.997	3.7234	2.2098	2.718	2.9844	2.8453	2.4715	3.1754	0.3973
Group 21 (.019 x .025) ss-non coated												
21A	2.7952	2.8692	3.6648	2.982	2.0109	3.5572	2.9684	2.6797	2.8135	2.2787	2.862	0.1584
21B	9.3033	6.4897	8.4222	8.0574	10.578	5.4796	8.1979	8.9153	5.7353	7.2455	7.8424	0.5108
Group 22 (.016) niti epoxy												
22A	0.5859	0.5038	0.4241	0.4789	0.5066	0.6067	0.6033	0.6715	0.7152	0.5597	0.5656	0.0283
22B	0.6164	0.5873	0.5199	0.5503	0.5615	0.537	0.5438	0.5883	0.6866	0.6475	0.5839	0.0167
Group 23 (.018) niti epoxy												
23A	0.4519	0.5396	0.5375	0.6383	0.6186	0.7627	0.7386	0.822	0.7962	0.8246	0.673	0.0424
23B	0.5635	0.5282	0.5377	0.5937	0.4755	0.5712	0.624	0.601	0.6648	0.597	0.5757	0.0169
Group 24 (.017 x .025) niti epoxy												
24A	0.4219	0.474	0.5351	0.6661	0.6006	0.5389	0.5718	0.6458	0.6494	0.6281	0.5732	0.0256
24B	1.0186	1.0221	1.0479	0.9514	1.0977	0.9457	1.0726	0.9504	1.0263	1.0416	1.0174	0.0167
Group 25 (.019 x .025) niti epoxy												
25A	0.6835	0.924	0.8928	0.6987	0.7595	0.7225	0.6805	0.7405	0.8035	0.7348	0.764	0.0268
25B	1.5179	1.4586	1.238	1.4021	1.2548	1.28	1.4332	1.3969	1.2728	1.3901	1.3644	0.0305
Group 26 (.018) ss epoxy												
26A	0.7936	0.6952	0.7752	0.736	0.6758	0.8393	0.7989	0.6079	0.7001	0.7105	0.7333	0.0219
26B	0.9656	1.0139	0.8685	0.884	1.0605	0.9728	0.8424	0.8349	0.8816	0.8866	0.9211	0.0243
Group 27 (.017 x .025) ss epoxy												
27A	1.1513	1.0947	0.765	0.8642	0.9097	0.7796	0.8865	0.8606	0.8	0.8276	0.8939	0.0411
27B	2.2192	2.6893	2.3461	2.1089	2.2384	1.7652	1.7539	2.2774	2.1799	1.6796	2.1258	0.0989
Group 28 (.019 x .025) ss epoxy												
28A	1.211	1.4846	1.2648	1.4428	1.2975	1.1546	1.1177	1.2604	1.2302	1.1434	1.2607	0.0385
28B	3.7184	3.121	2.5859	3.8674	3.0137	3.2166	4.6026	4.1159	3.1616	3.0549	3.4458	0.1931
Group 29 (.016) niti poly												
29A	0.5588	0.5423	0.5318	0.5422	0.5548	0.5335	0.4266	0.4628	0.494	0.4846	0.5131	0.0139
29B	0.5445	0.5531	0.6092	0.6157	0.5131	0.6455	0.5625	0.5454	0.587	0.6504	0.5826	0.0147
Group 30 (.018) niti poly												
30A	0.6768	0.6176	0.6876	0.6283	0.5784	0.526	0.6027	0.5374	0.5455	0.6466	0.6045	0.018
30B	0.6747	0.8476	0.6273	0.6928	0.6477	0.732	0.5577	0.5061	0.5978	0.6702	0.6554	0.03
Group 31 (.017 x .025) niti poly												
31A	0.7439	1.013	0.7728	0.853	0.8681	0.916	0.7782	0.8108	0.9422	0.8471	0.8545	0.0266
31B	1.2988	1.2357	1.2219	1.1985	1.2434	1.281	1.4889	1.3455	1.4245	1.4806	1.3219	0.0342
Group 32 (.019 x .025) niti poly												
32A	1.452	1.4654	1.7149	1.917	1.6355	1.5144	1.6365	1.2991	1.5101	1.2942	1.5439	0.06
32B	2.11	2.0546	2.0658	2.2437	2.0933	1.9265	1.963	1.9785	1.5908	1.8812	1.9907	0.0553



Group 33 (.018) ss poly													
33A	0.7734	0.6677	0.7226	0.6032	0.7243	0.5782	0.6039	0.6598	0.6297	0.6474		0.661	0.0197
33B	0.8035	0.7884	0.7927	0.7169	0.8612	0.7631	0.7486	0.7866	0.6998	0.8443		0.7805	0.0161
Group 34 (.017 x .025) ss poly													
34A	1.0238	1.148	1.1018	0.955	1.1948	0.9371	1.0834	1.0339	0.9633	1.009		1.045	0.0271
34B	3.1555	2.4448	2.2296	2.4772	1.9972	2.5834	2.0998	2.1445	1.6411	1.9196		2.2693	0.1331
Group 35 (.019 x .025) ss poly													
35A	2.5827	2.4733	1.9721	2.1691	2.1025	2.0995	1.8147	2.182	1.9698	1.7309		2.1097	0.0839
35B	5.2193	5.7479	6.6367	6.0433	6.8646	5.2951	5.0147	6.7739	5.7766	5.1424		5.8515	0.2226
Group 36 (.016) niti- epoxy- ortho													
36A	0.669	0.586	0.597	0.576	0.572	0.704	0.479	0.513	0.547	0.575		0.5818	0.0209
36B	0.586	0.56	0.591	0.626	0.555	0.548	0.597	0.632	0.659	0.709		0.6059	0.0158
Group 37 (.018) niti-epoxy-ortho													
37A	0.52	0.5043	0.4974	0.4702	0.4442	0.4907	0.5888	0.5785	0.6497	0.4558		0.52	0.0208
37B	0.5736	0.5568	0.57	0.5574	0.5649	0.5588	0.5089	0.5086	0.5911	0.4916		0.5842	0.0104
Group 38 (.017 x .025) niti-epoxy-ortho													
38A	0.5657	1.0698	0.5922	0.659	0.5675	0.663	0.6207	0.6585	0.5245	0.5748		0.6496	0.049
38B	0.8292	0.9283	1.009	0.8204	0.8531	0.9695	0.9172	0.7783	0.8648	0.6969		0.8717	0.0289
Group 39 (.019 x .025) niti-epoxy-ortho													
39A	0.9615	0.903	0.8805	0.8437	0.8148	0.8659	0.7558	0.882	0.7712	0.8866		0.8565	0.0196
39B	1.3852	1.3073	1.2103	1.3784	1.6304	1.476	1.3976	1.4548	1.3308	1.4797		1.405	0.0362
Group 40 (.018) ss-epoxy-ortho													
40A	0.5863	0.6244	0.6557	0.5284	0.6165	0.5853	0.6679	0.5946	0.6216	0.6579		0.6139	0.0133
40B	0.7556	0.7147	0.7813	0.7703	0.756	0.7767	0.7619	0.7943	0.7635	0.7349		0.7609	0.0073
Group 41 (.017 x .025) ss-epoxy-ortho													
41A	1.413	1.267	0.949	4.717	2.593	1.047	1.138	1.452	1.196	1.147		1.6919	0.3666
41B	2.661	2.654	2.274	2.168	3.238	1.86	2.319	2.382	2.202	1.39		2.3148	0.156
Group 42 (.019 x .025) ss-epoxy-ortho													
42A	5.456	3.533	3.148	2.388	2.694	1.085	1.195	1.236	1.049	1.125		2.2909	0.4611
42B	4.28	3.084	4.046	3.524	3.78	4.09	3.112	4.302	3.537	3.545		3.7303	0.1404

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