Equine Safety Equipment for Distal Limb Protection

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Abstract

Racehorses are subjected to continuous stress on their limbs, leading to catastrophic injuries. Wraps and boots are the current methods for preventing horse injuries, but have been unsuccessful. The goal of this project was to design an inner layer of an equine boot to increase heat conductivity from the leg, reducing the amount of moisture retention. A high performance material, an X-Static blend, was selected due to its light weight, flexibility, heat conductivity, and wicking properties.

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1 Introduction

One of the many challenges in the equine veterinary field is the catastrophic injury to the fetlock joint that often occurs in fatigued racehorses. Musculoskeletal injuries are the major cause of severe injuries and death for racehorses. Over 80% of racing and training deaths are associated with fracture injuries.(Butcher, 2002) Not only are horses affected, but owners, veterinarians, and fans of horseracing continuously watch healthy, young horses being euthanized due to injuries that can be prevented. (Riggs, 2002)

It has been clinically determined that lameness and catastrophic injuries are not caused by one single event. On the contrary, such injuries are caused by repeated stress on the bone. Stress on the bones is a natural process which induces bone remodeling. However, when the amount of stress on the bone becomes greater than the rate bone remodeling can occur, micro fractures begin to appear within the bones. Commonly, the micro fractures are not easily detectable by observation or by many available diagnostic tools, (Davidson, 2004) thus most injuries go unnoticed resulting in a catastrophic event. "Any horse that you enjoy riding, rather than doctoring, is worth putting boots on," says Billie Bray, marketing manager with Classic Equine. Therefore, most horse owners and trainers attempt to prevent such injuries by purchasing boots or wraps.

The preventative efforts thus far have focused on creating boots and wraps for the distal part of the limbs. These devices are typically made to protect the fetlock joint and the flexor and extensor tendons. Although many boots and wraps are on the market, none have been proven to provide adequate support to prevent stress-related injuries. Typically, these devices are made of neoprene, vinyl plasticol, and closed cell foam (for resiliency and cushioning). These materials attempt to support and protect the lower limb, but the ideal combination has not yet been achieved. (Armato, 1994)

The desired outcome for lower limb protection is to have an easily applicable and customized boot that provides adequate support to the fetlock region. The device must fit the natural contours of the leg while not applying too much pressure that could hinder blood flow. Shock absorbance is necessary to prevent the stress of racing fatigue from causing the joint to act beyond the physiological limits. Moisture resistance and the ability to redistribute heat are important in reducing irritability. (**Appendix D: AERI Meeting at Brown**)

The goal of this project was to contribute to the design of a lower limb safety device by creating the inner layer of the boot. The materials focused on reducing irritability by having moisture resistant qualities, heat resistance, and prevent extraneous materials from entering the boot. The material was tested on human participants after IRB approval to achieve a verbal feedback on the inner layering material's performance qualities. The material was used in the model for the final boot and presented to clients such as racehorse owners and veterinarians.

2 Background and Literature Review

2.1 Anatomy, Physiology, and Movement

The anatomy and physiology of the horse is complex because the large thoracic cavity must be supported by four long thin legs. The skeletal system functions to protect the organs and contribute to movement. The skeletal muscles are attached to the bones by tendons. Ligaments connect bone to bone and support joints. In particular, the fetlock joint is a hinge joint important for motion and transferring forces in the leg. Figure 1 below shows the anatomy of the equine lower limb depicting the individual components. Behind the fetlock are the sesamoid bones that behave in a pulley system with the tendons which pull on the phalanges. The normal function of the tendons is to pull on the skeleton in response to the contracting muscles. As a result, the tendons have limited elasticity. The joint contains lubricating synovial fluid between the joint and tendon sheaths. The suspensory ligaments prevent the tendon from being pulled down too far while the fetlock joint is weight bearing, preventing the fetlock from touching the ground. The fetlock joint also contains a suspensor ligament that tightens when pressure is added. The tendons that interact with the fetlock joint are the digital extensors and flexors. The function of the extensors is to carry the foot forward, whereas the function of the flexors is to flex the knee, fetlock joint, and foot. The fetlock joint, combined with the flexor and extensor tendons; and the sesamoid bones are involved in most catastrophic injuries that occur in thoroughbred racehorses. A catastrophic event consists of complete loss of support for the fetlock joint.

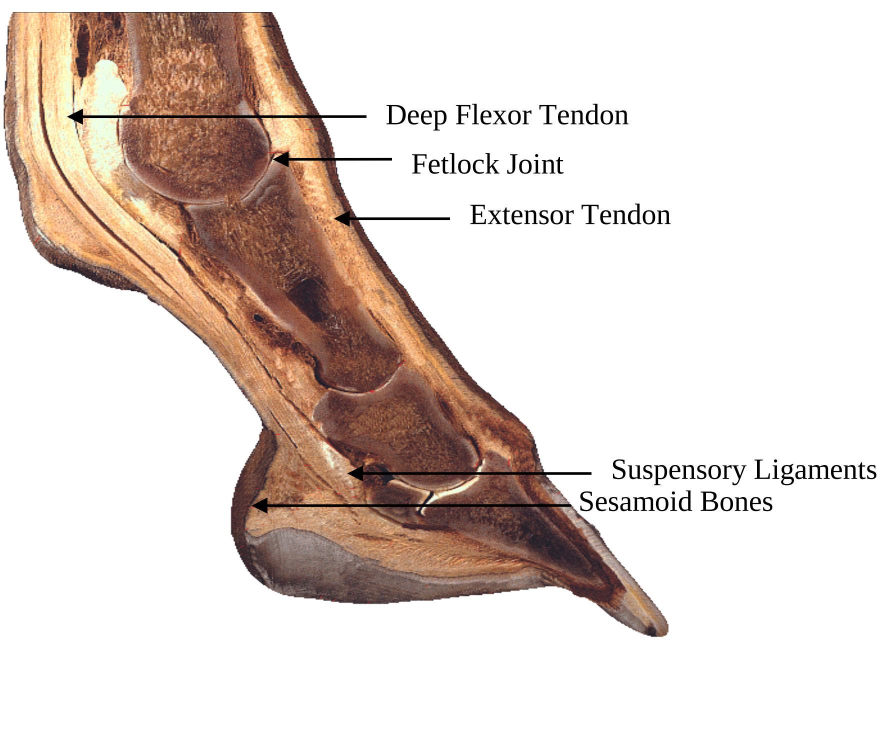

Figure 1 Longitudinal Section of Fetlock and Joint (Lower Limb, 2009)

2.1.1 Hoof Anatomy

The hoof of the horse is a nail covering made of keratin and soft tissue and surrounds the distal phalanx. Figure 2 is a labeled diagram of the structure of the hoof. It is a single digit responsible for supporting the entire limb and proximal structures. The first, second, and third phalanges are encapsulated in the structure in addition to several sesamoid bones, which are part of the metatarsus. The hoof capsule, which is the outermost layer, consists of keratin. The hoof capsule surface is hard and smooth. The inner part consists of the soft tissues and bone, and is considered the living portion. The sole of the hoof receives the most contact with the ground and is important in jumping and racing. Although the hoof is strong for protection, it has an elastic component. When loaded, it changes physiological shape in a similar way that bones can under varying strain. The soft portion of the bottom of the hoof is called the frog and provides flexibility. The bulb is the swelling in the rear of the hoof wall. The heel is considered the portion behind the horse's foot that aligns with the formation of the limb. At the region of the heel the horse's hair is present. The terms shod and not shod refer to whether the horse does or does not have a shoe. The horse anatomy is important in analyzing the distal limb and the catastrophic injuries that can occur during racing. (Betram, 1987)

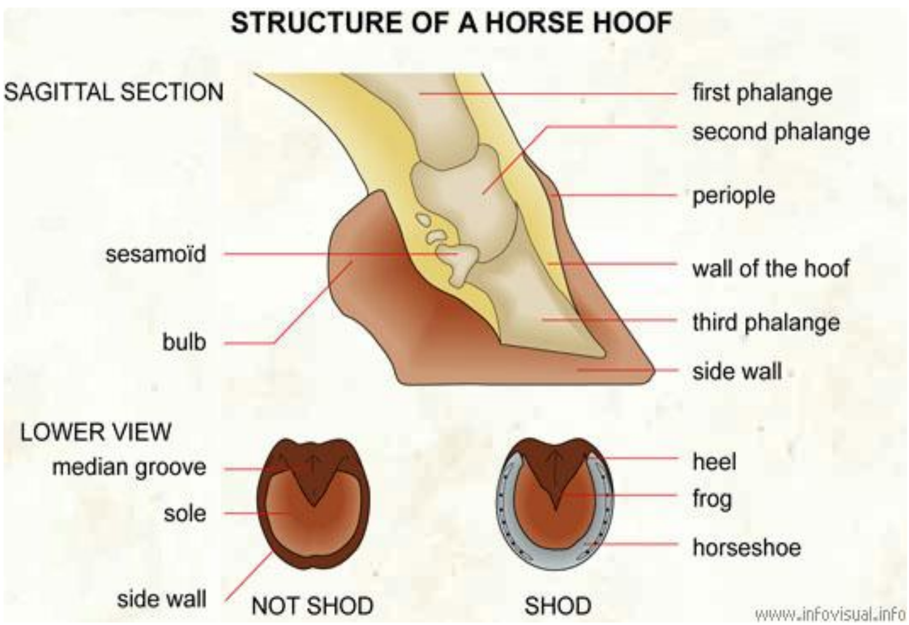

Figure 2 Hoof Anatomy (Structure of a Horse Hoof, 2010)

2.1.2 Limb Motion Cycle

When a horse is in motion, the limbs pass through repeated cycles of motion, or strides as demonstrated in Figure 3. One stride length is measured by each placement of the same foot. The stance phase is when the limb is in contact with the ground and the swing phase is when it is being carried through the air. The purpose of the swing phase is to slow the impact of the hoof with the ground upon landing. The stance phase has four parts: the initial heel contact, the mid contact phase, the full support phase, and the takeoff phase. During racing, the heel will come into contact with the ground first. The heel contact phase is responsible for shock absorption. Because it is such a short and instantaneous moment, there is insufficient time for the muscles to adequately protect the bone and joints. The full support phase is where the tendons and ligaments are stretched and the fetlock sinks to its lowest point which can be seen in Figure 4. The takeoff phase allows the tendons to recoil and the toes to proceed pushing off from the ground again.

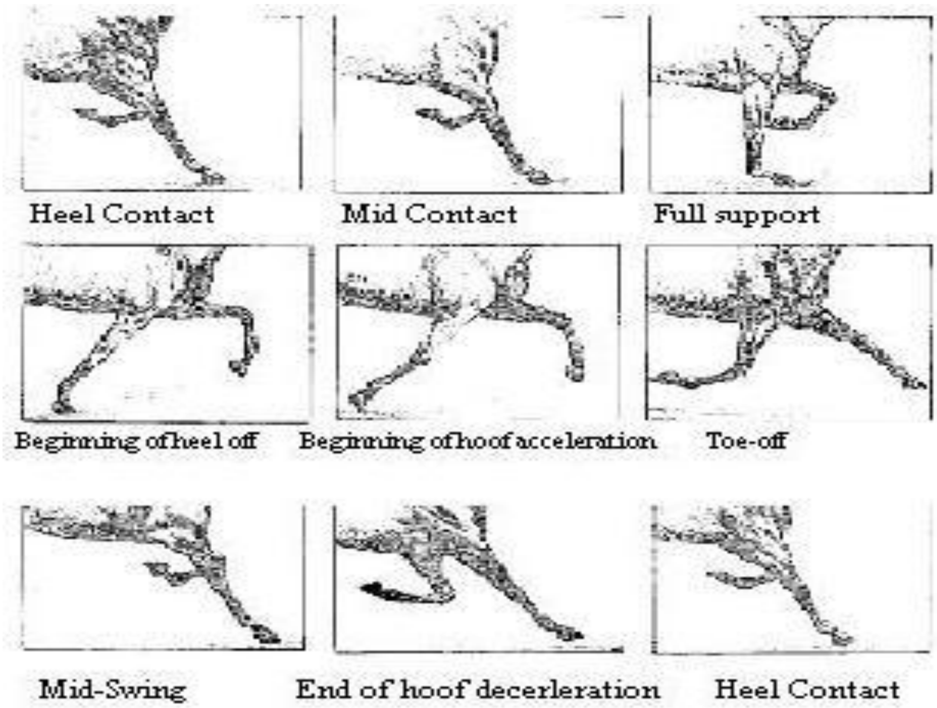

Figure 3 Limb Cycle of a Horse in Motion (Fredrics, 1972)

Figure 4 Full Support: Hyperextension of Front Limb (Dr. Kirker-Head, 2009)

Thoroughbred racehorses are typically injured during galloping in racing. The gallop is a high speed four-time beat that is also asymmetrical. The horse never has more than two feet on the ground simultaneously. The horse is in dynamic equilibrium during movement, meaning that as the body moves toward the center of gravity, a limb is placed in order to maintain balance. As the speed increases, the more the horse must depend on the dynamic equilibrium. The asymmetry of the gallop means that the horse can take either the right or left lead. A more fatigued horse will change leads more frequently. In addition to fatigue, there are internal and external causes that lead to catastrophic injury. (Pilliner, 2002).

2.2 Internal Causes

The culmination of micro and stress fractures cause catastrophic events that result in death or career ending injuries for racehorses. Such fractures are occurring when repeated excessive stress is placed on the bone. As stress and load are being placed on the bone, it enters the bone remodeling process. Bones respond to strain in the environment by adapting. Problems occur when bone absorption occurs faster than the bone can be replaced. As a result, the bone may become deformed and weakened. For example, it is common that the geometry of the third metacarpal bone changes. (Davidson, 2003) Because bone remodeling is cyclical, it is possible that most injuries occur during an imbalance in the process. Age is directly related to career length, therefore there will be an increased risk associated with career length which could result in career-ending, or superficial digital flexor tendon racing injuries. Repetitive stress on the distal limb will eventually cause catastrophic injuries. (Stover, 2004)

The three types of fractures are monotonic, pathological, and fatigue fractures. A monotonic fracture occurs when a bone that is loaded momentarily beyond its limit will fail. Pathological fractures are caused by neoplasia or osteoporosis, which cause the bone to be incapable of supporting normal loads. Fatigue fractures are characterized by cyclical loading and erosion of the material properties which will eventually lead to the inability to maintain normal, daily loads. Long bones are prone to higher strains due to the larger surface area and the fetlock joint will hyperextend beyond normal physiological limits. (Riggs, 2002)

These factures if noticed are viable ways to prevent the occurrence of catastrophic injury. Although diagnostic tools such as nuclear scintigraphy, and radiography exist, these tools are not utilized on a regular basis, thus these micro fractures go unnoticed. During a horse’s life time, race training and racing, cause repetitive high strain and loading, this contributes to stress fractures. The location of fractures can be easily predicted because they have a tendency to appear in the same bones and joints, such as the fetlock joint. Exams after fractures or death show evidence of long standing pathology around the fracture margins. When incomplete fractures occur, they are often precursors to where the catastrophic injury may occur. (Riggs, 2002)

2.3 External Causes

2.3.1 Race tracks

There are many parameters that can increase the risk of injury on a race track. Race tracks differ in many parameters including surface, climate, length, and training. For example, in New York, horses racing in the summer had 2.9 times increased risk for injury than horses racing in the winter, but higher proportions of injuries resulting in euthanasia occurred in winter and summer than in the spring.(Pinchbeck, 2002) Horses that had never raced the track were more susceptible to injury than horses that had, which could be due to either inexperience or different training methods. There is a lack of data on which factors directly relate to injuries suffered at a race track, but poor weather conditions, rougher racing surfaces, and training methods can contribute to injuries.(Pinchbeck, 2002) Awareness of these factors allows riders and trainers to reduce the chance of injuries by proper training methods and racing under adequate conditions.

2.3.2 Surface Race Tracks

Although there is a lack of research on the impact of surface racetracks on fetlock related injuries, variation in surfaces are a potential risk for such injuries. Most race tracks consist of either a natural surface (dirt) or synthetic surface (turf). The climate can have a significant impact on the surface of the race track. A synthetic surface provides the flexibility to maintain its consistency in the broadest range of weather conditions. Natural surfaces are dependent on weather conditions. Consistencies of natural surfaces range from uneven and muddy during rain and from even and soft during summer days. Muddy and uneven tracks could result in a horse stumbling and falling. A study performed in the UK for steeple races showed that soft and heavy track surfaces were associated with an increased risk of falling compared to good track surfaces. (Pinchbeck, 2002) However in a previous study, falling on softer ground was correlated with a decrease in severe injury. (Bailey et al., 1998;Williams et al., 2001) This could indicate that falls on softer ground result in fewer fatalities. (Pinchbeck, 2002)

2.3.3 Training

Initial training of racehorses entails that every 10-14 days, the speed of the exercise and or distance is increased. The gradual increase in speed and distance forces the muscles, tendons, and bones to cope with these high speeds through bone remodeling. Many problems in racehorse preparation are related to failure to gradually increase the training stimulus. Therefore, during a race when horses can reach speeds as high as 40 mi (64 km) per hour for a distance of one mile (1.6 km), this sudden increase in velocity can cause great stress to the bones, tendons, and muscles. Horses that had periods of rapid accumulation of high-speed exercise and distance (hazard period) had 4.2 times the risk of catastrophic musculoskeletal injury within 30 days. Horses were also 4.8 times more likely to have bone breaks after the hazard period. Recovery days allow for a race horse to recover after races or hard training. Generally, it takes one to three days for a horse to recover. During recovery days, minor injuries as well as past injuries should be addressed. A swollen or heated limb could be a sign of inflammation and is commonly iced. Also, ice packs are used immediately after rapid exercise on limbs that have been injured in the past. Treatment of limbs with a history of injury includes heating and stretching before training exercise, racing, and competitions. Minor injuries can go unnoticed however and the race horse will continue to train and race on an injured limb. These minor, usually stress related, injuries can progress into catastrophic, race-ending and in many cases life ending injuries. Detraining refers to the sudden cessation of training. Many horses have their training preparations interrupted by ill-health or injury. If the detraining period is too short a horse can continue training on a not fully healed injury that can lead to more devastating results. (Evans, 2000)

2.4 Consequences and Diagnostic Tools

Although micro and stress fractures are common in racehorses, the clinical signs and evidence are often misleading or nonexistent. During physical exams, the horse may not even feel pain in the area that has been strained. Pain is assessed by vital signs and physical reactions. An increase in the horse’s vital signs such as heart rate, blood pressure, and respiratory rate shows that the horse is in distress. Physical reactions would entail if the horse resisted or pulled away from the veterinarian during an examination.

However, lameness after a race or training session that worsens over time is a clear sign of an injury. The leading diagnostic tools for determining stress related bone injuries are flexion tests, nuclear scintigraphic examination, radiographs, and ultrasonographic exam. Flexion tests try to exacerbate evidence of lameness but may be inconclusive. This test physically manipulates the limb to flex. If the horse is in pain during flexion then this is evidence of stress fractures. Diagnostic anesthesia is another method that can be used in conjunction with other diagnostic tools. The anesthesia is a way to localize the pain, provided that the symptoms of lameness are evident. Radiographs can provide structural information about a particular region, but the structural deformities tend to appear after several weeks. Radiographs cannot diagnose the adaptations in the bone leading to stress fractures. Nuclear scintigraphy can identify lameness in horses as well as stress related bone injuries. It can detect induced bone remodeling and is more sensitive than radiographs. It measures the increased radiopharmaceutical uptake (IRU) by the fractured areas. Ultrasonic evaluation is most useful on smooth areas such as stress fractures in the ilial region. Therefore, the best option for diagnosing stress fractures in the lower limb is nuclear scintigraphy in conjunction with clinical examinations. Every diagnostic method is dependent on signs of initial lameness, which may or may not occur when microfractures begin to form. The difficulty in diagnosis shows that predicting catastrophic injury can be elusive. (Davidson, 2003)

2.5 Rehabilitation

After suffering catastrophic injury, it is very rare that a horse can ever race again or even survive after the limb is fractured. Statistics show that 1 in 700 racing starts are associated with severe musculoskeletal injury. In the UK, 60% of fatal racing injuries are associated with fracture and in the USA over 80% of horses that are euthanized in racing or training sustained a fracture. For catastrophic injuries, euthanasia is a more humane option than the difficult and painful rehabilitation process. However, because racing is a form of public entertainment, horses' treatments may be chosen based on public desires rather than the most humane option for the horse. The typical rehabilitation process consists of bandaging the injured leg, stall rest, and pain management. However, the bandaged limb may cause the horse to redistribute its weight onto the front limbs. This redistribution could cause complications with the non-injured limbs. For tendon injuries, there is a procedure called "tendon splitting" that has proved to be successful in many cases. However, the most severe tendon and joint fractures force owners and veterinarians to choose euthanasia. It is difficult to predict prognosis for lower limb injuries, but prevention is easier than treatment. Many injuries result from premature training during recovery. The time period for recovery is difficult to establish. Therefore, it is not recommended to begin training a horse again before the healing process is complete, which can be probably determined by a veterinarian examination.(Selhow, 2002)

2.6 Euthanasia

The alternative option to rehabilitation of a catastrophic injury is euthanasia. Euthanasia of horses is a controversial topic because neither method is received well by both the public and veterinarians. The two methods of euthanasia are lethal injection or gunshot. The drugs preferred for lethal injection are barbiturates because they shut down brain activity before any other bodily functions. Barbiturates are central nervous system depressants; therefore an overdose will lead to death. Other drugs used are T61 and succinylcholine, which cause heart attack, paralysis, or suffocation. These drugs can only be used humanely when the horse is under anesthesia. Barbiturates are preferred because they have faster effects. Barbiturates are considered controlled substances and as a result many veterinarians do not carry them.

Administration requires that a needle is injected in either the heart or a vein, and if the distributor does not hit their mark, severe and painful consequences ensue. Another controversy with barbiturates is that the horse's remains must be safely disposed of due to the potency of the drugs. If they are buried, the site must be very deep to prevent wildlife and other household pets from reaching the drugs and falling into a coma. However, despite the negatives, lethal injection is the preferred method of euthanasia in North America because it is bloodless and non violent. (AVMA, 2007)

On the contrary, in Europe the preferred method of euthanasia is by gunshot. If the gunshot is delivered properly, it is an instantaneous and painless death. Disposing of the horse's remains is less challenging because there are no toxins delivered. On the other hand, death by gunshot can be emotionally upsetting for owners and veterinarians and can be very dangerous if the administrator has no experience. It is suggested that horse owners have an emergency euthanasia plan in case the horse must be put to sleep immediately. The suggested protocol for this is gunshot, since most civilians do not posses drugs for lethal injections. The shooter must place the bullet perpendicular to the skull, or at the midline of the forehead aligning with the neck. Risks include missing the target, the bullet passing through the target and injuring a holder, ricochet, holding the gun too close to the body may cause a backfire, and emotional trauma. It is recommended to cover the horse's eyes to prevent increased struggle and anxiety. Although there is controversy surrounding both euthanasia methods, rehabilitation can be a far less humane route due to the complexity of the catastrophic injury. (Hayes, 2009)

In conclusion, catastrophic injuries are one of the main causes for the death of young and otherwise healthy racehorses. The fetlock joint is the region where these injuries occur, affecting the flexor and extensor tendons and ligaments involved in galloping. High forces applied to the fetlock joint and surrounding bones causes micro fractures that occur over time. Bone redevelopment and continuous training contribute to changing the morphology of the bone structures, which do not appear on routine physical exams. Although radiographs and nuclear scintigraphy are better methods of detecting such injuries, they are not performed routinely and micro fractures are undetected. Factors such as racetracks, training methods, and weather conditions can also create a poor environment for racing that could lead to injury. Both owners and veterinarians are searching for methods of prevention that will stop many racehorses from being euthanized for distal limb injuries. Current methods of prevention on the market include wraps and boots, but none have proved to be successful thus far.

2.7 Current Boot Models on Market

2.7.1 Introduction

Unfortunately most injuries go unnoticed until a catastrophic event occurs. "Any horse that you enjoy riding, rather than doctoring, is worth putting boots on," says Billie Bray, marketing manager with Classic Equine. Therefore, most horse owners and trainers attempt to prevent such injuries by purchasing boots or wraps. There is an extensive assortment of equine leg equipment commercially available. Each different boot or wrap serves many different functions. Current models on the market are described in **Appendix A: Boot/ Wrap Evaluation**. These functions rarely range beyond partial protection. It is a possibility that race horses can inflict severe damage to their distal limbs during a race. This damage can range from falling due to the track's surface to repetitive stress applied to the horse's joints. Though there are disadvantages as well as advantages to wearing the leg equipment, the potential of minimizing injury persuades many riders and trainers to outfit their horse with leg gear. The two most popular types of distal limb equipment are either wraps or boots.(Corkery,2005)

2.7.2 Support Boots

A support boot provides the horse's limbs with protection from environmental elements as well as dissipating some of the impact on the joints and bones. In addition to offering protection, the support boot aids in the structural stability of the horses limbs. In the horse's distal limb there is a large distance from the hoof to the muscle, which correlates with the lack of precision in placement on the hoof. A proper fit is crucial with this equine footwear. Poorly fit boots can cause irritation, sores, or even injury. Fastening the boot is another important parameter to consider. If too tight, the boot could cut off the circulation to the lower extremity causing detrimental pressure on the tendons. In the past, a majority of the boots on the market consisted of leather or canvas materials and metal clasps for attachment. These materials were rudimentary and no longer dominate the market. Support boots are made out of a variety of materials today. Most consist of synthetic materials that try to functionally aid the horse while not hindering its performance. Some of the more common materials used today include fleece, for an interior, and neoprene, for an exterior, with the use of Velcro as an attachment device. The price range for support boots varies, but usually falls between forty to a few hundred dollars. (Loving, 2008).

2.7.2.1 Neoprene Boots

One of the most popular boots currently on the market is the neoprene boot. These boots are used for all types of riding, ranging from dressage to polo. As a result there are many types and styles, but all consist of neoprene specifically. The ThinLine Cobra SMB Support Boot ® attempts to provide impact protection and support for tendons. Figure 5 is a picture of the product. It is thin and flexible. Stated by the manufacturer, the boot becomes a custom fit in response to the horse's body temperature and use. It's antimicrobial and thin-line vents prevent the buildup of moisture and bacteria. The outer lining does not attract dirt or extraneous materials. Velcro is used to fasten the boot. The boot costs $74.95, which is the average range for most neoprene boots. (Thinline Cobra SMB Support Boot, 2009). Although the boot claims to provide protection to the fetlock joint, this claim has not been proved. Also, adhering with Velcro may cause problems of detachment or becoming loose over time. Neoprene is an elastomer that has excellent toughness and thermal retention properties however these properties can affect the flexibility, elasticity, and heat and moisture transfer. (Yeh et al., 2007)

Figure 5 ThinLine Cobra SMB Support Boot

2.7.2.2 Brushing Boot

The brushing boot is an equine boot currently on the market used for all types of sports shown in Figure 6. This boot specifically prevents the horse from injuring itself by providing a PVC panel which stops the horse from "brushing" its legs together. The Woof Wear Sport Brushing Boot® is made of closed cell neoprene for durability and impact resistance. The manufacturer states, the outer layer made of nylon jersey provides limited water retention. The two layers are bound with hard wearing nylon. Its rot proof and recessed stitching method claim to extend the longevity of the boot. On the inner fetlock region, a vinyl striking pad is provided to minimize brushing. Beneath the vinyl pad is impact absorbent foam which provides additional protection. It is fastened with thin, but strong Velcro straps along the outside of the boot. The price of the boots ranges from $30 to $90. The brushing boot is the only model known to prevent tendon and ligament damage, but only in the context of self injury. The boots cannot prevent catastrophic injury (SmartPack, 2009)

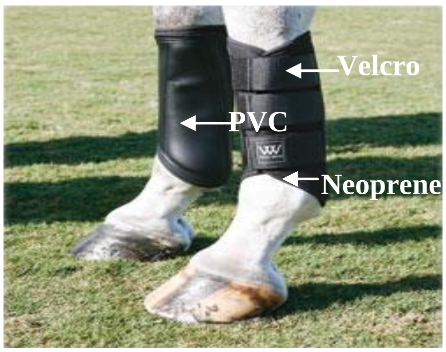

Figure 6 Woof Wear Sport Brushing Boot

2.7.2.3 Jumper Boots

The jumper boots are used specifically for sports involving low to high jumps and is shown in Figure 7. These boots are better equipped to provide shock absorbance for the fetlock joint when the horse lands after a jump. A popular type of jumper boot is the Equifit T-Boot EXP2 with Brass Stud Closures ®. The manufacturer states, this boot molds to the individual horse's leg. It consists of a removable inner lining that is washable. The boot is fastened by brass stud closures. The price of the boot is $178, which is in a higher price range than the neoprene and brushing boots. Since this boot is made for jumping sports, it is not equipped to accommodating the high speeds required for race horses (Beval Saddlery Ltd. 2009)

Figure 7 Equifit T-Boots EXP2 with Brass Stud Closures

2.7.3 Athletic Wraps

Wrapping a horse's leg is usually used as a physical therapy method. The wrap stabilizes injured soft tissues and helps prevent further injury. The wrap reduces the stretch of the flexor tendon preventing some hyperextension of the fetlock. A study done by researchers from the Universitat Autonoma in Barcelona, Spain and Michigan State University College of Veterinary Medicine showed that wrapping significantly reduced the peak flexion of the fetlock. (Piscopo, 2005) As the horse's limb headed towards the ground, the force applied was the same with or without wrapping, but with wrapping the force was slowed when hitting the ground. The data was collected with computerized force plates and markers placed strategically on the horses body and photographed at specific intervals. Fit is a major component of these wraps. If the wrap is too tight it could cut off circulation to the lower extremity causing detrimental pressure on the tendons. This is a rehabilitation tactic and would hinder the performance of a race horse if worn during a race. Wraps consist of adhesive sprays, sports tape, pretape wraps, and elastic bandage wraps. The price range of wraps varies, but would fall in the ten to hundred dollar ranges. (Piscopo, 2005)

2.7.3.1 Vet Wrap

Vet wrap is one of the most common types of horse wraps. It is commonly used on racehorses because it is very lightweight. Figure 8 is an image of the Equisport vet wrap product. Vet wrap is typically used as a rundown bandage, which means horses that are prone to injury or are recently recovered from an injury require the bandage. It consists of rubber latex, giving it elasticity. The manufacturers claim it reduces hyperextension of the fetlock joint, but it is difficult to prove this claim, since wraps are so thin and lightweight. One roll is used per leg, and a roll costs $2.95, which is the least expensive form of lower limb protection. Although wraps are beneficial for recovery, their elasticity could be detrimental to circulation if applied incorrectly. Therefore problems occur when the user is not educated in applying the product. (C&W Western Horse, 2009)

Figure 8 Equisport Vet Wrap

2.7.3.2 Polo Wrap

Another popular wrap is the polo wrap, used mostly for polo sporting events. This wrap is thicker than vet wrap because it is made of fleece and adhered by Velcro. It functions to maintain warmth on the leg. One example is the ANKY brand polo wrap shown in Figure 9. This wrap costs $35 which is higher than vet wrap, but provides more coverage. The manufacturer claims its thicker layering provides more support than vet wrap. However, the polo wrap is normally warn during warm ups or polo matches. It is not a sufficient method of supporting the fetlock joint in race horses because it consists of only one fabric and the moisture accumulation could cause the wrap to slip off, increasing the risk for injury. (Classic Dressage Collection, 2009)

Figure 9 ANKY Polo Wrap

2.7.4 Summary

Although there is a wide range of products on the market, there is limited variation between these boots and wraps. Most are made with the base material as neoprene with Velcro attachments. Neoprene serves in most cases as the inner and outer layering. There is a wide range of cost even though compositions are similar. Wraps are beneficial for healing rather than preventing racing injuries. There is a need for an innovative boot design that can be worn during racing and will prevent catastrophic injuries from occurring. An alternative material composition is required to design such a boot that can provide moisture and heat transfer, comfort and flexibility, and support for the fetlock joint.

2.8 Materials

2.8.1 Introduction

In order to prevent fetlock joint injuries, a new safety boot design must be created for race horses. Before creating an innovative design for a safety boot, alternative materials were researched. After the current materials were evaluated, new materials were researched for their properties of moisture absorption, heat conductivity, and comfort. These materials were evaluated on wicking properties which is the ability of the material to absorb a solution from a contact surface. A contact angle can be measured on the material's surface to determine hydrophobicity or hydrophilicity. Hydrophobicity is the repellence of water by a material. Hydrophicity is the attraction of water by a material. Materials that were to display both hydrophobic and hydrophilic properties would allow removal of moisture from the horse's limb without soaking the support boot. The novel material should demonstrate larger wicking properties than that of the current neoprene boot models. Thermal conductivity properties, which are the ability of the material to transfer heat, were also evaluated. A larger thermal conductivity was desired.

2.8.2 X-Static Fiber

One of the materials being considered in the construction of the inner layer of the safety boot is the X-Static fiber. It is composed of a pure silver layer bonded to a textile fabric. According to the product guide it contains properties of heat transfer, moisture transfer, antimicrobial, and anti odor as shown in Figure 10. In cold conditions, X-Static acts to insulate the subject through reflectivity, emissivity, and moisture transfer. Because silver has an infrared reflectivity rating of 95%, the heat produced by the body will be reflected back to itself. Silver has a low emission quality, which means that the element retains heat for long periods of time. This absorbed heat allows subjects to stay warmer for a longer period of time while wearing the fabric. X-Static assists the body's natural evaporation process through its natural conductive properties. Combined with a hydrophobic fabric, moisture will be wicked away from the skin and into the air at a more rapid rate.

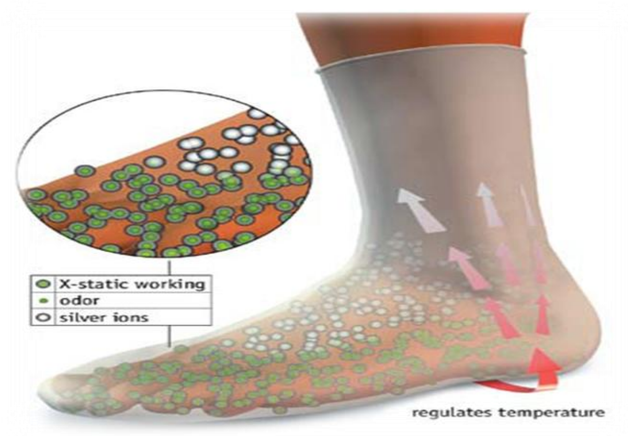

Figure 10 X Static Properties (X-Static Sales Guide, 2009)

During warm conditions, the silver fiber acts as a conductor to remove heat from the skin and release it into the air. Electrical conductivity also contributes to an anti-static property. Evaporation also allows the body to remain dry and cool during sweating. Silver, as an element, has antimicrobial and anti-odor properties and is therefore naturally clean. In hot and wet conditions, X-Static is able to maintain cleanliness in the area and prevent microbes from growing. It has been shown to kill up to 99.9% of bacteria and fungi within the first few hours of exposure. The final fiber is durable because the silver is irreversibly bound to the fabric. Therefore it can endure repeated cleaning without losing its properties. X-Static is typically bound to fabrics such as polyester and spandex. X-static fibers can be used in extremely small quantities approximately 10% of the overall fabric and still be completely effective. (X-Static Sales Guide, 2009)

2.8.3 Polyester Fiber

Polyesters are polymers that contain an ester functional group in their main chain. They are synthetic fibers which have controllable properties where natural fibers, such as cotton have properties that are harder to manipulate to obtain a desired property. (Polyethylene, 2009) Polyesters can be made into liquid crystal polymers that have mechanical and heat resistance properties. There is a wide range of polyesters with properties from moisture wicking, heat resistance, flexibility, strength, durability, and memory. In general, polyesters are synthesized by condensation reactions between a diol and a diacid. It is common for polyesters to be blended with other fabrics to obtain certain properties that are required by the manufacturers. It is a good option for a baseline fabric that can be improved or changed based upon the needs of the clients. The overall properties of polyester fiber are strong, resistant to stretching or shrinking, resistant to most chemicals, quick to dry, resistant under wet conditions, wrinkle and mildew resistant, heat transfer or heat retention, and easily cleaned. One of the most common uses of polyesters is in clothing, both inner and outer wear. (SwicoFil AG Textile Services, 2009)

2.8.4 Polyamide Fiber

Similar to polyester are nylons, which are polymers that are also polyamides. They are commonly used in clothing as a synthetic fiber. Polyamides contain amide linkages in their chains and are created by the polymerization of an amine and an acid chloride. The uses of nylon include hosiery, toothbrush bristles, carpet fibers, ropes for climbing, parachutes, and outerwear. Nylon is a versatile material that can be created with different blends that allows a range of properties. Some common properties include strength, elasticity, easily washed, dries quickly, shape memory, and heat resistant. It would be a good choice to be used as a base layer that can be blended with other fibers, such as X-Static. (Indianetzone Textiles, 2009)

2.8.5 Silk

In contrast to the polymers, silk is a natural fiber that is used in textiles. Silk is typically obtained from the cocoons of silkworms. Spiders produce silk in webs, which is much stronger and tougher than that of silkworms and could be used as a potential outerwear. It is smooth in texture but is not considered slippery. Silk is an extremely strong fiber but can be weakened in wet conditions or damaged by sunlight. It is a poor conductor and does not have good memory properties, but its absorbance properties provide insulation. If left unclean, silk can be eaten and destroyed by bugs. However, it is a natural fiber that is comfortable and prevents irritation. It could be a good inside layer if coated with an additional hydrophobic material such as Teflon. (Net Industries, 2009)

2.8.6 Wool

Wool is a natural fiber that has been harvested from the coat of a sheep and then is spun into a yarn that can be used in fabrics. The durability and flexibility of this fabric allow for continuous bending cycles to be performed up to 20,000 times without breaking. Cotton will break after 3,000 bending cycles are performed. Wool acts as an insulator trapping air within the fibers and retaining heat near the body. Moisture obtained on the surface of the wool is repelled and does not run into the fibers. Due to its durability and water repellency the amount of care in cleaning is minimal however when cleaning the wool must be dry cleaned to reduce shrinkage. Wool is considered a luxury fiber and the costs reflected that at higher amounts therefore synthetic substitutes such as acrylic are produced to mimic the characteristics of wool at a cheaper cost. (Kadolph et al., 2006)

2.8.7 Bamboo Jersey

Bamboo Jersey is a blend of two types of fabric; bamboo lyocell and cotton spandex. Bamboo lyocell makes up 67% of the bamboo jersey. The lyocell process chemically manufactures bamboo fibers in a more natural and eco-friendly way. This chemical manufacturing process produces lyocell from bamboo cellulose. The final product of this lyocell process would be bamboo cellulose fiber threads which can then be spun into bamboo yarn. (Bamboo, 2007) Cotton spandex incorporates both cotton and spandex and contributes 33% of the overall makeup of the bamboo jersey. Cotton Fibers are highly porous, making the fabric lightweight, and breathable. Its high porosity however causes shrinkage of the material. (Cotton Fabric, 2008) Spandex is a lightweight, synthetic fiber that is used to make stretchable clothing such as in sportswear. It is an elastomer, which means it can be stretched to a certain degree and it recoils when released. (Romanowski, 2009) This blend incorporates properties from each fabric. The bamboo jersey is lightweight and breathable. This fabric has a good wicking property which means that the fabric will draw moisture away from the body. Its breathability property allows for the skin to dissipate heat through the material and away from the skin. Bamboo jersey also has natural anti-bacterial and hypoallergenic properties which enables for repetitive usage without the potential of bacterial buildup. During usage the bamboo jersey is comfortable, covers a large range of movement, and has good original shape retention. (Product Technology, 2009)

2.8.8 Adhesive Materials

An adhesive material will provide a new method of securing the boot to the horse's hoof which will reduce the amount of exterior elements that tend to enter during racing. In **Appendix B: Adhesive Material Evaluation** is a Pro and Cons List of all the adhesive materials mentioned below.

2.8.8.1 Ethylene vinyl acetate (EVA)

Ethylene vinyl acetate is a copolymer of ethylene and vinyl acetate. It is typically used as a hot melt adhesive such as hot glue sticks, enhanced cling in plastic wraps, shock absorbent padding of sportswear, and adhesives for packaging and textiles. It is versatile because it is an expanding rubber, which means that its resin beads can be expanded and as a result it can be expanded when molding. EVA has many beneficial qualities necessary for a supportive adhering structure. It can be manufactured specifically for a function. For example, it can be made to varying degrees of softness or flexibility. It functions well as a barrier material, preventing other materials or natural products from diffusing through it. Unlike many other rubber polymers, EVA is resistant to UV rays and can be used in the sun. It can be used as a shock absorber and has good crack resistant qualities. Low moisture absorbance is another important function of EVA (Westerman, 2002). In Table 1 tensile testing was performed in test method ASTM D-882 to establish ultimate tensile strength, elongation to break, and toughness. (Zwick/Roell, 2010) A water vapor transmission test was performed in test method ASTM E-96 which encompasses measuring water dissipation over time due to vapor transmission to establish a water-vapor transmission rate. (Intertek Plastic Technology Laboratories, 2010)

Table 1 EVA Property Chart (Technical Data Sheet for ELVAX, 1996)

Property	Test Method	Unit(SI)	EVA Film-10
Ultimate Tensile Strength	ASTM D 882	MPa	24.3 21.4
Elongation to Break	ASTM D-882	%	600 740
Toughness	ASTM D-882	J/m^3	64.0 75.0
Water-vapor Transmission Rate	ASTM E-96	g/m^2	14.4

2.8.8.2 PTFE (Teflon)

Polytetrafluoroethylene, more commonly known as Teflon, is a synthetic fluoropolymer of tetrafluoroethylene resin, materials with similar properties to natural resins such as sap. It is manufactured from powder and heated to create various products. Teflon can be coupled to other material and therefore is considered a type of filler. As a result, it can accommodate a wide range of mechanical properties. A common use is mechanical seals and nonstick surfaces for pans. Properties of Teflon include low friction and antistick, can be elongated, and manufactured to have either high or low flexibility. Teflon does have some creep, which means that over time the shape can become deformed under pressures (DuPont, 2009). In Table 2 ASTM test method D-4894 is the standard specification for Polytetrafluoroethylene (PTFE) granular molding and ram extrusion materials which establishes melting peak, tensile strength, and elongation to break for PTFE. (American Society for Testing & Materials, 2010)

Table 2 PTFE Property Chart (DuPont, 2004)

Property	ASTM Test Method	Unit	Nominal Value
Melting Peak Temperature Initial Second	ASTM D-4894	°C	 342±10 327±10
Tensile Strength	ASTM D-4894	MPa (psi)	30 (4,400)
Elongation to Break	ASTM D-4894	%	2990

2.8.8.3 Thermoplastic Polyurethane films (TPU)

Aliphatic Polyether polyurethane film is a polyether based, low modulus aliphatic thermoplastic polyurthethane film/sheet which serves as adhesive films for an array of applications. A thermoplastic is a polymer that turns into a liquid when heated. Table 1 shows a list of the property values along with the ASTM testing methods used to determine these values. TPU is excellent in bonding to smooth, hard surfaces such as glass and polycarbonates. It's tough and durable hence TPU can be used several times without losing its property integrity. Another property of TPU is its ability to absorb thermal and mechanical shock from surfaces that it adheres to. Some adhesive polymers such as Teflon have sensitivity to UV lights which will actually denature the polymer; however TPU has excellent UV resistance. Applications for TPU can range from adhesive tapes, textiles, medical, and packaging. (Deerfield Urethane,2009). In Table 3 ASTM D-1004 is the standardized testing for tear resistance. (American Society for Testing & Materials, 2010)

Table 3 TPU Property Chart (Deerfield Urethane, 2009)

Mechanical Property	ASTM Test Method	Value
Ultimate Tensile Strength	D-882	5500 psi
Ultimate Elongation	D-882	500%
Tear Resistance	D-1004	250 pli
Appearance		Optically clear (dependent on thickness)

2.9 Rationale

Although there are several different boots and wraps on the market today no boot or wrap adequately resolves some of the major concerns that arise during racing. Shock absorption from the impact of the race horse with the ground is minimally addressed with a boot. Although a wrap reduces hyperextension, it hinders the race horse's performance. Therefore, a boot must be designed that will reduce hyperextension and angular velocity without hindering the horse's performance. In addition, the closure devices of these boots have many flaws. Velcro is not a secure locking system and allows outside particles to enter the boots. Velcro sticks to the horse's hair causing discomfort. Finally, moisture absorption and heat management are necessary for the novel design of the boot and are not resolved by any of the products currently on the market. Therefore, a composite boot must be designed that incorporates these needs.

This project will focus specifically on the engineering and design of the innermost layer of a composite support boot. This layer must have qualities of heat absorption and breathability, moisture wicking, comfort, viscoelasticity, lightweight, and secure. The layer must be able to take heat from the body and distribute it to the air. Sweat from the horse's leg must be absorbed and released. The boot must be comfortable and avoid causing irritation. If it is viscoelastic then it can return to its original shape despite strain and pressure. The material must be light weight so that it will not hinder the horse during racing and be able to secure other materials.

3 Project Approach

3.1 Specific Aims

The goal of this project is to design the inner layering of an equine support boot that permits maximum moisture absorption with maximum drying time, optimal thermal conductivity and a secure fit. The specific aims of this project are:

- To evaluate the materials for the composition of the support boot
- To determine the material composition that provides the best moisture absorption, thermal conductivity, and security aspects
- To purchase a blend of this material with the predetermined material, X-Static
- To create a final design that meets the demands of the inner layering of the equine support boot

3.2 Hypothesis

It was hypothesized that creating a new inner layering with blended fibers along with a removable securing component of the horse boot would reduce exterior environmental element intake along with creating good moisture absorption and thermal conductivity. By using a blend of fibers, a unique material was created harnessing favorable properties from each type of fiber. Also by incorporating a removable securing component, the securing component can be changed periodically to ensure that favorable properties are maintained. In general, the securing component maximizes the reusability of the boot along with minimizing the occurrence of irritation and injury to the limb from external debris.

To test this hypothesis we performed analyses on material samples to evaluate their properties and determine their abilities to meet the project objectives. To test the fibers' thermal conductivity and moisture absorption, a wicking testing, sessile drop test, and thermal conductivity test were utilized. Polyester, nylon, silk, cotton, and wool were evaluated for all three of the tests. A larger distance traveled by a solution on the material indicates a better wicking property. It was predicted that for the wicking test wool would wick the least and polyester would have the optimal wicking properties. A larger contact angle indicates hydrophobic properties while a small contact angle indicates hydrophilic properties. It was predicted that in the sessile drop tests, the largest contact angle would be observed with wool and the smallest contact angle with polyester. A smaller difference in temperatures indicates better thermal conductivity properties. It was predicted that for the thermal conductivity test, wool would conduct the least amount of heat and silk would conduct the most.

Human trials were performed to more specifically test the conditions under which the boot would be used by the race horse. A verbal response was recorded to assess irritation, which is not possible using an equine model. The goal of these trials is to evaluate the final fiber blend of the inner layering and provide further analysis of irritation, moisture absorption, and thermal conductivity. It was predicted that during the human trials the subjects would experience no irritation from the fiber blend.

4 Design

4.1 Initial Client Statement

Every year, thousands of racehorses around the world die from catastrophic injuries that are caused by repeated stresses of working outside the body's physiological limits. In order to reduce the number of lives lost and money spent, a boot or leg wrap must be created to reduce the many issues that a race horse experiences without causing the horse to reach beyond physiological limits. Therefore, various biomaterials must be tested in order to create a device that will allow the horse to remain within physiological limits but maintain speed at the same time.

4.2 Objective, Functions, and Constraints

4.2.1 Objectives

In order to determine objectives for designing the new boot, a meeting was held with the Advanced Equine Research Institute (AERI), a non-profit organization interested in preventing catastrophic injuries in race horses. The meeting with AERI, along with an extensive collection of reviewed literature, allowed for the design objectives to be generated for the inner layering of the safety boot. The three main investors for this project include the designers (students and project advisors), the clients (Advanced Equine Research Institute), and the users (race horses). **Appendix C: Stakeholders Concerns and Appendix D: AERI Meeting at Brown** displays a detailed account of the investors and their concerns. The investors "wants" for the inner layering were also taken into consideration when formulating the objectives. An evaluation of these objectives and their relative importance to the investors can be found in the pair-wise comparison chart, weighted objectives list and objective tree in **Appendix E: Objectives**. These objectives are presented below:

1. Thermal conductivity

- Will conduct heat away from the distal limb
- Will reduce the amount of heat conducted into the inner layering

2. Moisture absorption

- The inner layering should resist intake of moisture from the outside environment
- The inner layering should wick moisture away from the distal limb to the outside environment.

3. Weight and flexibility

- The inner layering must be light weight and flexible to ensure the performance of the race horse is not being hindered
- Though flexible, the inner layering should be able to retain its shape for multiple uses

4. Secure

- The inner layering should encompass a secure component at both the upper part of the leg and the lower part of the leg that includes the hoof
  - Upper part: a secure fit without constricting blood flow
  - Lower part: a removable component that secures the upper part to the hoof

The primary goals of this project were presented in the ordered objectives above. Heat is a constant concern for race horses. Heat intake causes moisture build up that can result in irritation and even injury. As heat is lost, the race horse is also exerting more energy that could lead to injury or even death. Conducting heat away from the distal limb would provide the horse with proper ventilation to reduce moisture build up and prevent injuries. The second objective entails promoting any moisture created by the distal limb to be wicked through the layering away from the limb. A material that exhibits a fast drying period would reduce the amount of moisture exposure to the distal limb providing protection from irritation and injury. Minimal moisture absorption from the outer environment would further prevent any negative effects associated with moisture intake. A light weight material would reduce any extra weight exerted on the horse that could slow them down during a race. A flexible material would mimic the natural movement of the horse's leg without equipment. It would allow for maximum flexibility while retaining the original shape of the boot to reduce any loosening. A secure fit on the distal limb would provide a race horse with protection from environmental elements such as dirt and water that tend to transfer into safety boots during races causing irritation and even injury to the race horse. A removable securing component to the hoof would allow for the material to be replaced when damaged and provide the horse with maximum security during every race. To minimize any damage that could be caused by the safety boot, the inner layering should not restrict the blood flow in the distal limb. By creating a securing component that is reusable, provides protection, and minimizes damage the safety boot would be marketable as equine safety equipment.

4.2.2 Functions

While an objective is something that the design *must be*, a function is something that the design *must do*. An elaborate listing of functions and means can be found in the morphological chart **Appendix F: Morphological Chart**. The following list is a brief overview of the functions of the inner layering that must be achieved to accomplish our project goals and objectives:

- Must conduct heat
- Must wick moisture
- Must provide full coverage to the fetlock joint and tendons
- Must adhere to the supportive and outer layering
- Must adhere to the hoof
- Must reduce environmental element intake

The fetlock joint and tendons are most frequently injured by race horses leading to lameness and even death. The inner layering must provide full coverage to the fetlock joint and tendons which when working in combination with the supportive and outer layering will provide overall protection to the fetlock joint and tendons. Once full coverage of the inner layering is provided it must be securely attached to the supportive and outer layering so that the boot will work uniformly with all its components. During placement of the completely assembled boot, an adhesive must be supplied to provide an interface which will securely join the lower part of the boot to the hoof. This adhered boot/ hoof interface will ultimately lead to the reduction of environmental elements entering the boot and causing irritation and injury.

4.2.3 Constraints

- Cannot hinder or enhance horses performance during racing
- Must be cost effective for both producers and the consumers
    - Cannot cost more than our allotted budget of $300
- Must be finished by April 2010

These constraints provide a method for determining which design alternatives are not feasible. The design must not hinder or enhance horse's performance during racing as specified by horse racing guidelines. The costs must remain within the designated cost budget for both the allotted project budget and the final production budget. The deadline for the project is April 2010.

4.3 Specifications

The primary specification was derived from the project objectives, functions and constraints; a specific performance standard of the design was compiled. This specification helped determine the efficacy of the design after the experimental analysis. Table 4 displays the specification that should be achieved by the inner layering of the boot.

Table 4 Design Specifications (Butcher et al., 2001)

Physiological Specifications	Description
Temperature	Do not exceed the average temperature during racing (37.5 -40 ˚C)

As defined by the initial problem statement, the goal of this project was to design a safety boot that would allow the race horse to stay within its physiological limits. **Appendix G: Specifications** gives a full list of specifications that could be considered in relation to normal physiological limits of a race horse. Exceeding the normal temperature causes several negative effects to the race horse. Race performance will be reduced and moisture production will be increased. Temperature increase past normal limits can even lead to heat stroke and death. Current boots on the market are aimed at supporting and protecting the distal limb and do not successfully reduce heat production that results from placing a boot over the distal limb.

4.4 Revised Client Statement

Based on the constructed objectives, functions, constraints, and specifications, the client statement was re-evaluated.

Design the inner layering of an equine safety boot that will allow the horse to remain within physiological limits but maintain speed at the same time. The inner layering must be securely attached to the distal limb to prevent environmental elements such as dirt and water from entering into the boot. Thermal conductivity through the material must allow for maximum release of heat away from the leg to reduce moisture. However, any moisture formation should be quickly absorbed through the material and have a short drying period. The inner layering should allow for complete flexibility of the leg to be maintained while not contributing to any additional weight that could hinder the horses performance.

4.5 Design Alternatives

The design selection process from the development of the basic concepts, the formulation of the alternatives, and the final selection are all depicted in this section. The process began by identifying means that fulfill the functions described in the previous section and developing alternative designs. The design alternatives were assessed based on whether each one was able to fulfill the objectives, functions, and constraints. The final design selection was based on the most compatible of the design alternatives with the given objectives, functions, and constraints.

4.5.1 Morphological Chart and Evaluation Matrices

The morphological chart, shown in **Appendix F: Morphological Chart** includes all of the functions along with possible means to accomplish them. Through a combination of process of elimination and availability of materials the design alternatives were formulated. Below depicted the possible alternatives inner boot layer designs that were developed:

- **Minimal coverage** provided to the hoof with a removable adhesive strip that lines the front section of the hoof
- **Partial coverage** provided to the hoof by extending the inner layering down and over the back of the hoof adhering to the base of the hoof. A removable adhesive strip that lines the front section of the hoof will be applied.
- **Full coverage** provided to the hoof by extending the inner layering over the entire hoof while incorporating a removable adhesive strip that lines the front section of the hoof.

Numerical evaluation matrices were used to weight each of the design alternatives with the objectives, function, and constraints. **Appendix H: Design Alternatives** show these initial matrices Each design alternative was defined on a scale of 1-3, with 1 being the design did not fulfill the stated objective, function, or constraint at all and 3 being the design fulfilled the stated objective, function, or constraint with the most accuracy.

For example, the minimal design alternative in relation to the first objective which was that the inner layering must be secure was given a score of 1 due to the fact that design left the back of the hoof vulnerable to the intake of elemental elements such as dirt. The full coverage design scored a 3 in relation to the first objective due to the fact that all possible surfaces were covered to provide maximum reduction of environmental element intake. Table 5 shows a sample of the evaluation matrix for the design alternatives to the objectives.

Table 5 Sample Evaluation Matrix

DESIGN →	Design 1	Design 2	Design 3
OBJECTIVE ↓			
Objective1	Weight(1-3) →		
Total			

The top row of each matrix lists the design alternatives, and the left column lists the design objectives, functions, or constraints. Using the scoring metrics (1-3) each design was ranked and totaled in the last row of the table. A final evaluation matrix was developed to calculate each design alternative's total perform in relation to the objectives, functions, and constraints and indicate the top design candidate which is seen in Table 6. The full list of evaluated designs and total scores, along with a description of each design can be found in **Appendix H: Design Alternatives**.

Table 6 Evaluation of Design Alternatives

DESIGN ALTERNATIVES	TOTAL SCORE
Minimal coverage provided to the hoof with a removable adhesive strip that lines the front section of the hoof	32.5
Partial coverage provided to the hoof by extending the inner layering down and over the back of the hoof adhering to the base of the hoof. A removable adhesive strip that lines the front section of the hoof will be applied.	33.5
Full coverage is provide to the hoof by extending the inner layering completely of the hoof while incorporating the removable adhesive strip that lines the front section of the hoof.	29.5

5. Methods

In order to test the properties of each material and determine the best option for the inner layering and adhesive portion, moisture wicking, sessile drop, and heat transfer were performed. The moisture wicking test served to determine which materials most adequately adsorb and released moisture that was formed at the limb. The sessile drop test was another assessment of moisture absorption abilities. The heat transfer test showed which materials could conduct heat and provide breathability. The wicking, heat, and sessile tests were used for the materials considered in the innermost layering of the boot. Finally, once the inner layering was determined, the material blend was tested on human subjects to provide feedback on irritation, heat, and moisture.

5.1 Purpose of the Testing

Each material and fabric used has a list of known properties that were found upon searching the literature. The purpose of testing these known standards is to ensure each property remained constant under the specification of a racing horse. The preliminary materials considered for the inner layering include cotton, wool, polyester, nylon, and silk. Upon analyzing the results of each test, a blend was considered for the final composition of the inner layer. It was determined that a blend of materials would be more beneficial than a single material because specific properties of each can be combined to create the desired effect of providing comfort and security to the horse while racing. The purpose of the human testing was to provide verbal feedback on the comfort level of the inner layering, which cannot be obtained from animal testing.

5.2 Moisture Wicking Test

The moisture wick test provided information on the ability of the fabric to draw moisture away from the limb of the horse. The fabrics being tested included polyester, nylon, cotton, wool, and silk. The moisture was simulated by placing 500 ml of distilled water at 21^{o}C into a beaker. This test was repeated using the final material choice with the addition of salt into the water to further replicate the environment of the horse's limb during moisture production. The materials were cut into pieces with dimensions 3 cm wide X 15 cm long. One end was clamped vertically and 3 cm of the other end was submerged into the water as shown in Figure 11. The height of the water was measured at 3 time intervals: 1 minute, 5 minutes, and 10 minutes. High wicking values signify greater water transport ability. The materials used for the experiment included six samples of each material (n=6), a 500 ml beaker filled with distilled water, clamps, ruler, and a timer. Results were recorded and photographed as the test proceeded. All materials were obtained from the WPI BME lab. (Textile & Apparel Technology & Management,2009)

Figure 11 Wicking Experiment Set Up

5.2.1 Hypotheses

Hypotheses were developed in accordance with the known properties of the materials. Wool has hydrophobic properties whereas silk has hydrophilic properties. Two hypotheses were predicted before beginning the wicking experiments, which will either be supported of refuted by the wicking data.

Hypothesis 1: Of cotton, wool, silk, nylon and polyester, silk will have optimal wicking properties and wool will have the least amount of wicking ability.

Hypothesis 2: Of X-Static and neoprene, neoprene will have least amount of wicking ability and X-Static will have the greatest wicking properties.

5.2.2 Data Collection and Analysis

The wicking data was collected by measuring the moisture level on the material at each time point and recording it in the data table. A sample of the data table for polyester is shown below in Table 7. For each fabric, the six trials are listed for each time interval. The data was averaged and converted into a graphical representation, including a trend line and standard deviation. Wicking ability was analyzed by the height of the moisture on the fabric in the given time intervals.

Table 7 Sample Wicking Data Chart
Distance of water traveled up the material was measured in cm

Fabrics	1 min	5 min	10 min
Polyester			
1			
2			
3			
4			
5			
6			

5.3 Sessile Drop Test

The sessile drop test quantifies the hydrophobicity of the fabric by measuring the contact angle of a water droplet placed upon the fabric. Each fabric was cut into 7cm X 7cm samples and laid upon a flat heated surface. A camera was set up at the level of the fabric. A 20 µl water droplet was placed upon the fabric and the camera was set to take a snapshot every 10 seconds for 70 seconds. Figure 12 shows the actual set up of the sessile drop test described previously. (Ratner et al., 2004)

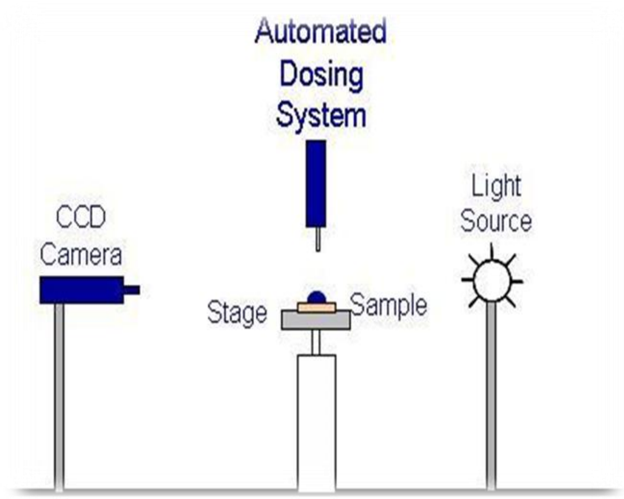

Figure 12 Sessile Wicking Test Setup (Wettability Measurement, 2009)

From the first to the seventh photograph, the contact angle was measured using a protractor. The lower the angle measurement, the more the fabric absorbs the water droplet as shown in Figure 13. The first sessile test was performed without a heat source and the second test utilized a heat source of 37.5°C to mimic the horse's body temperature. Each test was run 3 times. The materials used were a camera, a camera stand, a 20µl pipette, sections of each fabric, distilled water, a protractor, and a hot plate. (Ratner et al., 2004)

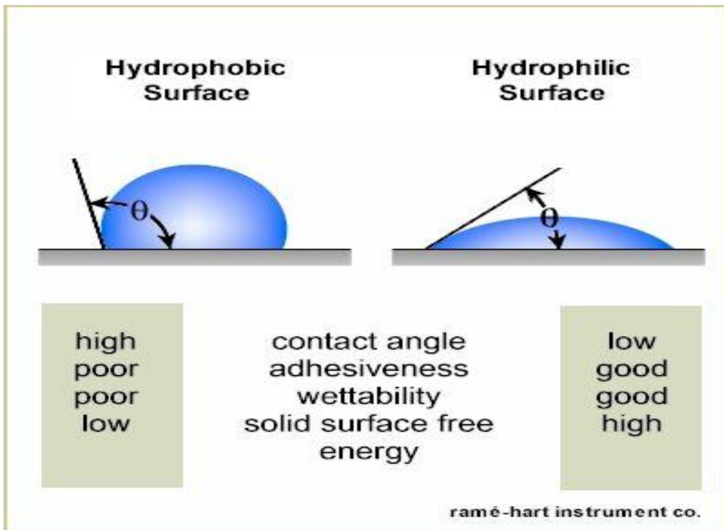

Figure 13: Angle Measurement Analysis (Rame-Hart, 2009)

5.3.1 Hypotheses

Upon literature research, hypotheses were developed in accordance with the known properties of the water absorbency of the materials. Two hypotheses were predicted before beginning the experiments, which will either be supported or refuted by the angle measurement data.

Hypothesis 1: Of cotton, wool, silk, nylon, and polyester, silk will absorb the most water and wool will absorb the least.

Hypothesis 2: Of neoprene and X-Static, X-Static will be more hydrophilic than neoprene which will be highly hydrophobic.

5.3.2 Data Collection and Analysis

The data was collected through photographs of the drop upon the fabric at 10 second time intervals for 70 seconds. The angle could be obtained by using a protractor on the enlarged images. Three trials were performed for each fabric. A lower angle signifies a greater absorption of the water droplet.

5.4 Heat Transfer

The heat transfer test will provide information about the thermal conductivity of each of the five fabrics. In the experiment, a heat source will be set at two temperatures: 37.5°C and 45°C. The temperature 37.5˚C is the normal body temperature of the horse and 45˚C is above the physiological limits. The heat source is a circulating water bath connected to a heating pad. The fabrics were suspended approximately 1 cm above the heating pad by four clamps attached to each corner of the material as shown in Figure 14. A thermo-sensor was taped onto the top and bottom of the fabric. Another thermo-sensor recorded the atmospheric temperature for the duration of the experiment. The thermo-sensorsrecorded the temperature over a 3 minute time period.

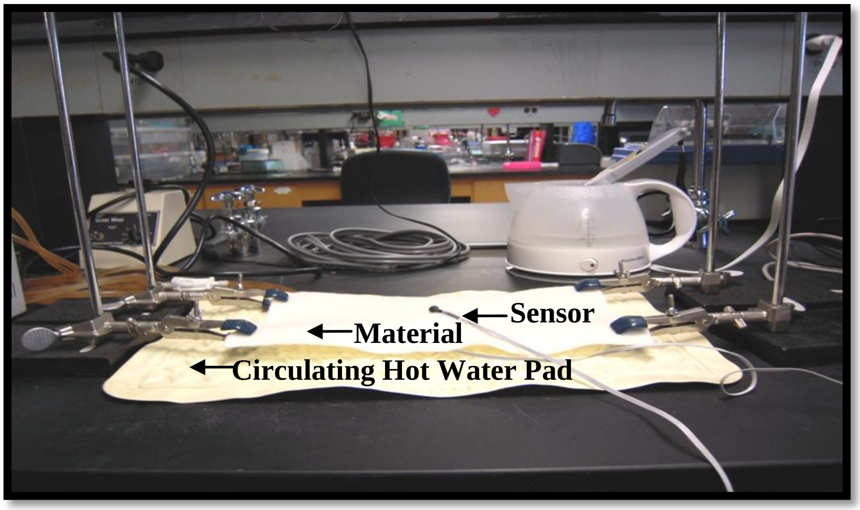

Figure 14 Heat Conductivity Test Set Up

5.4.1 Hypotheses

Hypotheses were developed in accordance with the known thermal properties of the materials. Two hypotheses were predicted before beginning the experiments, which will either be supported of refuted by the heat transfer experimental results.

Hypothesis 1: Of cotton, wool, silk, nylon and polyester, silk will release the most heat and will be the most breathable fabric, whereas wool will retain most of the heat.

Hypothesis 2: Of X-Static and neoprene, X-Static will release most of the heat whereas neoprene will retain the most heat and will be the least breathable fabric.

5.4.2 Data Collection and Analysis

The data was collected by taking readings from each thermo-sensor for the 35 and 45 degree water baths. The difference in temperature was determined from thermo-sensors 1 and 2. The measurement of difference shows the ability or inability of the fabric to absorb and conduct heat. The data was recorded in the data table sample shown in Table 8. The averages were converted into a graphical representation.

Table 8 Heat Conductivity Sample Chart

Fabric	35^{o}C			45^{o}C		
	T_1	T_2	Difference	T_1	T_2	Difference
Polyester						
1						
2						
3						

5.5 Human Testing

The final material chosen was based on the previous experiments. This material was manufactured into a sock form, which is ideal for human use. The human testing provided verbal feedback about the comfort, thermal conductivity, and moisture absorption of the material. The subjects chosen were young athletic male students in the weight range of 170-200 pounds. Between five and ten subjects wore the socks and ran the length of the racetrack in a 5 minute period. After racing, the subjects were given a survey with questions regarding the product, considering each property (See **Appendix I: Human Trail Documents)**.

5.5.1 Hypothesis

Hypothesis: If the final material is tested on human subjects for comfort, the fabric will prevent irritation caused by moisture and excess heat.

5.5.2 Data Collection and Analysis

Data was collected in the form of a survey with questions regarding the satisfaction of the product (See **Appendix: I Human Trail Documents).**

6. Results

This chapter is divided into three main components; the preliminary material data, the X-Static comparison data, and X-Static performance data. Preliminary material testing involved wicking, heat conductivity and the sessile drop test on five material specimens to determine which material would be in the final compositional make up of the inner layering. Once the material was determined from the preliminary material testing, a material blend with X-Static fibers was purchased. Wicking, sessile drop, and heat conductivity testing were conducted on the X-Static fiber blend and neoprene, a material commonly used in racehorse equipment. Human test subjects were utilized to give verbal feedback on the X-Static material under performance conditions similar to that of the racehorse.

6.1 Preliminary Material Data

In order to obtain a material to blend with the X-Static fiber, initial experiments were conducted to investigate the moisture and heat conductivity properties of five material specimens (polyester, nylon, cotton, wool, and silk).

6.1.1 Preliminary Wicking Data

The results of the preliminary wicking experiment can be seen in Figure 15 and Table 9. The results were obtained by taking six samples of each of the five material specimens and submerging the sample 3cm into a 500 ml beaker filled with distilled water. Measurements were taken at one, five, and ten minute intervals. The data in numerical form can be viewed in **Appendix J: Preliminary Wicking Data.** The hypotheses stated for this experiment was that silk would have optimal wicking properties and wool would have poor wicking properties.

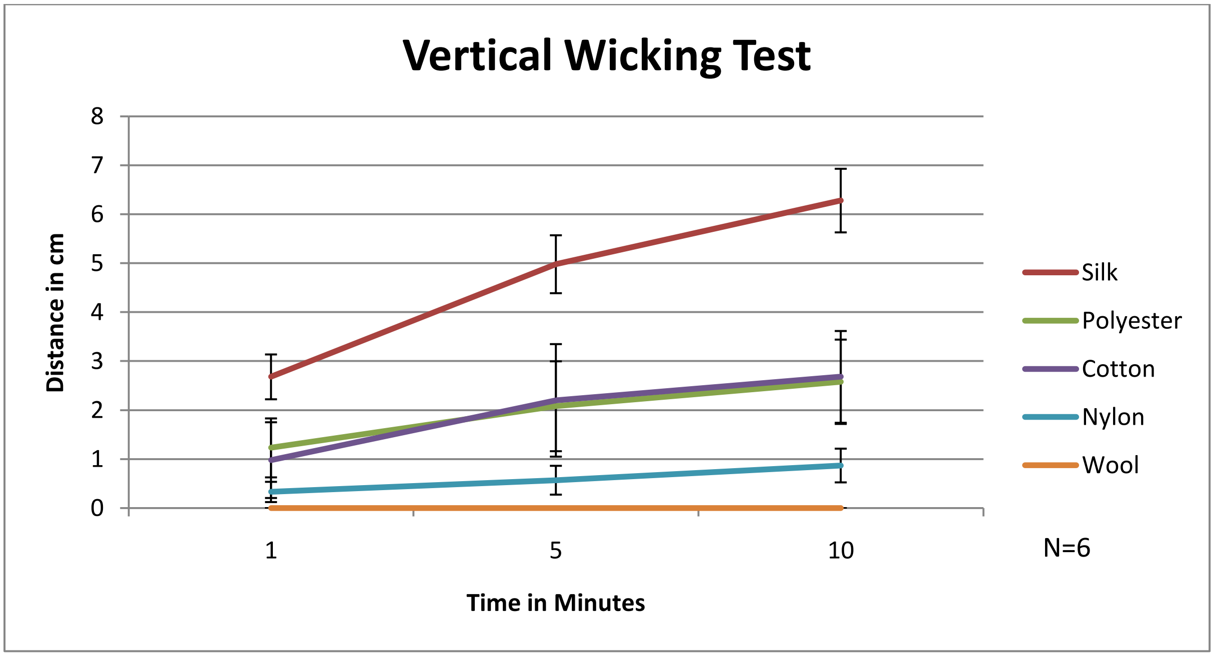

Figure 15 Preliminary Wicking Test

Table 9 Preliminary Wicking Data Average and Standard Deviation

MATERIAL	1 Minute	5 Minutes	10 Minutes
Silk	2.68±0.458 cm	4.98±0.591 cm	6.28±0.649 cm
Polyester	1.23 ± 0.602 cm	2.08+±0.917 cm	2.58±0.861 cm
Cotton	0.983±0.773 cm	2.20±1.15 cm	2.68±0.937 cm
Nylon	0.333±0.207 cm	0.567±0.294 cm	0.867±0.344 cm
Wool	0±0 cm	0±0 cm	0±0 cm

Figure 15 presents the wicking properties of the five material specimens over a period of 10 minutes. The x-axis represents the time period in which the wicking experiment was conducted (1, 5, and 10 minutes). The distance the water traveled up the material is represented by the y-axis in centimeters. The largest distance traveled by the water over the ten minute period was seen in the silk material at an average value of 6.28±0.649 cm shown in Table 9. Silk also showed the greatest increase in distance between each recorded time interval at approximately two centimeters per interval. Wool showed no increase in distance over the time period, which translates to having low wicking properties. The nylon material showed an almost linear trend over the ten minute period, wicking slightly above the wool. The average distance traveled at ten minutes by the water in the nylon material was 0.867±0.344 cm shown in Table 9. Cotton and polyester showed an average wicking capability falling between the high range of silk and the low range of wool. At ten minutes cotton and polyester had average distances of 2.68±0.937 cm and 2.58±0.861 cm shown in Table 9. Images of wool, silk, and polyester samples were taken after the wicking experiment and can be viewed in Figure 16.

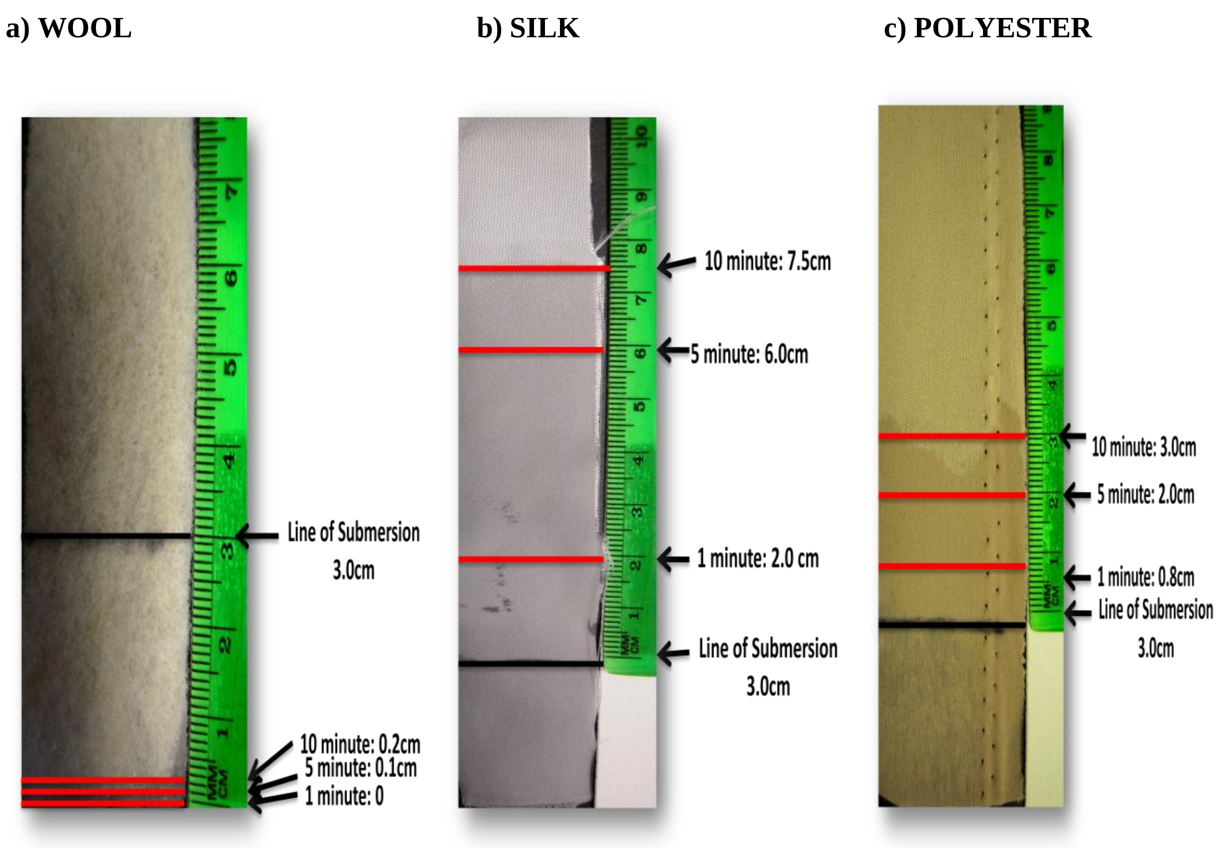

Figure 16 Minimum, Maximum, and Mean Wicking Data
a) Wool, b) Silk, c) Polyester samples post wicking experiment.

6.1.2 Sessile Water Drop Data

The results of the sessile water drop test can be seen in Figures 17-21. The results were obtained by dropping a 20 µl distilled water droplet on the material and taking photographs of the progression of this droplet every 10 seconds over a 70 second interval. This experiment was conducted twice: once with the material placed on a hot plate at 37.5 degrees Celsius, mimicking that of the normal physiological temperatures of the horse, and then on a circulating hot water bath at 70.0 degrees Celsius, which represented an extreme temperature value in order to induce a visible change in the shape of the water droplet. It was hypothesized that silk would absorb the most water (hydrophilic) and wool would absorb the least amount of water (hydrophobic).

Silk and cotton, displayed in Figures 17 and 21 showed angles of zero degrees upon the first second out of the pipette because the drop was instantly absorbed by the materials. This indicates that these materials were highly hydrophilic. Wool had the largest angle at 158 degrees when placed on the hot plate at 37.5 degrees Celsius and held constant for the seventy seconds, which indicated the material was highly hydrophobic. However, when exposed to the extreme temperature of 70.0 degrees Celsius, the angle decreased to 150 degrees, but still held constant for the seventy seconds which is seen in Figure 18. Nylon and polyester, seen in Figures 19 and 20 also showed a decrease in angle upon higher temperature exposure, but still exhibited hydrophobic qualities. Since Polyester and nylon fell in an average range with angles between 115 and 125 degrees, these materials can be considered to have a preference for hydrophobicity.

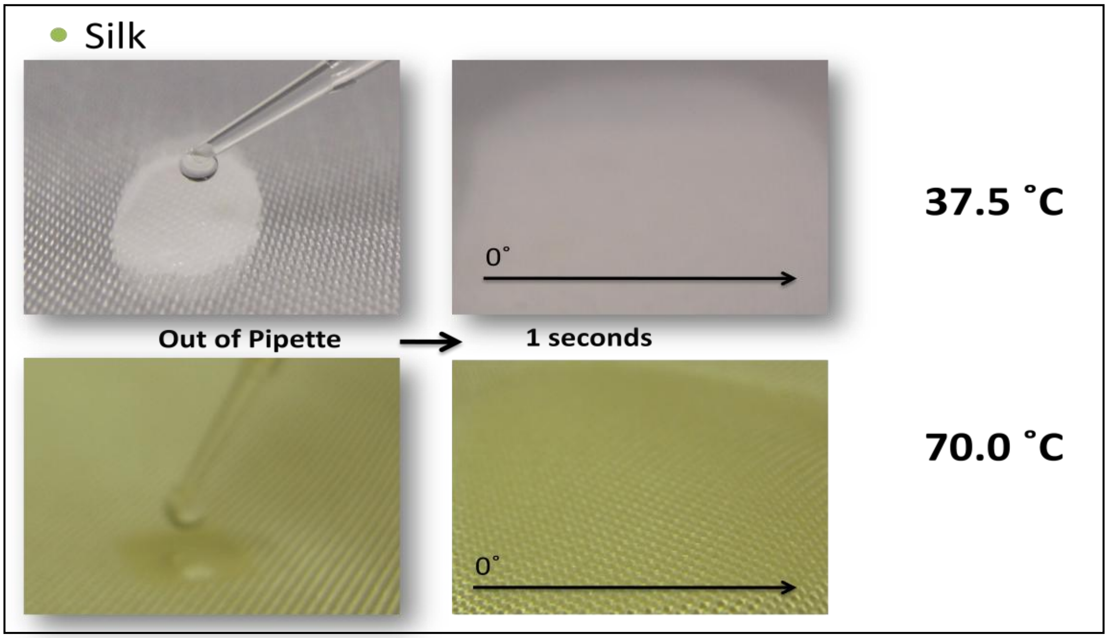

Figure 17 Silk Sessile Drop Data

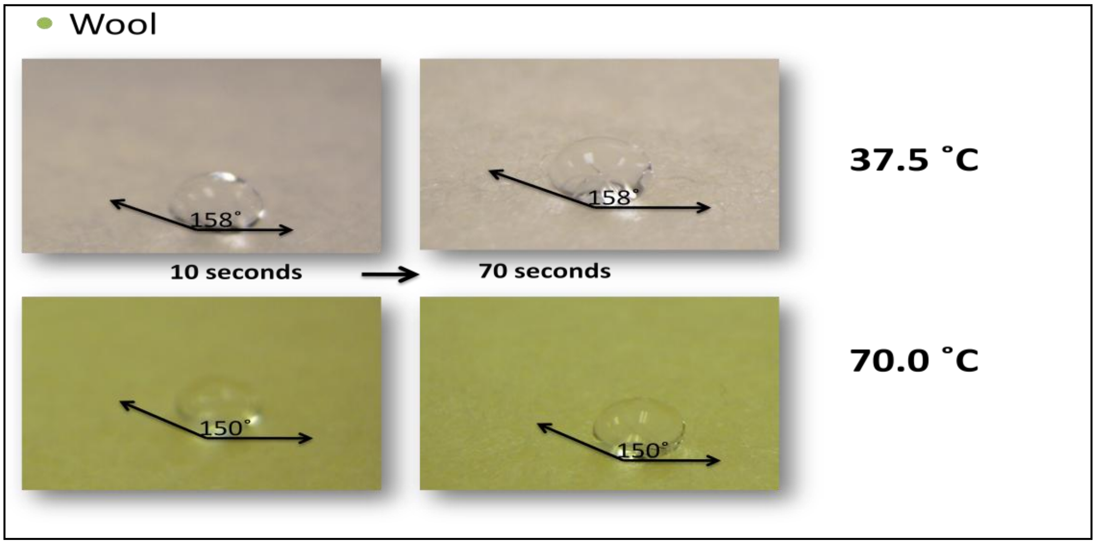

Figure 18 Wool Sessile Drop Data

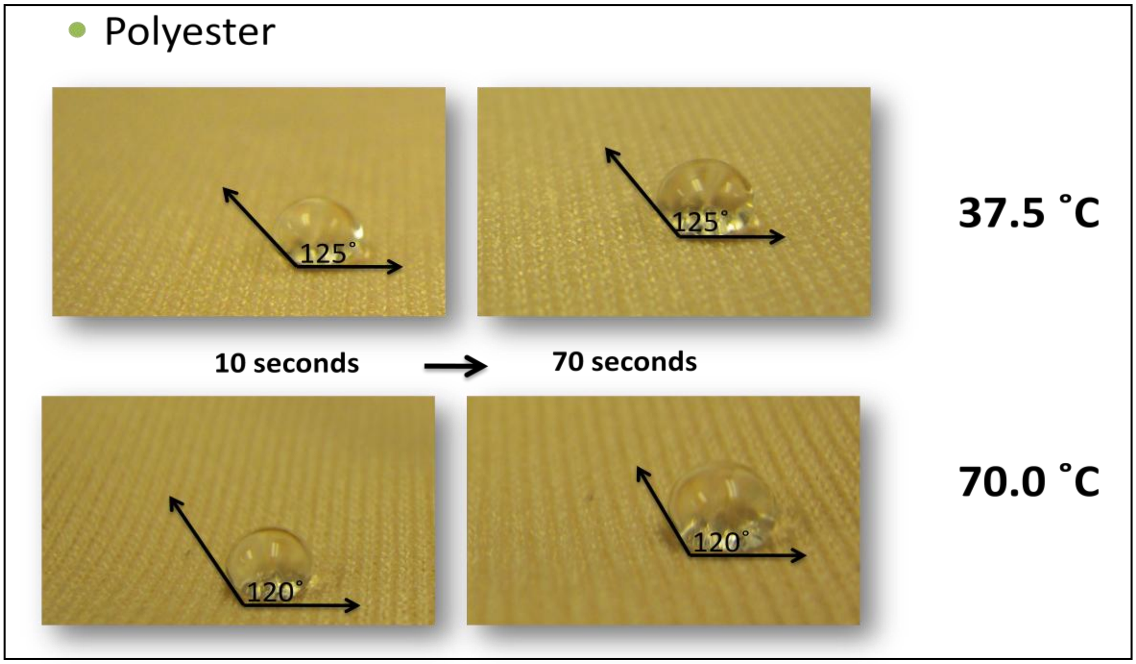

Figure 19 Polyester Sessile Drop Data

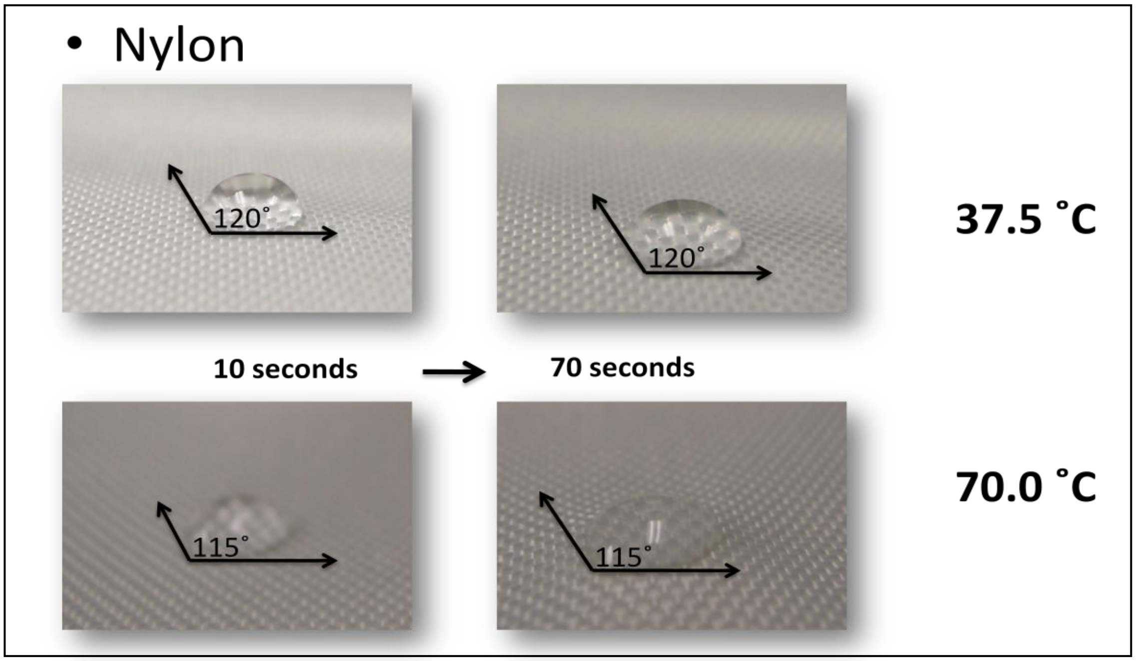

Figure 20 Nylon Sessile Drop Data

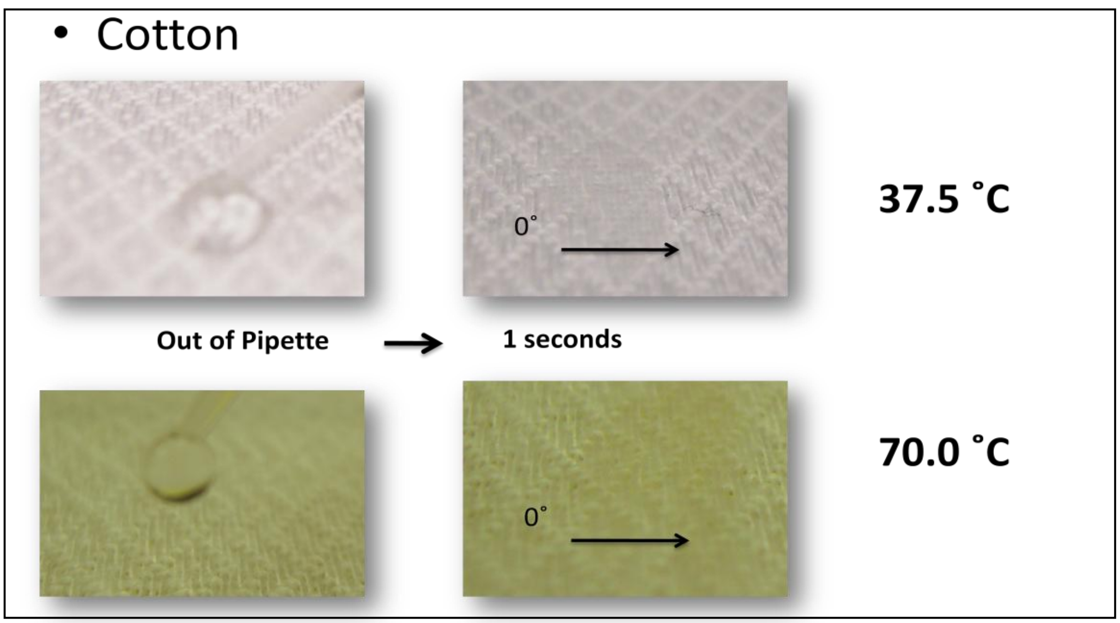

Figure 21 Cotton Sessile Drop Data

6.1.3 Preliminary Heat Conductivity Data

The results of the preliminary heat conductivity experiment can be seen in Figure 22 and Table 10. The results were obtained by taking three samples of each of the five material specimens and attaching three thermo-sensors. The sample was placed on a circulating hot water bath at temperatures 37.5 and 45 degrees Celsius, which correlate to normal and extreme temperatures of a racehorse. Measurements were taken on each of the sensors at one, three, and five minute intervals. The data in numerical form can be viewed in **Appendix L: Preliminary Heat Conductivity Data.** The hypothesis for the heat conductivity experiment stated that silk would have optimal heat transfer abilities, whereas wool would have the worst heat transfer abilities. The data resulted in the hypothesis being rejected, since polyester showed optimal heat transfer ability.

Figure 22 shows the heat conductivity data obtained for wool, silk, polyester, cotton, and nylon at 37.5^{o}C, meant to mimic the natural body temperature of a horse. The x-axis shows time in minutes (1, 3, and 5) and the y-axis shows the difference in temperature. Wool had the greatest difference in temperature, with a relatively large standard deviation of 6.73±0.907 ˚C at five minutes which can be seen in Table 10. Results for silk, cotton, and nylon fell between wool and polyester, while polyester showed the least difference in temperature of 2.63±0.153 ˚C at five minutes. The low difference in temperature concluded that polyester had optimal heat transfer abilities among the preliminary specimens. Table 10 shows the average temperature differences and standard deviations in Celsius of each material at the recorded time intervals. Polyester showed the overall smallest difference in temperature, averaging 2 to 3 ˚C. Wool showed the highest temperature difference, averaging 6 to 7 ˚C. Low temperature difference signifies a greater amount of heat transfer through the material, which results in a breathable material.

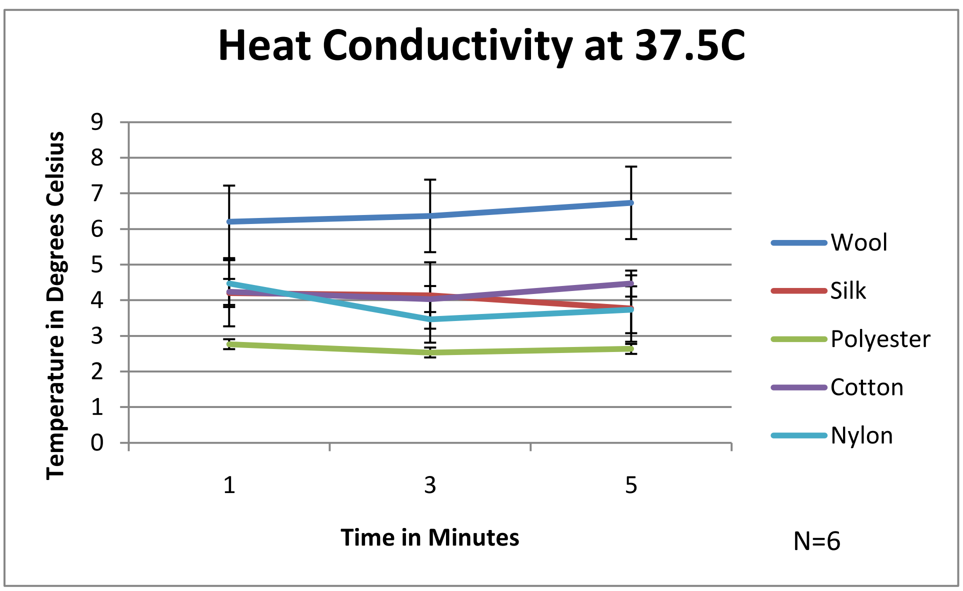

Figure 22 Preliminary Heat Conductivity at 37.5 C

Table 10 Preliminary 37.5 ˚C Heat Conductivity Averages and Standard Deviations

MATERIAL	1 Minute	3 Minutes	5 Minutes
Silk	4.20±1.13˚C	4.13±1.101˚C	3.77±0.569˚C
Polyester	2.77±0.0578˚C	2.53±0.208˚C	2.63±0.153˚C
Cotton	4.23±0.493˚C	4.03±0.252˚C	4.47±0.351˚C
Nylon	4.46±1.0017˚C	3.47±0.651˚C	3.73±0.321˚C
Wool	6.20±1.04˚C	6.37±1.11˚C	6.73±0.907˚C

Figure 23 shows the data obtained for wool, silk, polyester, cotton, and nylon at 45^{o}C, which served as an extreme body temperature value for a racehorse during a race. The x-axis shows time in minutes (1, 3, and 5) and the Y-axis shows the difference in temperature. The results of this experiment showed similar results to the experiment performed at 37.5 ˚C. Wool had the highest temperature difference, whereas polyester had the lowest temperature difference. Results for silk, cotton, and nylon again fell between that of wool and polyester. Nylon had a larger temperature difference at 45˚C (9.67±3.95 ˚C at five minutes) than at 37.5 ˚C (3.73±0.321 ˚C at five minutes). The experiment at 45˚Cconfirmed that polyester had favorable heat conductivity and that wool had minimal heat conductivity. Table 11 shows the average temperature differences and standard deviations in degrees Celsius of each material at the recorded time intervals. Although polyester averaged larger at 45˚C than at 37.5 ˚C with a slightly higher standard deviation, it still averaged the lowest temperature difference compared to all of the other preliminary materials tested. At 45˚C the temperature difference for polyester averaged between 4 and 5˚C. Wool had the highest temperature difference, averaging between 13 to 15˚C.

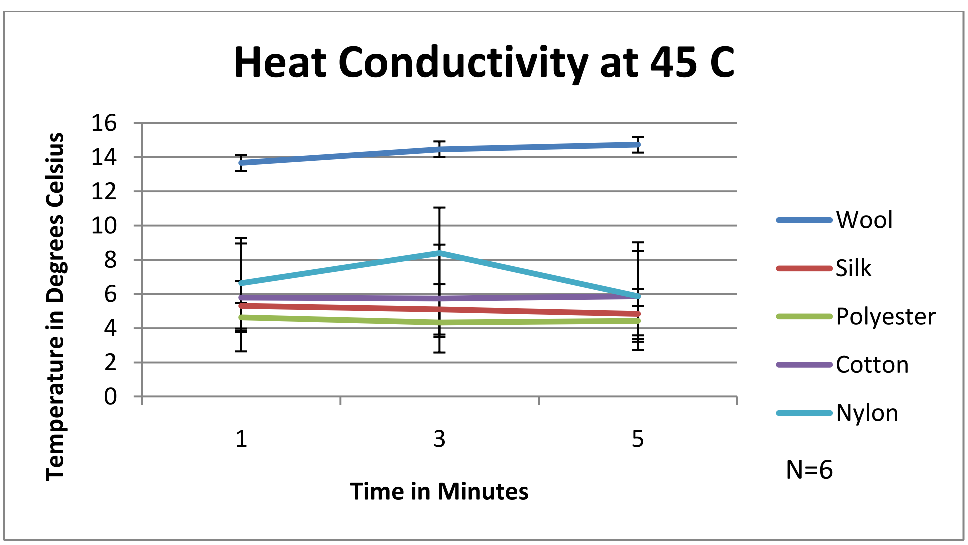

Figure 23 Preliminary Heat Conductivity Test at 45 C

Table 11 Preliminary 45 ˚C Heat Conductivity Averages and Standard Deviations

MATERIAL	1 Minute	3 Minutes	5 Minutes
Silk	5.3±0.794˚C	5.10±1.80˚C	4.83±0.777˚C
Polyester	4.63±1.67˚C	4.33±0.569˚C	4.43±0.321˚C
Cotton	5.80±3.00˚C	5.73±3.27˚C	5.87±3.19˚C
Nylon	6.63±2.12˚C	8.40±1.90˚C	9.67±3.95˚C
Wool	13.67±0.153˚C	14.5±0.451˚C	14.7±0.777˚C

6.1.4 Preliminary Data Conclusion

The conclusion obtained from testing the materials showed that the polyester specimen had the overall best performance. The inner layering should have wicking capabilities that allow the material to absorb moisture away from the limb without completely soaking the boot in the given racing period, approximately three minutes.(**Appendix P: Suffolk Down Communication)** Silk showed the fastest wicking properties, cotton and polyester fell in an average range, and nylon and wool fell below average. Polyester displayed the desired wicking effect, while wool and silk are shown as extreme values. The sessile drop test concluded that silk is highly hydrophilic, polyester displayed hydrophobic properties, and wool was highly hydrophobic. The results of the heat conductivity experiment rejected the original hypothesis because polyester, instead of silk, had optimal heat conductivity. With the results of the preliminary experiments, the polyester material was chosen as the optimal specimen, leading to the test of the polyester and X-Static blends.

6.2 X-Static Comparison Data

Following the preliminary results, which indicated that the polyester material would result in the most desirable characteristics for the inner layering, polyester was blended with the X-Static fibers in a material composite. This X-Static blend was used in the following experiments and compared with the material neoprene which is commonly used in racehorse equipment.

6.2.1 X-Static vs. Neoprene Wicking Data

The results of the X-Static and neoprene wicking experiment can be seen in Figures 24-25 and Tables 12-13. The results were obtained by taking six samples each of the X-Static and the neoprene materials and submerging the sample 3cm into a 250 ml beaker filled with distilled water. Measurements were taken at one, five, and ten minute intervals. It was hypothesized that X-Static would have better wicking properties then the neoprene in both an aqueous and saline solution. In Figure 24 the wicking experiment for X-Static and neoprene in an aqueous solution is shown. At ten minutes X-Static wicked water an average distance of 3.00±0.316 cm and neoprene of 0.167±0.258 cm which is shown in Table 12.

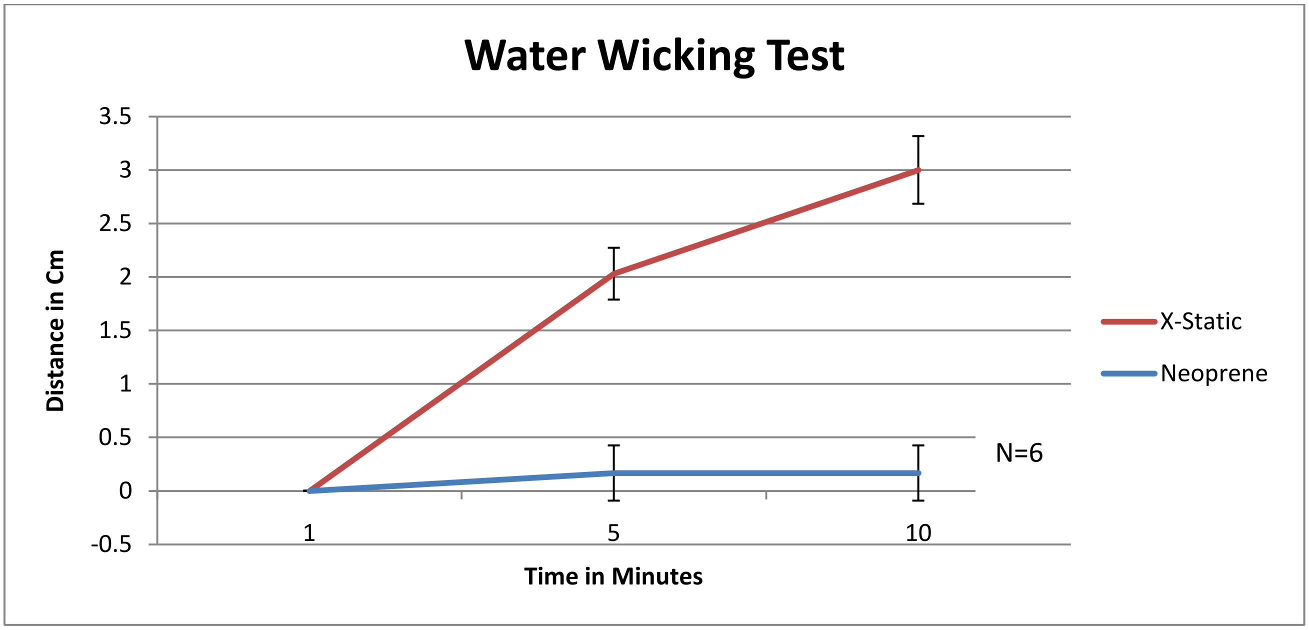

Figure 24 Aqueous Wicking Test

Table 12 Aqueous Wicking Data Average and Standard Deviation

MATERIAL	1 Minute	5 Minutes	10 Minutes
X-Static	0 ±0 cm	2.03±0.242 cm	3.00±0.316 cm
Neoprene	0±0 cm	0.167±0.258 cm	0.167±0.258 cm

A follow up wicking test was performed where the solution in the beaker was exchanged for a 0.9% saline solution. These results can be seen in Figure 25 and Table 13. In Figure 25 the wicking experiment for X-Static and neoprene in a saline solution is shown. At ten minutes X-Static had an average distance of 4.33 ±1.83 cm which had a larger standard deviation compared to the samples in the aqueous solution. At ten minutes, neoprene showed an average distance of 0 ±0 cm which held constant for all the recorded time intervals. Both averages for X-Static and neoprene can be viewed in Table 13. Overall X-Static still showed a larger increase in distance over the time period of ten minutes compared to the neoprene in both a water and saline solution. The data in numerical form can be viewed in **Appendix M: X-Static vs. Neoprene Wicking Data.**

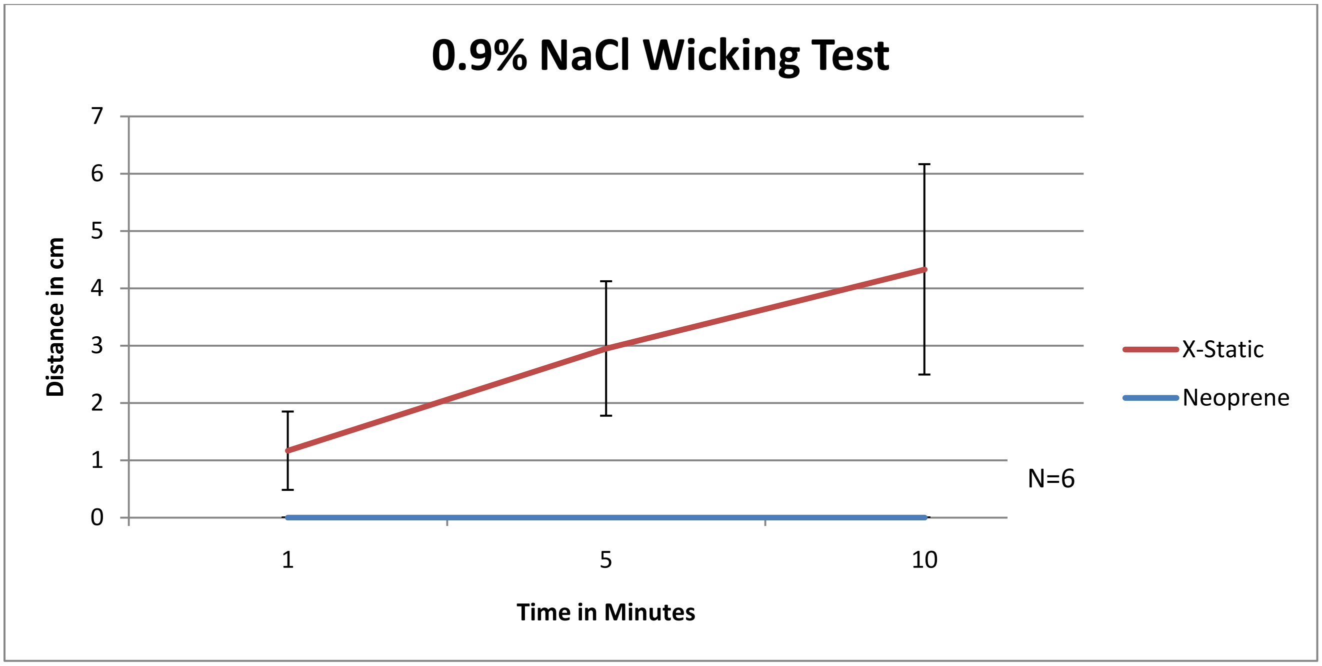

Figure 25 Saline Solution Wicking Test

Table 13 Saline Solution Wicking Data Average and Standard Deviation

MATERIAL	1 Minute	5 Minutes	10 Minutes
X-Static	1.17±0.683 cm	2.95 ±1.17 cm	4.33 ±1.83 cm
Neoprene	0 ±0 cm	0 ±0 cm	0 ±0 cm

6.2.2 X-Static vs. Neoprene Sessile Drop Data

The results of the sessile water drop test can be seen in Figures 26-27. The results were obtained by taking photographs of the X-Static and neoprene specimens beginning upon dropping a 20 μL droplet on the material and thereafter at ten second intervals for seventy seconds. This experiment was conducted twice: once with the material placed on a hot plate at 37.5 degrees Celsius, mimicking that of the normal physiological temperatures of the horse, and then on a circulating hot water bath at 70.0 degrees Celsius, which represented an extreme temperature value. The complete seventy second session for each of the materials can be viewed in **Appendix K: Sessile Drop Results.** It was hypothesized that X-Static would depict intermediate hydrophobic/hydrophilic qualities, and neoprene would absorb the least amount of water (hydrophobic).

X-Static displayed in Figure 26 showed angles of 120 degrees upon the first second out of the pipette indicating that these materials were slightly more hydrophobic then predicted. Upon increasing the temperature to 70.0 degrees Celsius no change was observed. Neoprene had an angle 135 degrees when placed on the hot plate at 37.5 degrees Celsius and held constant for the seventy seconds, which indicated the material was hydrophobic. However, when exposed to the extreme temperature of 70.0 degrees Celsius, the angle decreased significantly to 45 degrees, indicating increased wettability in Figure 27.

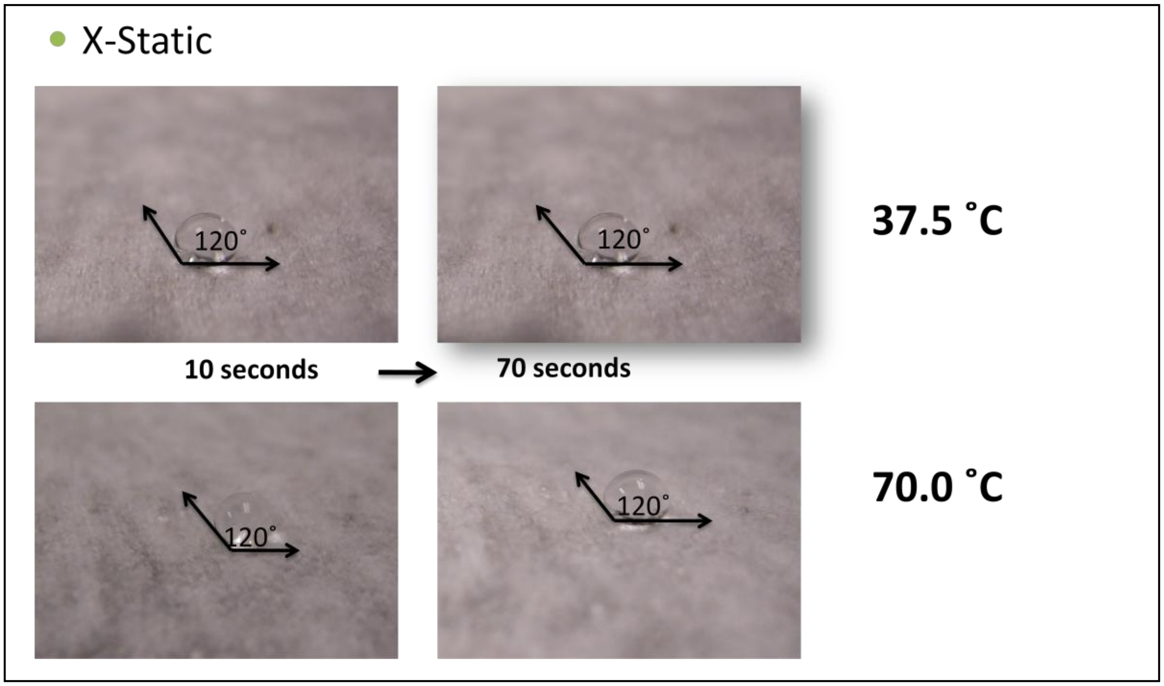

Figure 26 X-Static Sessile Drop Data

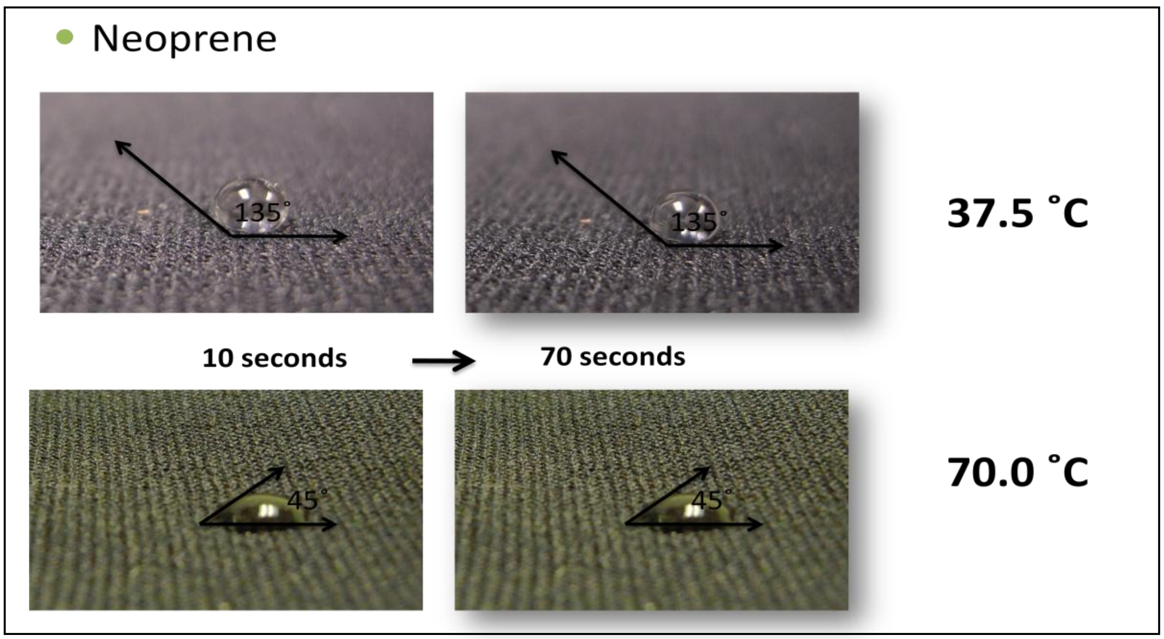

Figure 27 Neoprene Sessile Drop Data

6.2.3 X-Static vs. Neoprene Heat Conductivity Data

The results of the X-Static and neoprene heat conductivity experiment can be seen in Figure 28 and Table 14. The results were obtained by taking three samples of each of the two materials and attaching three thermo-sensors. The sample was placed on a circulating hot water bath at temperatures

37.5 and 45 degrees Celsius which correlate to normal and extreme temperatures of a racehorse. Measurements were taken on each of the sensors at one, three, and five minute intervals.

Figure 28 shows the comparison of the X-Static to the neoprene material during the heat conductivity test at 37.5°C, mimicking normal body temperature of the horse. As previously described, the x-axis shows time in minutes (1, 3, and 5) and the Y-axis shows the difference in temperature. The results of the experiment support the original hypothesis that the X-static polyester blend material will have greater heat transfer in comparison to the neoprene material. As shown in the graph, the X-Static data, marked by the blue line, has a much lower temperature difference and standard deviation than the neoprene, marked by the red line. The low difference in temperature shows greater heat conductivity for the X-Static polyester blend than the neoprene. Table 14 shows the average values of the temperature difference and standard deviations for each material. As shown below, the X-Static averaged a temperature difference of 1-2°C, with a low standard deviation of 0.019. The neoprene averaged a temperature difference of 3-4 °C, with a higher standard deviation around 0.272. In comparison to the results of polyester alone, the X-Static fiber had a decreased temperature difference.

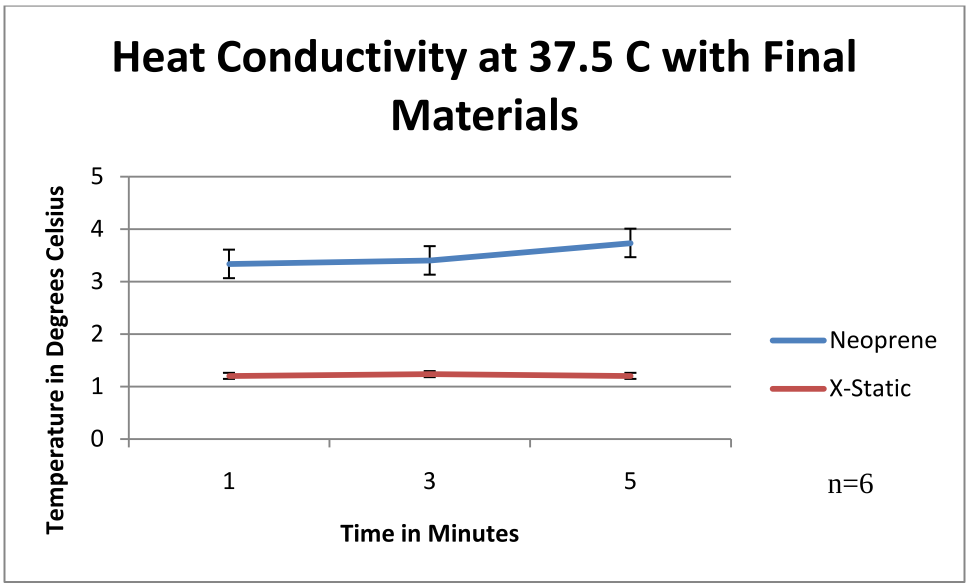

Figure 28 X-Static Heat Conductivity Test at 37.5 C

Table 14 Averages and Standard Deviations: X-Static and Neoprene at 37.5 C

MATERIAL	1 Minute	3 Minutes	5 Minutes
X-Static	1.2±0˚C	1.23±0.058˚C	1.2±0˚C
Neoprene	3.33±0.058˚C	3.4±0.265˚C	3.73±0.493˚C

Figure 29 shows the data obtained for the X-Static polyester blend and neoprene at 45˚C, which served as an extreme body temperature of a racehorse during a race. The x-axis shows time in minutes (1, 3, and 5) and the Y-axis shows the difference in temperature. The results of this experiment showed similar results to the experiment performed at 37.5 ˚C. The graph shows neoprene with the highest temperature difference and X-Static with the lowest temperature difference. The test at 45˚C confirmed that X-Static has greater heat conductivity and that neoprene has minimal heat conductivity. Table 15 shows the average temperature differences and standard deviation in degrees Celsius of each material at the recorded time intervals. Although the temperature difference of X-Static averaged larger at 45˚C than at 37.5 ˚C with a slightly higher standard deviation of 0.812, it still averaged lower temperature differences compared to neoprene. At 45˚C the temperature difference for X-Static averaged 2 ˚C. Neoprene averaged a temperature difference between 3 and 4˚C, with a standard deviation of 0.643.

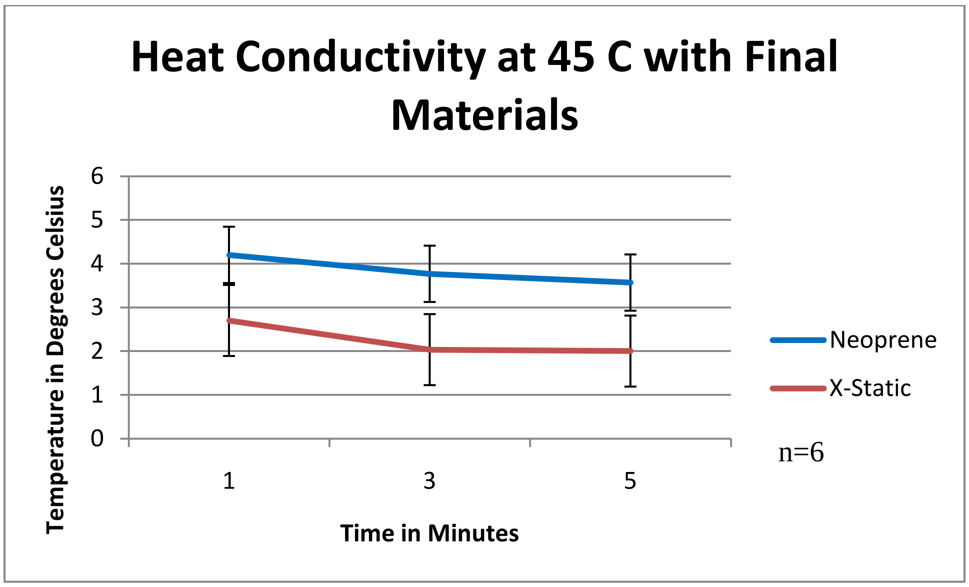

Figure 29 X-Static vs. Neoprene Heat Conductivity test at 45 C

Table 15 Averages and Standard Deviations: X-Static and Neoprene at 45 C

MATERIAL	1 Minute	3 Minutes	5 Minutes
X-Static	2.7±0.3˚C	2.03±0.907˚C	2.0±1.23˚C
Neoprene	4.2±0.1˚C	3.77±0.901˚C	3.57±0.929˚C

A follow up heat conductivity test was performed in which the thickness of the X-Static material was increased to 3mm to match the thickness of neoprene. These results can be seen in Figure 30 and Table 16. The data in numerical form can be viewed in **Appendix N: X-Static vs. Neoprene Heat Conductivity Data.**

Figure 30 shows the heat conductivity data obtained for the X-Static polyester blend and neoprene at 37.5˚C, with a thickened sample of X-Static. The results of the X-Static were compared to the original Neoprene results. The x-axis shows time in minutes (1, 3, and 5) and the Y-axis shows the difference in temperature. The thickened X-Static temperature difference increased compared to the single layered X-Static. It was predicted that the X-Static blend would perform well in heat transfer, but increasing the thickness proved to lower the heat transfer abilities. The graph shows neoprene with the lower temperature difference in red and X-Static with a slightly higher temperature differences compared to neoprene in blue.

Table 16 shows the average temperature differences in degrees Celsius, as well as their standard deviations, for each material at each time period. The temperature difference of X-Static was larger with the thicker sample. It averaged a greater difference than the neoprene with a slightly higher standard deviation. The average difference for X-Static is between 3 and 4 ˚C, compared to the average difference of neoprene which is also between 3 and 4 ˚C. Although the X-static results were much higher and closer to Neoprene when thickened, the final material will mimic the thinner layering of X-Static.

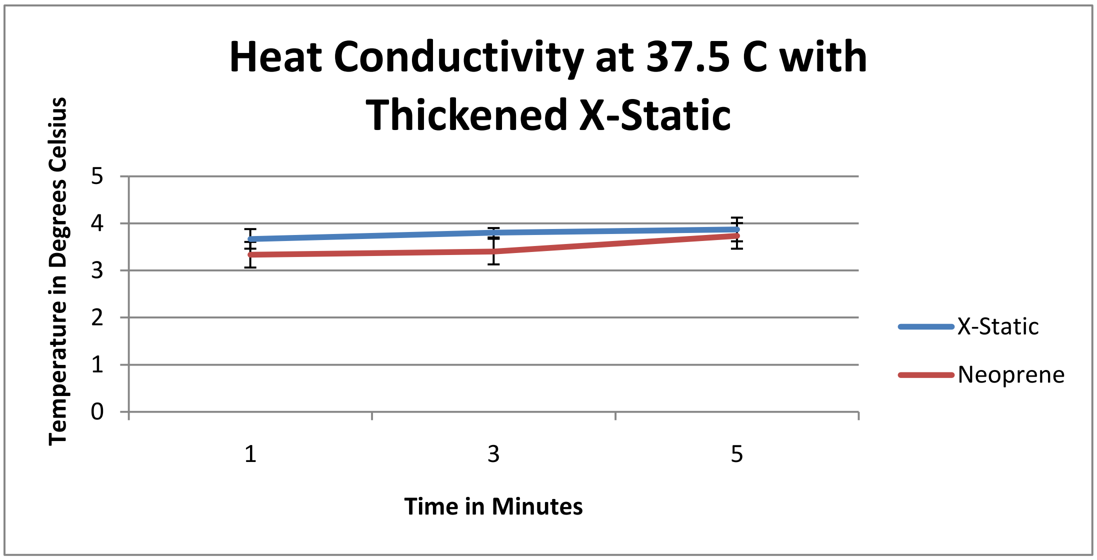

Figure 30 Thickened X-Static Heat Conductivity Test at 37.5 C

Table 16 Averages and Standard Deviation: Thickened X-Static and Original Neoprene at 37.5 C

MATERIAL	1 Minute	3 Minutes	5 Minutes
X-Static	3.67±0.208˚C	3.8±0.1˚C	3.87±0.251˚C
Neoprene	3.33±0.058˚C	3.4±0.265˚C	3.73±0.493˚C

Figure 31 shows the heat conductivity data obtained for the X-Static polyester blend and neoprene at 45^{o}C, with a thickened sample of X-Static. The results of the X-Static were compared to the original Neoprene results at 45^{o}C. The x-axis shows time in minutes (1, 3, and 5) and the Y-axis shows the difference in temperature. The results of this experiment again showed some variation from the original heat conductivity test. It was predicted that the X-Static blend would perform optimally in heat transfer again, but its new thickness proved to lower the heat transfer abilities.

Table 17 shows the average temperature differences and standard deviation in degrees Celsius of each material at the recorded time intervals. The average temperature difference of X-Static was similar to neoprene after the thickening. X-Static averaged a difference between 3 and 4˚C and the Neoprene averaged a difference between 3 and 4 ^{o}C.

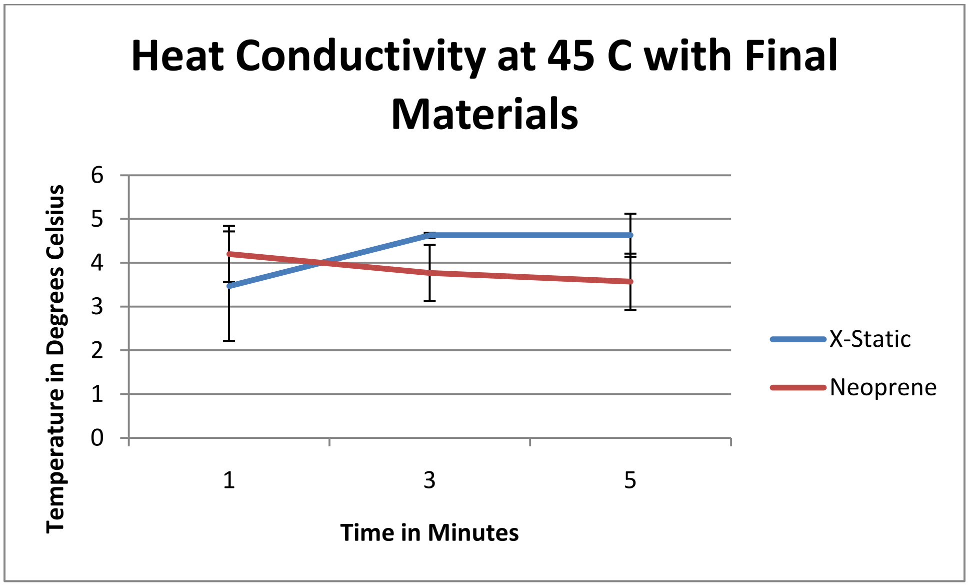

Figure 31 Thickened X-Static Conductivity Test at 45 C

Table 17 Averages and Standard Deviation: Thickened X-Static and Original Neoprene at 45 C

MATERIAL	1 Minute	3 Minutes	5 Minutes
X-Static	3.467±1.25˚C	4.63±0.058˚C	4.63±0.493˚C
Neoprene	4.2±0.1˚C	3.77±0.901˚C	3.57±0.929˚C

6.3 X-Static Performance Data

X-Static showed desirable characteristics for the inner layering compared to the neoprene material which is commonly used in race horse equipment. Therefore, human trial testing was conducted to provide verbal feedback on the X-Static's performance. Two different experimental groups were utilized for this study.

The first group consisted of five participants who placed the X-Static sock on their right leg and had a cotton control sock on the left leg. Once this was done both legs were wrapped with an ace bandage which represented an outer layering and can be seen in Figure32. Participants were asked to run one mile or twenty laps on the Worcester Polytechnic Institute indoor Alumni Gymnasium track. A survey which can be seen in **Appendix I: Human Trial Documents** was started before and completed after running. The results for the first experimental group can be viewed in Figure33 and Table 18. Participants were asked questions pertaining to moisture and heat production, as well as the comfort of the X-Static sock. These performance qualities were ranked on a scale of 1 to 5; 1 being no discomfort, moisture production, or heat production and 5 being the highest level of discomfort, moisture production, or heat production. Participants ranked an average of 1±0 for heat production before running. This increased to 2.2 ±1.10 after completing the one mile. On the comfort scale participants ranked an average of 1.6 ±0.894 after completing one mile. Moisture production after completion was ranked an average of 2.00 ±0.707.

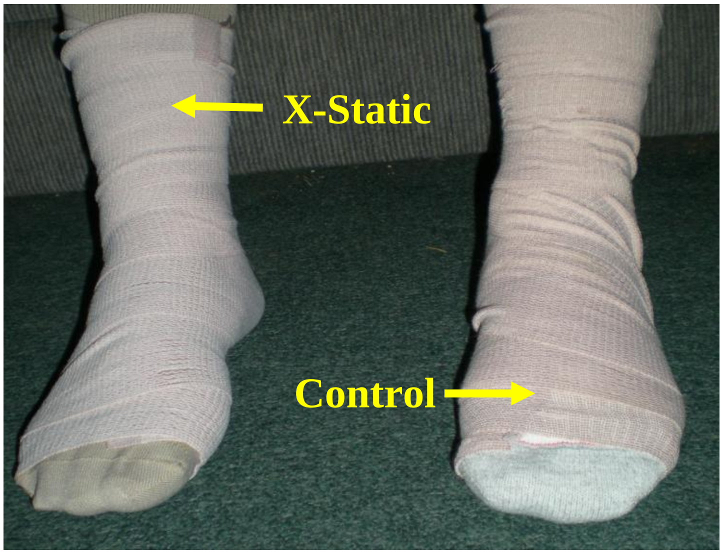

Figure 32 X-Static with Ace Bandage Wrap

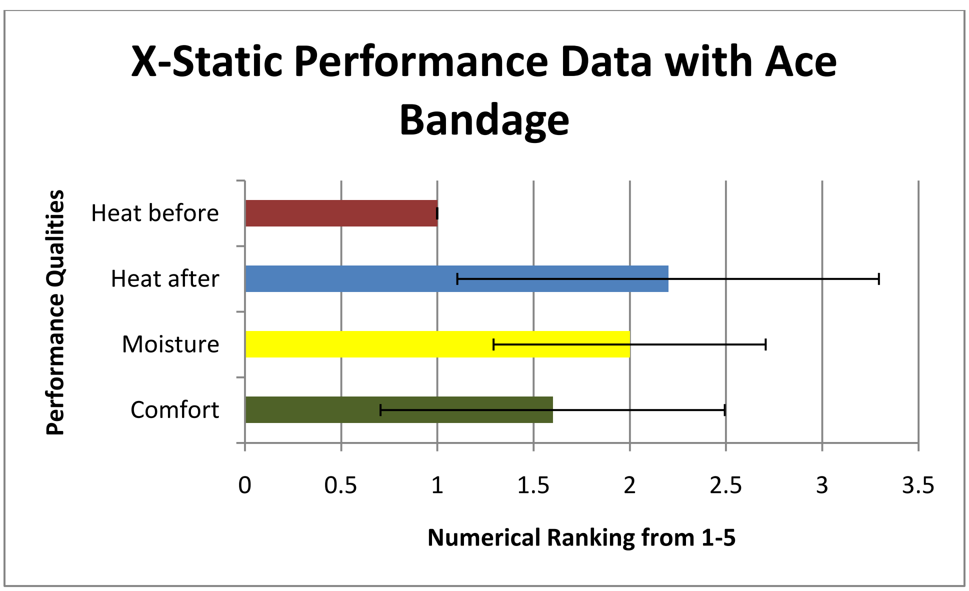

Figure 33 X-Static Performance Test with Ace Bandage

Table 18 X-Static Performance Data with Ace Bandage

Participant	Comfort	Moisture	Heat before	Heat after
A	1	2	1	4
B	3	2	1	2
C	1	2	1	1
D	2	3	1	2
E	1	1	1	2
Average	1.6	2	1	2.2
Standard Deviation	0.894	0.707	0	1.10

The second group consisted of five participants who placed the X-Static sock on their right leg and had a cotton control sock on the left leg with no ace bandage wrap; this can be viewed in Figure 34. Participants were asked to run one mile or twenty laps on the Worcester Polytechnic Institute indoor Alumni Gymnasium track. A survey which can be seen in **Appendix I: Human Trial Documents** was started before and completed after running. The results for the second experimental group can be viewed in Figure 35 and Table 19. Participants were asked questions pertaining to moisture and heat production, as well as the comfort of the X-Static sock. These performance qualities were ranked on a scale of 1 to 5; 1 being no discomfort, moisture production, or heat production and 5 being the highest level of discomfort, moisture production, or heat production. Participants ranked an average of 1±0 for heat production before running. This increased to 1.8 ±1.10 after completing one mile. On the comfort scale, participants ranked an average of 1.7 ±0.837 after completing one mile. Moisture production after completion was ranked an average of 2.2 ±0.447.

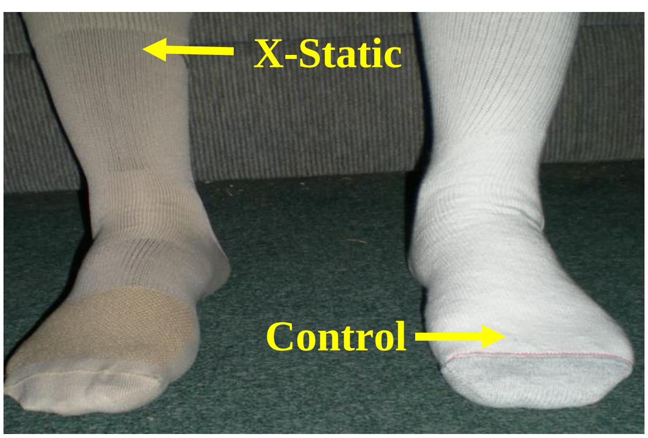

Figure 34 X-Static Without Ace Bandage

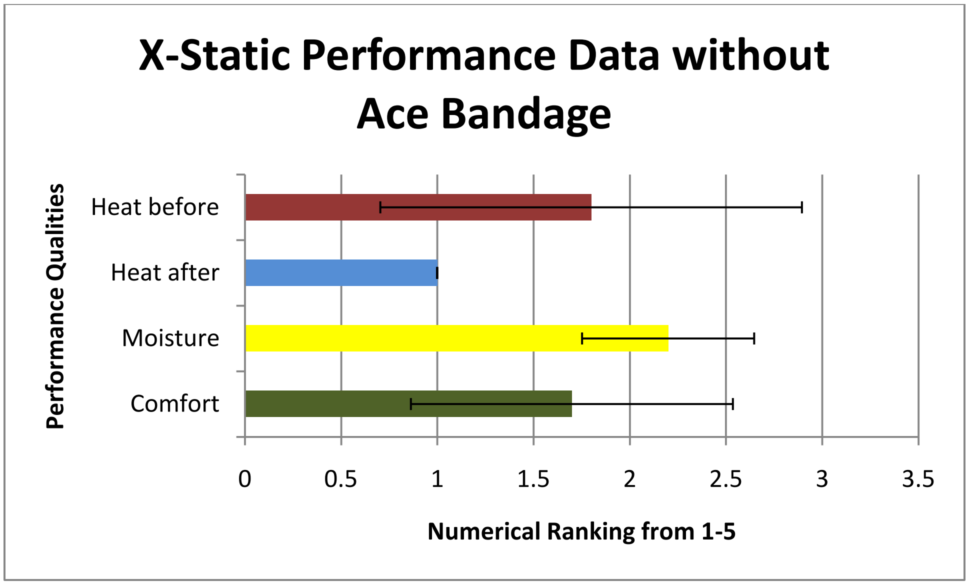

Figure 35 X-Static Performance Data without Ace Bandage

Table 19 Static Performance Data without Ace Bandage

Participant	Comfort	Moisture	Heat before	Heat after
F	1.5	2	1	3
G	1	2	1	1
H	1	3	1	1
I	2	2	1	1
J	3	2	1	3
Average	1.7	2.2	1	1.8
Standard Deviation	0.837	0.447	0	1.10

7. Discussion

7.1 Preliminary Material Data

The preliminary material testing involved analyzing common fabric materials that could be used for the inner lining of the boot. The preliminary materials tested include wool, cotton, polyester, nylon, and silk. These materials were chosen to gauge the desired properties, such as moisture absorption, hydrophobic/hydrophilic properties, and heat conductivity. From the results of the preliminary experiments, the final materials were chosen in order to create a blend that was purchased.

7.1.1 Preliminary Wicking Data

Before the Wicking test was performed on each sample, it was predicted that silk would have optimal wicking properties whereas wool would wick the least. The results supported the hypotheses, as shown in Figure 15, because the water reached the highest level on the strip of silk fabric. Polyester and cotton wicked at a moderated rate, not soaking the entire material in the given ten minute period. Nylon ranked low with respect to wicking properties of the other materials while wool had the lowest results. Wool and silk represented extreme wicking values, the wool absorbed the least moisture while silk absorbed the most moisture.

Although the silk absorbed the most moisture in the allotted ten minute interval, the desired wicking ability for the inner lining material should fall at a more moderate range as to not soak the entire material in the given racing time period. The reason for requiring a moderately wicking fabric is because during a race that lasts three minutes, it would be detrimental for the fabric to be completely saturated in the midst of competition. If the inner lining became saturated with moisture, it would cause irritation to the lower limb, distracting the horse from the race or hindering performance. If the lining became soaked while racing, the entire boot could slip down to the hoof causing a potentially dangerous situation where the horse could trip and fall while galloping at high speeds.

Affecting the performance of the horse must be avoided by the safety boot, therefore a material is needed that can both wick moisture and distribute it moderately throughout the fabric. Polyester showed desirable results due to its moderate wicking capabilities in which moisture would be absorbed, but not soak the material in a three minute time period. Figure 16 compares wool, silk, and polyester as an example of the extremes and the desired outcome. Polyester was able to absorb the water up to 3 inches in the allotted 10 minutes. Although the polyester performed well in the wicking test, further material testing was necessary to determine which fabric would be chosen for the inner lining.

7.1.2 Preliminary Sessile Water Drop Data

The sessile water drop test was performed on the five preliminary materials in order to test their hydrophobic/hydrophilic properties. Measuring the angle of a water droplet showed whether the fabric was hydrophobic or hydrophilic. A small angle signifies hydrophilic properties, because the fabric absorbs the droplet. A larger angle represents a hydrophobic material, because the droplet is resting intact upon the fabric. An angle close to 90˚ represents a material that displays intermediate hydrophobic/hydrophilic properties. A material with both hydrophobic and hydrophilic properties is necessary for the inner lining of the boot because it must be able to absorb and disperse water throughout the material at a moderate rate.

The test was performed at both 37.5^{o}C and 70.0^{o}C to mimic the normal body temperature of a horse and then an extreme temperature. An extreme temperature was used to determine if excess heat could affect the properties of the fabrics. Images were taken every 10 seconds for 70 seconds in total, and Figures 17-21shows the results at 10 seconds and 70 seconds. The hypothesis of the experiment was that silk would be the most hydrophilic material while wool would be the most hydrophobic material. The results of the experiment support the hypothesis. Both silk and cotton were determined to be hydrophilic because upon releasing the droplet, the angle produced was 0^{o}. Such a result is unfavorable because it shows an inability to distribute water throughout the fabric at a moderate rate. Wool proved to be the most hydrophobic material, which is also an unfavorable quality because it shows an inability to absorb moisture from the leg of the horse. Polyester and nylon resulted in at 125^{0} and 120^{0} angles respectively, which indicate these materials exhibit both intermediate properties that allow water to be absorbed at a moderate rate. At the 70^{o}C temperature, both nylon and polyester's angles where decreased by 5˚. Both materials had a slightly reduced angle, meaning there was more water absorption at the higher temperature. However, since it was a minimal decrease in angle for such a high increase in temperature, it can be concluded that the polyester and nylon materials will maintain their properties when exposed to higher temperatures during a race.

Although the sessile water drop test involves some estimation, it provides adequate information about the hydrophobic and hydrophilic properties of each material in conjunction with the wicking results. There may have been some experimental error when taking the photos, since this was done by hand, but the angle for each droplet was seen clearly. It was impossible to create a perfectly straight line to form the angle, and a computerized program that can approximate angles could be useful for future experimentation. Pairing results of sessile drop test with the moisture wicking test provided quantitative results that supported the conclusion that polyester has desirable hydrophobic/ hydrophilic and moisture wicking properties.

7.1.3 Preliminary Heat Conductivity Data

In order to determine how the preliminary fabrics could handle the heat on a horse's leg during a race, a heat conductivity test was performed. The test set up involved three thermo-sensors recording the passage of heat through the material while ensuring that atmospheric temperature was kept at a constant (room temperature). Readings were taken at the material's surface facing the heat source and the opposite side of the material facing the ambient environment. The heat was recorded periodically through a five minute interval. The two thermo-sensors were compared and the difference was taken for each sample. A small heat difference signifies a greater passage of heat through the fabric, reaching towards equilibrium. The test was performed at 37.5^{o}C, which is the normal temperature of a horse, and at 45^{o}C, which represents an extreme temperature that exceeds the maximum temperature achieved by a racing horse.

The hypothesis for the heat conductivity experiment was that silk would have the smallest heat difference while wool would have the largest. Previous research on silk led to the hypothesis that it would conduct heat most efficiently. However, testing showed that it produced moderate heat conductivity results at both temperatures. Wool was expected to retain heat, since it is an insulating fabric, typically worn in cold climates. The hypothesis regarding wool was supported by the results of the experiments, since it had the greatest difference in temperatures. Results of the experiment, shown in Figures 22-23 and Tables 10-11showed that polyester had the best heat conductivity. It consistently had the smallest difference in temperatures, showing that it was conducting heat most efficiently from one side of the fabric to the other.

Although the heat conductivity produced clear results, there were some extraneous factors that could not be controlled for. The environment where the heat conductivity test was performed was not closed off from the external environment, meaning that a gust of air from a vent or a person walking by could affect the heat flow. Although barriers were placed around the immediate testing area, one side was left open in order to access the materials, thermo-sensors, and heating pad. A completely closed environment would be optimal to conduct the heating test because it would control outside factors affecting air flow. However, due to limitations in equipment, these factors could not be eliminated. Despite any possible interference, it was clear based upon the results that polyester was able to conduct heat most favorably.

Based on the wicking, sessile drop, and heat conductivity tests, polyester was chosen as a component of the final material for further testing and comparison to neoprene used in boots on the market. Polyester's ability to wick at a moderate rate will decrease irritation and moisture accumulation during racing. Having both hydrophobic and hydrophilic properties allow for water to be able to be repelled and absorbed. The ability to conduct heat in a 5 minute period is essential during racing. The horse's leg can overheat quickly, causing discomfort. Polyester's ability to conduct heat away from the leg is a beneficial quality for the inner lining of the safety boot. Further testing will need to be conducted to compare the polyester/X-Static blend with the commonly used material, neoprene.

7.2 X-Static Comparison Data

The X-Static material comparison results indicated that X-Static would be a more desirable material for the inner lining of this novel equine safety boot instead of the commonly used neoprene material. The wicking, sessile, and heat conductivity tests performed on both the X-Static and neoprene allowed a comparison study to be formulated in which the novel X-Static material and the commercially utilized neoprene were analyzed.

7.2.1 X-Static vs. Neoprene Wicking Data

The X-Static and neoprene were subjected to wicking tests in both distilled water and saline solutions. In the distilled water solution both materials behaved as expected; the X-Static wicked the water at a moderate rate and the neoprene did not wick past the submersion line within the given ten minute time period. However, there were slight variations in the data. At one minute, the X-Static had a level of zero wicking. This was unexpected since the X-Static material was composed of polyester and it was assumed the X-Static would behave in a similar manner to that of the polyester. At one minute, polyester showed an average wicking distance of 1.23 ± 0.602 cm. This discrepancy could be accounted for by the fact that the X-Static had a light grey with dark grey coloring, making the water on the material difficult to detect. Also, it appeared that the X-Static was drying even though it was still submerged in the water. Once the X-Static material became wet its shape began to curl which could pose a problem if the material served as the only layer of the boot. However, since there will be an outer layering as well as the inner lining, the outer will be the more structurally sound layer and will provide structure to the X-Static even when wet.

The saline solution mimicked the composition of the horse's sweat during a race since it contained 0.9% NaCl. This test was performed in order to subject the material to the conditions of racing. In order to better visualize the distance traveled of the solution along the X-Static material, a blue highlighter was used to mark the line of submersion on three of the six samples. As the water travelled up the material, the blue highlighter bled with the solution allowing the distance travelled to be more clearly defined. Three samples were not marked with the highlighter, this could account for the higher standard deviations at each recorded interval (1 minute: 1.17±0.683 cm, 5 minutes: 2.95 ±1.17 cm, 10 minutes: 4.33 ±1.83 cm), however this was a minor error and therefore the test was not repeated with all samples marked. Since the inner lining of this equine safety boot will need to remove sweat produced on the leg, the results of the neoprene tests show that it is an ineffective material. The X-Static removed the moisture at a moderate rate and allowed for the material to dry which is depicted in the wicking test results.

7.2.2 X-Static vs. Sessile Drop Data

As stated previously, the sessile drop test provides an estimation that can be used to verify the quantitative data of the wicking test. A large angle depicts a hydrophobic material whereas a small angle shows a hydrophilic material. It was hypothesized that the X-Static would have an angle close to 90.0˚ which would indicate that material had intermediate properties. The test was performed on the chosen temperature values of 37.5˚C and 70.0˚C which represented that of a normal horse's physiological limits and an extreme value, respectively. X-Static showed results similar to what was predicted, holding a constant angle of 120˚ for both temperature values. Since the angle did not decrease in the high temperature value, this indicates that X-Static has heat conductivity values that allow the heat to dissipate through the material. This is important because if the moisture remained under the fabric, the hydrophobic/hydrophilic properties would be affected. Therefore the hypothesis for X-Static was confirmed by the results of the sessile drop test.

It was hypothesized that neoprene would express a high angle and have highly hydrophobic properties. At 37.5 ˚C the angle was 135˚ and at 70.0 ˚C the angle was 45˚. This drastic decrease could be due to the fact that neoprene consists of a foam layer which, when applied to the heating source, caused the fabric to burn. Due to the lack of neoprene material, the test was run with the burnt fabric which skewed the results. Therefore, the neoprene hypothesis was rejected and further tests should be run to either confirm or disprove the results obtained for this test.

7.2.3 X-Static vs. Neoprene Heat Conductivity Data

Heat conductivity testing was performed in order to determine how the X-Static would react to heat on a horse's leg during a race, compared to that of the commonly used neoprene. It was hypothesized that the X-Static would have smaller heat conductivity than that of the neoprene. For both the 37.5˚C and the 45 ˚C temperatures the materials acted as predicted, shown by the average heat conductivity values at five minutes. The X-Static had a 1.2±0˚C difference and the neoprene a 3.73±0.493˚C difference.

To determine whether the thickness of the neoprene caused the larger heat conductivity difference, the thickness of X-Static was matched at 3mm and the tests were repeated. The X-Static showed larger values than that of the neoprene at both temperature values of 37.5 and 45 ˚C. Since the equine safety boot requires a light weight design, the inner lining material will be relatively thin and thus X-Static would never be used at the 3mm thickness.

7.3 X-Static Performance Data

A human trial test was run to determine the X-Static's performance qualities. It was hypothesized the X-Static sock would produce suitable performance in moisture absorption, heat conductivity, and comfort. The data was collected on each quality: moisture and heat production, and comfort in a quantitative range between 1-5(1 being no moisture and heat production or discomfort and 5 being the most moisture and heat production or discomfort). Each participant gave verbal feedback as well as the quantitative answers to the survey. These verbal responses will be discussed in this section.

Six out of the ten participants preferred ankle socks during running. Since high socks were required for this study in order to obtain a reading on the leg, it could have accounted for the larger standard deviation in the comfort data at 0.894 and 0.837 with and without an ace bandage wrap. Three out of the ten participants stated that pain reduction was noted in the X-Static sock. One of those claims was made when the sock was wrapped in an ace bandage which could have been the reason for the pain dissipation.

Experimenter observations were also made immediately after the X-Static sock was removed. These results can be viewed in Table 20. No real heat or moisture production was noticed upon observations. A smell test was conducted to validate or disprove the antimicrobial X-Static claims. No real odor was observed from the sock after the participants had run the one mile around the indoor track.

Table 20 Experimenter Observational Data

Observations	A	B	C	D	E	F	G	H	I	J
Moisture	Damp	No moisture	No moisture	Damp	No moisture	Damp	No moisture	Damp	No moisture	No moisture
Heat	Cool	Cool	Cool	Cool	Warm	Warm	Warm	Warm	Cool	Cool
Smell	Subtle odor	Strong odor	Gold bond smell	No odor	No odor	Subtle odor	No odor	Subtle odor	No odor	No odor

8 Conclusion

The purpose of creating a novel safety boot for racehorses is to protect their lower limbs from catastrophic injuries. Preventable injuries claim the lives of many racehorses each year and there is a need for improved safety equipment. Since such injuries result from accumulation of microscopic stress fractures over time, detection and diagnoses are often too late. Diagnostic tools that are able to detect these injuries, such as diagnostic anesthesia and nuclear scintigraphy, are expensive and not routinely performed during physical examinations. Euthanasia becomes the most humane option for horses with catastrophic injuries.

Although there are many safety boots and wraps on the market, none have proved to prevent serious injuries that occur during races. Most of these devices are methods of healing or are worn when a horse is not racing. They do not adequately support and protect the fetlock joint, extensors, and flexors. These boots are usually made with neoprene, which acts as the inner and outer layering. After studying these designs and performing literature searches on common materials, it was determined that a novel composite design must be created. The project focused on creating an inner layering for the safety boot that would have properties of moisture absorption, intermediate hydrophobicity/hydrophilicity, heat conductivity, and comfort.

The five materials that underwent preliminary testing were silk, cotton, polyester, nylon, and wool. The tests performed included moisture wicking, sessile drop, and heat conductivity. These tests determined which material would proceed to the final testing stages. Polyester performed optimally in each test, whereas wool and silk served as extreme values for the moisture tests. Polyester was then tested as a blend of polyester, spandex, and the X-Static silver fiber. Such a blend was expected to have antimicrobial properties, heat conductivity, and moisture absorption. The polyester blend was compared with neoprene, in order to show the novel product's performance over the currently used popular product. The wicking test was performed in an aqueous solution and in a solution containing 0.9% NaCl to mimic the contents of sweat. X-Static performed optimally in the wicking and sessile drop tests. The X-Static and polyester blend was also found to conduct heat much better than neoprene, and even proved better than polyester alone. The performance of the material was tested on 10 human subjects who provided data on the heat, moisture, and comfort of the product.

In conclusion, it is recommended that an X-static, polyester, and spandex blend should be used as the inner lining of the equine safety boot for the distal limbs. Polyester's wicking, heat conductivity, and hydrophobic/hydrophilic properties are enhanced by the X-Static fiber and adds an antimicrobial component, reducing irritation during racing. Spandex should be added in order to provide additional stretch and comfort of the product. Use of this blend as an inner lining will provide a novel design that can reduce irritation caused by moisture and heat buildup, allowing the safety boot to be worn during racing and preventing further catastrophic injuries in racehorses.

9 Recommendations

The inner layering is just one of three layers that need to be considered in this multifunctional equine safety boot. Therefore, the procedures performed on the inner layering can be repeated on the supportive and outer layering to obtain data on how well these materials perform in heat conductivity, comfort ability, and moisture production properties. Once individual material property tests are performed an analysis on the performance of the interaction of the layers in the completed boot should be conducted.

Preliminary research and testing were performed on the adhesion component, however different modes for achieving an interface between the inner layering and adhesion material need to be explored. Further testing to validate the data obtained on the adhesion component which can be seen in **Appendix O: Adhesion Component Testing** should to be conducted as well.

Finally animal trials would establish how the boot affects the performance of a horse during the race. Short term studies will determine detrimental effects that would possibly hinder the racehorse's performance. Long term studies should be done to identify if any internal or external injuries occur due to the boot.

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Glossary

Barbiturates- Drugs that act as central nervous system depressants and produce a wide spectrum of effects, from mild sedation to total anesthesia. Over dosing can lead to death.

Distal-Anatomically located far from a point of reference, such as an origin or a point of attachment.

Elongation to break-Elongation recorded at the moment of rupture of the sample, often expressed as a percentage of the original length. It corresponds to the breaking or maximum load.

Extensor tendons-A muscle that extends a joint or limb in the body.

Fatigue fractures- Characterized by cyclical loading and erosion of the material properties which will eventually lead to the inability to maintain normal daily loads.

Fetlock-The fetlock is a hinge joint, allowing flexion and extension, but minimal rotation, adduction, or abduction. While sometimes the fetlock is referred to as an "ankle," the fetlock actually is a metacarpophalangeal joint which corresponds to the human upper knuckle, such as that on the ball of the foot.

Flexor tendons- Attached to a muscle that when contracted acts to bend a joint or limb in the body.

Furlong- one eighth of a mile

Hazard period- Periods of rapid accumulation of high speed exercise and distance

Heat transfer-Heat transfer is thermal energy in transit due to a temperature difference.

Hydrophilic-A physical property of a molecule that can transiently bond with water (H_2O) through hydrogen bonding.

Hydrophobic-A physical property of a molecule (known as a hydrophobe) that is repelled from a mass of water.

Hyperextension- The movement or extension of joints, tendons, or muscles beyond the normal limit or range of motion.

IRB- An institutional review board (IRB), also known as an independent ethics committee (IEC) or ethical review board (ERB), is a committee that has been formally designated to approve, monitor, and review biomedical and behavioral research involving humans with the aim to protect the rights and welfare of the research subjects.

Keratin- An intermediate filament; when assembled in bundles, it is tough and insoluble forming hard, unmineralized structures.

Monotonic fracture- Occurs when a bone that is loaded momentarily beyond its limit will fail.

Morphological chart- A matrix comprised of a single left-hand column in which a listed of parameters essential to the design are displayed. To the right of each parameter t in the column is a row containing the possible ways of achieving that particular parameter.

Neoplasia- Abnormal proliferation of cells.

Neoprene- Synthetic rubbers that in general have good chemical stability, and maintains flexibility over a wide temperature range. Commerically used in horse boots.

Nuclear scintigraphy- Also known as bone scan, provides a screening tool to locate areas of increased metabolic activity in soft tissue or bone which may indicate a site of injury.

Osteoporosis-bone mineral density (BMD) is reduced and fracture is more likely to occur.

Pairwise comparison chart- An objective is matched one by one with each of the other objectives. Each objective gets 1 point when considered the more important objective and a 0 when not. Totals are made on the right hand column next to each objective. These totals represent the ranking importance of each objective.

Pathological factures- Caused by neoplasia or osteoporosis, which cause the bone to be incapable of supporting normal loads.

Phalanx bone- Bones that form fingers and toes.

Proximal-Nearer to a point of reference such as an origin, a point of attachment, or the midline of the body.

Radiograph-Uses of X-rays to cross materials to view inside objects.

Sesamoid bones-Where a tendon passes over a joint, such as the hand, knee, and foot. Functionally, they act to protect the tendon and to increase its mechanical effect.

Sessile water drop- A method used for the characterization of solid surface energies, and in some cases, aspects of liquid surface energies. The main premise of the method is that by placing a droplet of liquid with a known surface energy, the shape of the drop, specifically the contact angle, and the known surface energy of the liquid are the parameters which can be used to calculate the surface energy of the solid sample.

Stance phase- When the horse’s limb is in contact with the ground. Consists of four parts: the initial heel contact, the mid contact phase, the full support phase, and the takeoff phase.

Succinylcholine- Muscle relaxation medicine.

Suspensory ligaments- Any ligament that supports a body part, especially an organ.

Swing phase- When the horse’s limb is being carried through the air. Slows the impact of the hoof with the ground upon landing.

T61-A veterinary euthanasia drug.

Tear resistance-Measure of the ability of sheet or film materials to resist tearing.

Thermal conductivity-The property of a material that indicates its ability to conduct heat.

Thoroughbred racehorse- A horse breed best known for its use in horse racing.

Toughness-The resistance to fracture of a material when stressed. It is defined as the amount of energy per volume that a material can absorb before rupturing.

Ultimate tensile strength- The maximum stress a material can withstand when subjected to tension, compression or shearing. It is the maximum stress on the stress-strain curve.

Ultrasonography- An ultrasound-based diagnostic imaging technique used to visualize subcutaneous body structures including tendons, muscles, joints, vessels and internal organs for possible pathology or lesions.

Water vapor transmission- This technique ranges from gravimetric techniques that measure the gain or loss of moisture by mass, to highly advanced instrumental techniques that in some designs can measure extremely low transmission rates.

Weighted objective list-A listed of objectives that have been ranked on relative importance to the overall problem statement.

Wicking- The ability of a material to vertically absorb a given solution. The faster a solution is absorbed the better the wicking property.

Appendix A: Boot/ Wrap Evaluation

Boots	Riding Style	Features	Price
Vet wrap	Racehorses	• Rubber latex • elastic • Used as rundown bandage: horses returning from or prone to injury • "It also helps to reduce hyperextension of the fetlock joint and protect against fatigue"	$2.95 per roll 1 roll=4 in X 5 yd
Polo Bandage (ANKY)	Dressage, polo	• Fleece • Maintain warmth on leg • Worn during warm ups • Thicker and more support than vetrap	$35 per roll
Neoprene boot (ThinLine Cobra SMB Support Boot)	Western, dressage, polo, everything, etc	• Consist of neoprene • "impact protection" • "tendon support" • Thin and pliable, allow joint flexion • Custom fit molded in response to body temperature • Thin line vents • Antifungal • Lining does not gather dirt	$74.95
Brushing boot (Woof Wear Sport Brushing Boots)	Any sport	• 5.5mm PX closed cell neoprene for impact protection and flexibility • PVC strike pad • Claims it will not absorb water	Range: $30-90
Jumpers (Equifit T-Boots EXP2 with Brass Stud Closures)	Jumping	• Shock absorbing • Molds to leg • Brass stud closures • Removable lining is washable	$178.00

Appendix B: Adhesive Material Evaluation

Secure Component Materials	Pro	Con
PTFE(Teflon)	Low friction Antistick High elongation Form is dependent on manufacturing (can be flexible) Little creap(to help conform to surface)	No memory(alittle creep)
TPU (Thermoplastic Polyurethane films)	Bonds to glass, polycarbonate, acrylic Tough/durable Excellent flex fatigue UV resistant Absorb thermal/ mechanical shock	
EVA(Ethylene vinyl acetate)	Soft Flexible Barrier properties Stress-crack resistance Low moisture absorption Resistant to UV Shock absorber	

Appendix C: Stakeholders concerns

Stakeholders:	*Concerns*
Sponsors/Owners	Cost
Trainers/ Horse riders	Design Complexity Cost Performance Hindrance Safety (Pain/Comfort)
Manufacturers	Device manufacturing time Material-cost, availability, “workability”
Engineers + Advisors	Completion time: 4 terms Cost Proposed Final Design

Client: person, group, company that wants a design conceived

- Trainings and riders (internal)
- Manufacturers (internal and external)
- Funding Companies (external)

Users: set of people that will actually use the device being designed

- Race Horses
- Riders

Designers: set of people who develops specifications such that something can be built to satisfy everyone

- MQP group (including Advisors)

Appendix D: AERI Meeting at Brown

Time: 9am-1:30pm
Date: September 5, 2009
Attendees: Wendy Drumm, Dr. Carl Kirker-Head, Sheryl Torr-Brown, Clifford M. Les, Trey Crisco, Robert Knudsen, Dan Pflaster

Critical Factor to Fetlock Injury

- Repetitive Stress
- Not necessarily hyperextension, but it is a part of this hypothesis
- Understanding mechanisms of working within and out of the horses physiological limits
- Angular Velocity
- Stress/Pressure Points

Causes

- Stress on tendons causes hyperextension
- As horse fatigues, hyperextension occurs more frequently
- Unknown speed at which this hyperextension occurs
- Correlation can be made with injury to fatigue levels
- Proprioception – having extra sleeve on joint increases proprioception

Assumptions

- Fatigue causes stress- catastrophic injury
- Fetlock can hyperextend under normal conditions in a safe way
- Natural osculation occurs within the fetlock joint
- Needs some apparatus that will prevent overextension of tendons will prevent injury

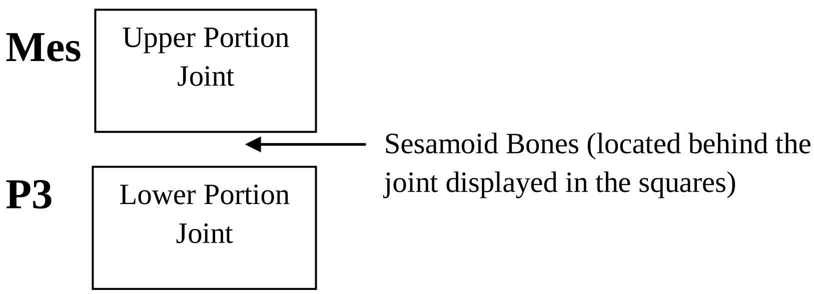
Research Question

- Wobble-Misalignment- injury?
- Could device be used post race?
- Healthy tendons vs. fatigued tendons?

Interlocking Anatomy

- Not much lateral- medical motion

- 2-D approximated joint



- Medial > lateral
- Lesions located along medial
- Diarthrotial joint
- Small surface area
- Cartilage

- Injuries several places on/around joint/tendons
    - Numerous foci where events occur
    - Why th**e**y occur is unclear
- Fibrocartilage located behind bony protrusion, therefore not much injury there
- Natural degeneration with age
- Area also becomes too hot (>40˚C) – contributes to cell death
- 7% heat lost to the fatigued tendons
- Temperature control- preventing heat production or removing excess heat
- Gradual transition to a hard material
- Angle and speed to which angle is achieved understood
- Injury from opposing leg contact
- Different loading patterns
- More injury to front limbs
- Acceleration, maintain speed, deceleration all need to be accounted for
- Last furlongs fatigue of horse at maximum level

Factors

- Mass of horse
- How leg is landing
- Leading leg or trail leg
    - Trail leg has more vertical force
    - Lead leg has propulsive force

- Back legs propel
- Reduce abnormal angular velocity and hyperextension

- Sheer load- frictional, parallel surface
- Side to side osculation
- Strain gait study to measure different concussive forces
- Intimately contoured to skin
- NO NEOPRENE!!!!(Stated by Founder of AERI, Wendy Drumm)
- Remove heat away from leg
- Muscles located higher on limb

Overall Project Objectives

- Shock wave attenuation
- Limit angular velocity
- Limit angular displacement
- Heat dissipation
- Modulate/control sheer force (osculation, rotation)

Risk/Limitations Factors

- Fatigue
- Remodeling
- Training strain
- Biomechanical
- Chronic damage accumulation
- Adequate repair time after injury needed
- Overextension
- Microdamage
- Surface/hoof interaction

Materials

- Loadable materials
- Material that will displace load
- It will radiate heat away from the limb

Vectron Outer Layering

- Liquid crystal polymer
- Long stitches better
- High bend fatigue resistance provided
- Polyurethane coating provides shock absorption
- Creep issues
- Not Time dependent stiffness

D30 Supportive Layering

- Time dependent- applying load quickly provides a stiffer material
- A gelatin like substance

Appendix E: Objectives

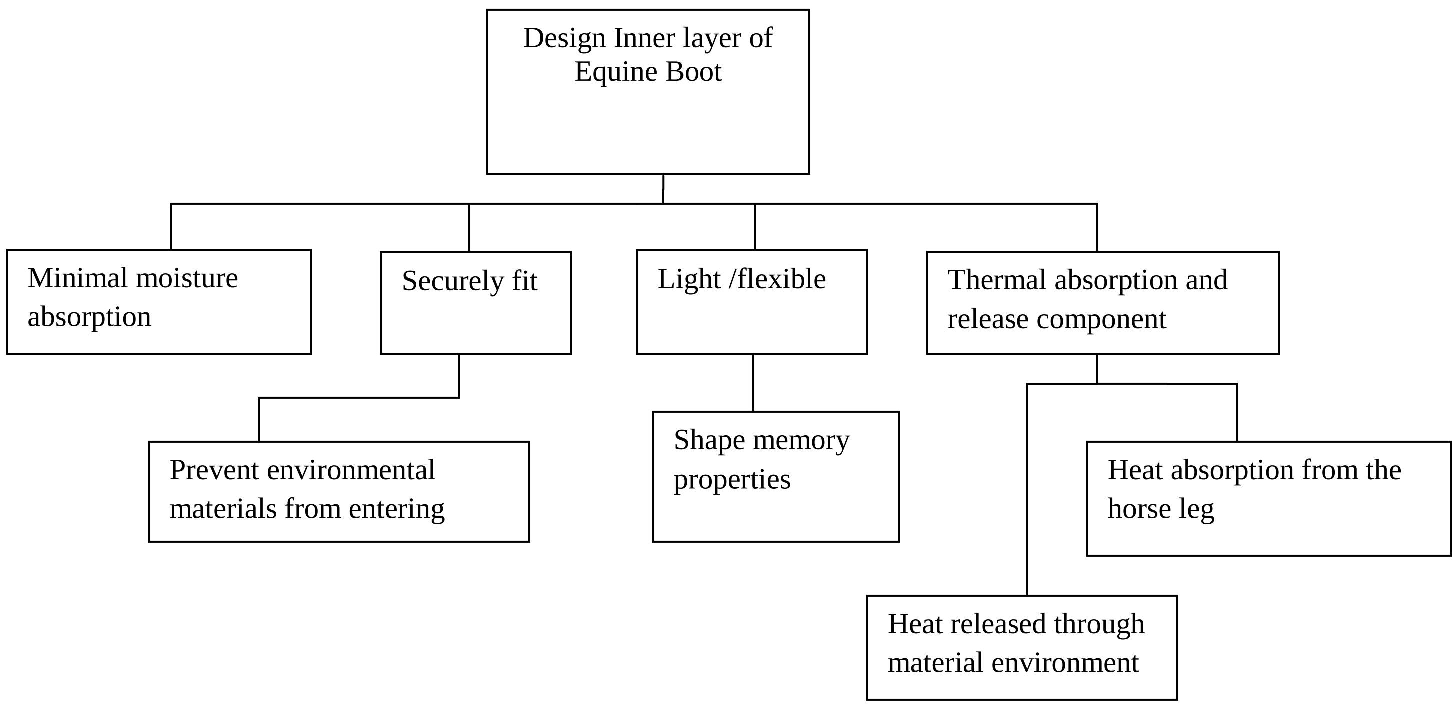
Weighted Objectives Chart

Design Inner Layering of Equine Safety Boot Objectives	**Weighted**
Secure Fit	4.0
Thermal Conductivity	3.0
Moisture Absorption	2.0
Flexible	1.0
Light weight	0

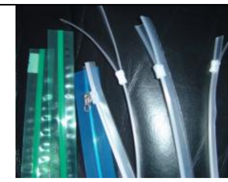
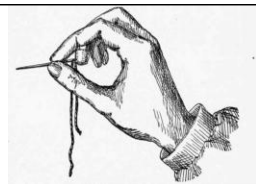
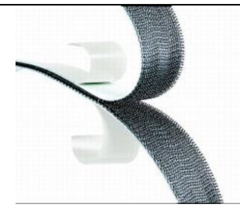
Pairwise Comparsion Chart

Goals	**Minimal moisture absorption**	**Secure fit**	**Light weight**	**Flexible**	**Thermal absorption/ release**	**Score**
Minimal moisture absorption	****	0	1	1	0	2
Secure fit	1	****	1	1	1	4
Light weight	0	0	****	0	0	0
Flexible	0	0	1	****	0	1
Thermal absorption and release	1	0	1	1	****	3

Objective Tree



Appendix F: Morphological Chart

Function	Mean			
Must provide full coverage to the fetlock joint and tendons	One uniformed material stretch to put on			
Must adhere to the supportive and outer layering				
Must adhere to the hoof				Bone cement
Must reduce environmental element intake		Partial heel coverage	Adhesive polymer	***

Additional Functions:

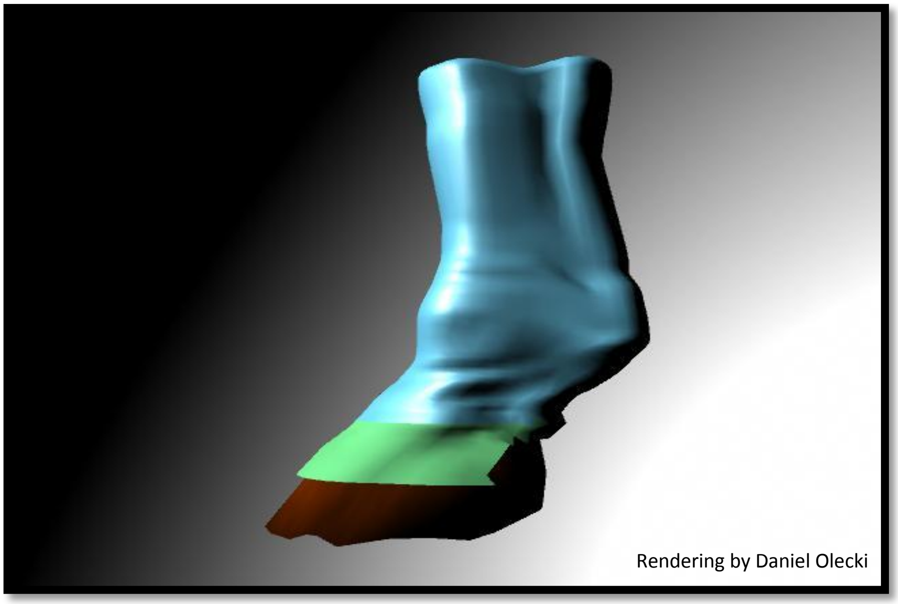
- Must conduct heat
- Must wick moisture
- Must provide full coverage to the fetlock joint and tendons
- Must adhere to the supportive and outer layering
- Must adhere to the hoof
- Must reduce environmental element intake

Appendix G: Specifications

Physiological Specifications	Description	Value
Temperature	Do not exceed the average temperature during racing	37.5 -40 ˚C
Speed	Race time specifies the number of seconds it takes to complete a race. This is the direct measure of the horses speed however taking into account all circumstances associated with that racing.	15.91-16.76 m/s
Distances	Distance horse travels during a race	1000-2000m
Angular velocity	Minimal reduction of normal angular velocity which is a vector quantity which indicates the angular speed of the horses leg and the axis about which the leg rotates on	1.2±0.30–1.6±0.30deg/ms 1.5±0.241.9±0.36deg/ms

Appendix H: Design Alternatives

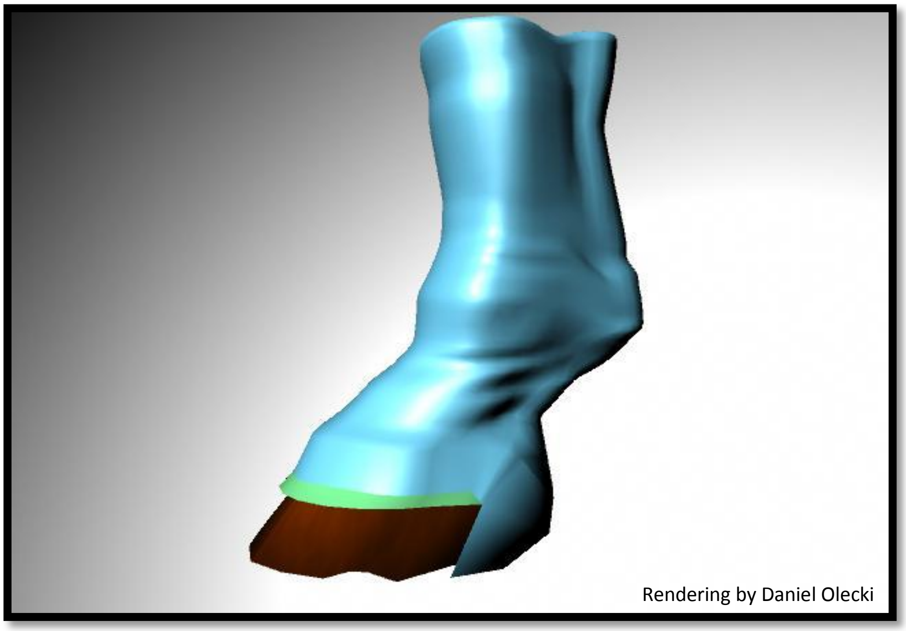
Minimal Coverage Design Alternative



Design 1

The first design is demonstrated by in the figure above and is composed of an inner layer with a polyester or nylon material. Both spandex and the X-static silver fiber will be incorporated for comfort, breathability, heat transfer, and moisture control. The material will be manufactured as a blend of the fabrics represented in the blue. The inner layering will be stitched to an outer layering which will provide protection, strength, shock resistance, and support. Between the two layers will be the D3O material that hardens upon impact. This material will be placed at the fetlock joint as a brace to protect the joint against the impact of landing. On the hoof, a removable adhesive material will be attached to the inner and outer layers represented in the red. The function of this material will be to prevent extraneous materials such as dirt and water from entering the boot from the bottom. The material will need to suction to the hoof, reaching a few centimeters below the other materials. It will taper around the hoof and stop at the rear. The rear of the hoof indents and has a hairy portion, which will not adhere to the material. Therefore, this design does have a weakness because it does not cover the back of the hoof, possibly allowing extraneous material to enter through the orifice. The benefit to this design is that it is the least cumbersome and complicated in fitting. It is sleek in appearance and allows the horse to stand on its actual shoe, unhindered. It provides minimal coverage of the hoof. The suction material can be replaceable after many uses, in order to maintain the suction property.

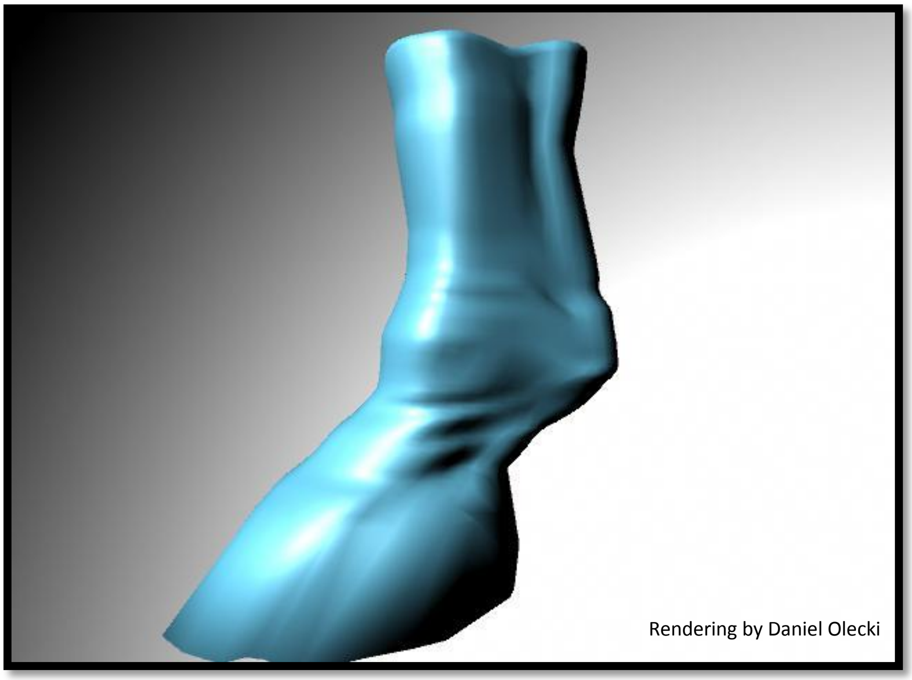
Partial Coverage Design Alternative



Design 2

Similar to design one, design two will contain the same inner and outer layers, placement of D3O, and adhesive material. However, in order to accommodate the open area behind the hoof, the inner and outer layers will reach below the hoof, creating a half sleeve as shown in the figure above. The material will reach underneath the hoof and include a thin piece of D3O between the inner and outer layers in order to accommodate the shock absorbency. The material will also adhere to the base of the hoof with the incorporation of a Velcro component. The features of this design include a medium level of coverage and reusability. It will prevent extraneous materials from entering the boot through the back.

Full Coverage Design Alternative



Design 3

The third design incorporates the same inner, outer, and adhesion materials, as well as the D3O. This design differs in that the outer material will cover the entire hoof, over the inner layer and the adhesive material. The adhesive material will also come down very low on the hoof. Underneath the bottom of the hoof will be a thin layer of D3O for shock absorbance upon impact. This design provides maximal coverage and protection for the entire lower limb, including all areas of the hoof. However, covering the entire bottom of the hoof could cause complications that affect performance.

Numerical Evaluation Matrix (Designs to Objectives)

	Minimal Coverage	Partial Coverage	Full Coverage
OBJECTIVES			
(5) Secure	(1.0)	(2.5)	(3.0)
(4) Thermal Conductivity	(3.0)	(3.0)	(3.0)
(3)Moisture Absorption	(3.0)	(3.0)	(3.0)
Light Weight	(3.0)	(2.5)	(1.0)
Flexible	(3.0)	(2.5)	(1.0)
Total	13.0	13.5	11.0

Numerical Evaluation Matrix (Designs to Functions)

	Minimal Coverage	Partial Coverage	Full Coverage
FUNCTIONS			
Full coverage to fetlock joint and tendons	(3.0)	(3.0)	(3.0)
Adhere to other Components of boot	(3.0)	(3.0)	(3.0)
Adhere to hoof	(3.0)	(3.0)	(3.0)
Must not take in environmental elements	(1.5)	(2.5)	(3.0)
Total	10.5	11.5	12.0

Numerical Evaluation Matrix (Designs to Constraints)

	Minimal Coverage	Partial Coverage	Full Coverage
CONSTRAINTS			
Don't hinder or enhance performance	(3.0)	(2.5)	(1.0)
Cost effective	(3.0)	(3.0)	(2.5)
Completed April 2010	(3.0)	(3.0)	(3.0)
Total	(9.0)	(8.5)	(6.5)

Final Numerical Evaluation Matrix

	Minimal Coverage	Partial Coverage	Full Coverage
Objectives	(13.0)	(13.5)	(11.0)
Functions	(10.5)	(11.5)	(12.0)
Constraints	(9.0)	(8.5)	(6.5)
TOTAL	32.5	33.5	29.5

Appendix I: Human Trial Documents

The human testing will be used to assess the irritation, moisture wicking, and thermal conductivity of the final material. The human testing will allow verbal feedback on these properties. The inner layer material will be fashioned into sock form for this test in order to fit the test subjects. The subjects will run for 5 minutes in the required environment. The subjects will run on a treadmill indoors for 5 minutes. After a break, they will be asked to run on the outdoor track, where there is the possibility of external materials. The control will require the subject to run without the inner layer material on their left foot. The inner layer material will be placed on their right feet. The weight and age of each subject will be recorder, but their identities will be kept anonymous. Below are listed ideal criteria for the test subjects:

- Between 5-10 subjects
- WPI males between the ages of 18-22
- Weight: 170-200 lbs
- Members of a sports team

Survey: Below is a list of questions the subjects will be asked before and after running with the inner layer material on their foot.

1) On a scale of **1** to **5**, (1 being no discomfort, 5 being extremely irritable) how comfortable is this product?
2) On a scale of **1** to **5** how moist did the product become during running? (1 being dry, 5 being completely saturated)
3) On a scale of **1** to **5** (1 being cool, 5 being hot) how overheated did your leg become while wearing this product?
   a. Before running:
   b. After running:
4) Follow up 2 days later: On a scale of **1** to **5** have you developed any irritation in the past week in the area that the product was worn? (1 being no irritation, 5 being extreme irritation)

5) Follow-up 10 days later: On a scale of **1** to **5** have you developed any irritation in the past week in the area that the product was worn? (1 being no irritation, 5 being extreme irritation)

Informed Consent to Participate in Human Subject Research

Students Meggan Birmingham and Marcella Granfone at Worcester Polytechnic Institute are conducting a study to determine if a prototype for an equine safety boot could cause any discomforts. You are being asked to participate in this study.

As part of the study, you will be asked to place this boot on your leg and perform some running exercises. One of these exercises will be to sprint a distance while wearing the boot. Another test will be to run for an extended period of time with the boot on. Each of these exercises will be performed on two different surfaces (dirt and turf).Because you will be asked to perform multiple exercises, it is anticipated that all testing will take approximately one hour of your time.

It is helpful to be able to compare the results from each exercise on the same individuals.

Participating in this study should pose no serious medical risk to you. However, because this test is a measure of comfort ability, there could be some risk of skin irritation from the material of the boot. If there is any irritation that occurs feel free to contact Meggan Birmingham or Marcella Granfone from the information provided below.

As a result of your participation in this study, you will contribute to the development of a safety device that could potentially save horses lives.

For the purpose of the study, your test results will be coded so that your name will not appear on any of the forms used for data analysis. No information about you will be released to anyone other than yourself and publication or presentation of the study data would in no way identify you as a participant. Only Meggan Birmingham and Marcella Granfone will have access to the names associated with the codes and this information will be kept in a locked file cabinet in her office and destroyed at the end of the study.

If you want to withdraw from the study, at any time, you may do so without penalty. Any information collected on you up to that point would be destroyed.

Once the study is completed, you may receive the results of the study. If you would like these results, or if you have any questions in the meantime, please contact:

Meggan Birmingham
Biomedical Engineering Student
Worcester Polytechnic Institute
meggan@wpi.edu
(781) 443-2090

Marcella Granfone
Biology Student
Worcester Polytechnic Institute
marcella@wpi.edu
(781) 507-3197

If you have any complaints about your treatment as a participant in this study or believe that you have been harmed in some way by your participation, please contact:

Kent J. Rissmiller, Chair
Institutional Review Board
WPI
Worcester, MA 01609
kjr@wpi.edu

Although you may be ask your name, all complaints are kept in confidence.

I have received a complete explanation of the study and I agree to participate.
Name____ Date____________________
(Signature of subject)

Appendix J: Preliminary Wicking Data

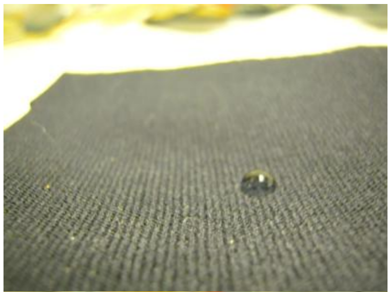
Polyester	1	5	10
Sample 1	1	2	2.5
Sample 2	0.5	0.5	1
Sample 3	0.8	2	3
Sample 4	1.5	3	3.5
Sample 5	1.4	2	2.5
Sample 6	2.2	3	3
Average	1.233333	2.083333	2.583333
Standard Deviation	0.602218	0.917424	0.861201
Nylon			
Sample 1	0.5	0.5	1.3
Sample 2	0.3	0.7	0.7
Sample 3	0.2	0.3	0.7
Sample 4	0.5	0.7	0.7
Sample 5	0	0.2	0.5
Sample 6	0.5	1	1.3
Average	**0.333333**	**0.566667**	**0.866667**
Standard Deviation	**0.206559**	**0.294392**	**0.34448**
Cotton			
Sample 1	0.3	1.7	2
Sample 2	0.4	1.5	2.3
Sample 3	2	3.5	4.1
Sample 4	1.5	3	3.2

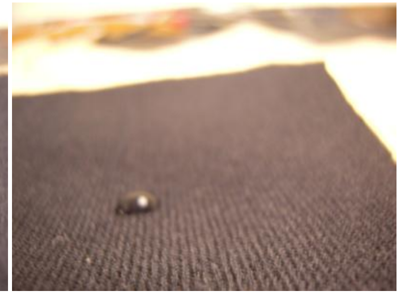
Sample 5	0.2	0.5	1.5
Sample 6	1.5	3	3
Average	**0.983333**	**2.2**	**2.683333**
Standard Deviation	**0.773089**	**1.148913**	**0.936839**
Wool			
Sample 1	0	0	0
Sample 2	0	0	0
Sample 3	0	0	0
Sample 4	0	0	0
Sample 5	0	0	0
Sample 6	0	0	0
Average	**0**	**0**	**0**
Standard Deviation	**0**	**0**	**0**
Silk			
Sample 1	2	6	7.5
Sample 2	3	5	6
Sample 3	2.5	4.5	6
Sample 4	3	5	6
Sample 5	2.4	4.3	5.7
Sample 6	3.2	5.1	6.5
Average	**2.683333**	**4.983333**	**6.283333**
Standard Deviation	**0.457894**	**0.591326**	**0.649359**

Appendix K: Sessile Drop Results

X-Static
37.5 C (first seven images)
45 C   (last seven images)

Neoprene
37.5 C (first nine images)
45 C   (last seven images)






Appendix L: Preliminary Heat Conductivity Data

Results at 37.5^{o}C

Material	Sensors	1 minute	3 minutes	5 minutes
Wool				
Sample 1	1, 2, 3	34.4, 27.0, 23.9	34.7, 27.3, 23.9	34.7, 27.3, 24.0
Sample 2	1, 2, 3	32.5, 26.9, 23.9	33.7, 27.2, 23.9	34.3, 27.2, 23.9
Sample 3	1, 2, 3	32, 26.4, 23.9	32.1, 26.9, 23.9	32.6, 26.9, 23.9
Silk				
Sample 1	1, 2, 3	35.3, 30, 24.1	35.4, 30, 24.1	35.4, 31, 24.1
Sample 2	1, 2, 3	31.4, 27.8, 23.9	32, 28.4, 24.0	32.3, 29, 24.0
Sample 3	1, 2, 3	31.6, 28.1, 24.0	31.8, 28.4, 24.0	32, 28.4, 24.0
Polyester				
Sample 1	1, 2, 3	33.5, 30.7, 24.0	33.5, 30.8, 24.0	33.6, 30.8, 24.0
Sample 2	1, 2, 3	31.2, 28.4, 24.0	31.9, 29.6, 24.0	32.2, 29.6, 24.0
Sample 3	1, 2, 3	31.4, 28.7, 24.0	31.7, 29.1, 24.0	32, 29.5, 24.0
Cotton				
Sample 1	1, 2, 3	33.6, 28.8, 24.0	32.6, 28.8 , 24.0	33.9, 29.4, 24.0
Sample 2	1, 2, 3	31.7, 27.8, 24.0	32.4, 28.1, 24.0	32.6, 27.8, 24.0
Sample 3	1, 2, 3	32, 28, 24.0	32, 28, 24.0	32.1, 28, 24.0
Nylon				
Sample 1	1, 2, 3	32.2, 27.8, 24.0	32.8, 28.7, 24.0	33, 28.9, 24.0
Sample 2	1, 2, 3	32.2, 26.7, 24.1	32.4, 29.6, 24.1	33.1, 29.6, 24.1
Sample 3	1, 2, 3	32, 28.5, 24.1	32.2, 28.7, 24.1	32.6, 29, 24.1

Results at 45^oC

Material	Sensors	1 minute	3 minutes	5 minutes
Wool				
Sample 1	1, 2, 3	44.8, 31.0, 24.0	45.5, 30.6, 24.1	45.1, 29.5, 24.0
Sample 2	1, 2, 3	44.4, 30.9, 24.1	45.0, 31.0, 24.0	45.3, 31.2, 24.0
Sample 3	1, 2, 3	44.7, 31.0, 24.0	45.4, 30.9, 24.1	45.4, 30.9, 24.0
Silk				
Sample 1	1, 2, 3	38.3, 32.1, 24.1	38.5, 31.4, 24.1	38.6, 31.7, 24.1
Sample 2	1, 2, 3	38.7, 33.2, 24.1	38.7, 34.1, 24.1	38.7, 34.6, 24.1
Sample 3	1, 2, 3	38.5, 33.8, 24.1	38.1, 34.5, 24.1	38.1, 34.6, 24.1
Polyester				
Sample 1	1, 2, 3	37.7, 34.4, 24.1	37.8, 34.1, 24.0	37.9, 33.7, 24.1
Sample 2	1, 2, 3	41.5, 35.0, 24.1	40.5, 35.7, 24.0	40.1, 35.8, 24.1
Sample 3	1, 2, 3	36.9, 32.8, 24.1	38.6, 34.1, 24.1	39.6, 34.8, 24.1
Cotton				
Sample 1	1, 2, 3	39.8, 31.0,24.1	40.8, 31.4, 24.1	40.9, 31.4, 24.1
Sample 2	1, 2, 3	39.1, 33.3, 24.1	39.1, 34.4, 24.1	39.6, 35.0, 24.1
Sample 3	1, 2, 3	36.1, 33.3, 24.1	37.4, 34.3, 24.1	38.2, 34.7, 24.1
Nylon				
Sample 1	1, 2, 3	36.5, 30.2, 23.8	37.3, 31.0, 23.8	37.9, 32.5, 23.8
Sample 2	1, 2, 3	37.7, 33.0, 24.1	39.6, 30.7, 24.1	41.0, 30.6, 24.1
Sample 3	1, 2, 3	39.6, 30.7, 24.1	41.0, 31.0, 24.1	45.0, 31.8, 24.1

Appendix M: X-Static vs. Neoprene Wicking Data

Final Material Raw Wicking Data in Aqueous Solution

X-Static	1	5	10
Sample 1	0	2	2.5
Sample 2	0	2.5	3.5
Sample 3	0	2	3
Sample 4	0	2	3
Sample 5	0	1.9	3
Sample 6	0	1.8	3
Average	0	2.033333	3
Standard Deviation	0	0.242212	0.316228
Neoprene			
Sample 1	0	0	0
Sample 2	0	0	0
Sample 3	0	0	0
Sample 4	0	0	0
Sample 5	0	0.5	0.5
Sample 6	0	0.5	0.5
Average	0	0.166667	0.166667
Standard Deviation	0	0.258199	0.258199

Final Material Raw Wicking Data in 0.9% Saline solution

X-Static	1	5	10
Sample 1	2	5	8
Sample 2	2	3	4
Sample 3	0.5	2.2	4
Sample 4	1	2	3
Sample 5	1	2	3.5
Sample 6	0.5	3.5	3.5
Average	1.166666667	2.95	4.33333333
Standard Deviation	0.683130051	1.17260394	1.83484786
Neoprene			
Sample 1	0	0	0
Sample 2	0	0	0
Sample 3	0	0	0
Sample 4	0	0	0
Sample 5	0	0	0
Sample 6	0	0	0
Average	0	0	0
Standard Deviation	0	0	0

Appendix N: X-Static vs. Neoprene Heat Conductivity Data

Final materials test at 37.5°C

Material	Sensors	1 minute	3 minutes	5 minutes
X-Static				
Sample 1	1, 2, 3	34.4, 27, 24.1	34.7, 27.3, 24.1	34.7, 27.3, 24.1
Sample 2	1, 2, 3	32.5, 26.9, 24.1	33.7, 27.2, 24.1	34.3, 27.2, 24.1
Sample 3	1, 2, 3	32, 26.4, 24.1	32.1, 26.9, 24.1	32.6, 26.9, 24.1
Neoprene				
Sample 1	1, 2, 3	35.3, 30, 24.0	35.4, 30, 24.0	35.4, 31, 24.0
Sample 2	1, 2, 3	31.4, 27.8, 24.0	32, 28.4, 24.0	32.3, 29, 24.0
Sample 3	1, 2, 3	31.6, 28.1, 24.0	31.8, 28.4, 24.0	32, 28.4, 24.0

Final materials test at 45°C

Material	Sensors	1 minute	3 minutes	5 minutes
X-Static				
Sample 1	1, 2, 3	33.2, 30.2, 23.9	32.9, 30.2, 23.9	32.7, 30.2, 23.9
Sample 2	1, 2, 3	35.4, 33.0, 24.1	35.0, 34.0, 24.1	35.0, 34.4, 24.1
Sample 3	1, 2, 3	34.6, 31.9, 24.1	34.6, 32.2, 24.1	35.7, 32.8, 24.1
Neoprene				
Sample 1	1, 2, 3	32.9, 28.6, 23.9	31.8, 28.9, 23.9	33.4, 29.2, 24.0
Sample 2	1, 2, 3	33.4, 29.3, 24.1	33.8, 30.1, 24.1	32.3, 29.8, 24.1
Sample 3	1, 2, 3	33.1, 28.9, 24.1	32.8, 28.1, 24.1	33.5, 29.5, 24.1

Final Materials Test with increased thickness test at 37.5^{o}C

Material	Sensors	1 minute	3 minutes	5 minutes
X-Static				
Sample 1	1, 2, 3	29.7, 26.2, 24.0	30.1, 26.2, 24.0	30.3, 26.2, 24.0
Sample 2	1, 2, 3	29.9, 26.3, 24.0	31.0, 27.3, 24.0	31.0, 27.4, 24.0
Sample 3	1, 2, 3	30.0, 26.1, 24.0	31.3, 27.5, 24.0	31.4, 27.5, 24.0

Final Materials Test with increased thickness test at 45^{o}C

Material	Sensors	1 minute	3 minutes	5 minutes
X-Static				
Sample 1	1, 2, 3	33.7, 28.8, 24.0	32.8, 28.2, 24.0	32.3, 27.9, 24.0
Sample 2	1, 2, 3	32.4, 29.8, 24.0	34.0, 29.4, 24.0	33.6, 29.3, 24.0
Sample 3	1, 2, 3	30.8, 27.9, 24.0	32.9, 28.2, 24.0	33.7, 28.5, 24.0

Appendix O: Adhesion Component Testing

MATERIALS:

TPU:
Company: Deerfield Urethane Company
Material Information:
Teflon:
Company: DuPont
Material Information: Thickness-
Adhesion Component:
Medical Adhesion Spray
Industrial Adhesion Spray
Super Glue
Adhesion Remover:
Product Information:
Hooves:
Cadaver hooves obtained and sliced at Tufts
Weights:
Weight holder(50g)
Weight increments (10, 20, 50, 100, 500, 3000g)

METHODS:

First Procedure

Slices of a thorough bred hoof obtained from cadavers at Tufts were position on a laboratory bench. Adhesive components (medical adhesion spray, industrial adhesion spray, super glue) were applied to the front potion of the hoof completely covering the surface. A material (TPU, Teflon) was then adhered to the hoof by applying pressure for the stated five minute drying period. The TPU and Teflon samples were punctured at the base that was not attached to the hoof. A weight holder (50g) was inserted into the puncture spot. Weights were then added in two minute intervals (10, 20, 50, 100, 500, 3000 grams) until the bond between the hoof and TPU or Teflon broke. Between the tests adhesive remover was used to clean the hoof.

First Procedure:

Observations: Hooves were not thawed, cold temperature may have affected the adhesion. The use of the adhesive remover on the hoof between tests removed some of the dirt build up which may have caused the realistic application of these product to be skewed. (realistic application- dirt will be present on the hoof)

Material	Breaking Weight
TPU	5000 g (max weight) When applying a cycling test(involving oscillating the TPU sample up and down) was able to withstand 3 cycles
Teflon	5000 g (max weight) Torn immediately upon applying

TPU	
Adhesion Method	Breaking Point Weight
Medical adhesion spray	0 g Did not stick after 5 minutes
Industrial adhesion spray	880g Broke immediately
Super glue	3,050 g Held for 2 minutes after applying weights

Teflon	
Adhesion Method	Breaking Point Weight
Medical adhesion spray	0g Did not stick after 5 minutes
Industrial adhesion spray	0g Did not stick after 5 minutes
Super glue	0g Did not stick after 5 minutes

Post Observations: TPU performed the best when subjected to the adhesives applications. The super glue adhesive application worked the best.

Second Procedure

This procedure was performed in order to obtain strength information on the Velcro and zipper components. The Velcro or zipper component would be used to attach the TPU or Teflon to the X-Static. The zipper and Velcro were punctured on one side which was allowed to overhang once the other side was attached. A weight holder (50g) was inserted into the puncture spot. Weights were then added in two minute intervals (10, 20, 50, 100, 500, 3000 grams) until the bond between Velcro or zipper broke.

Second Procedure:

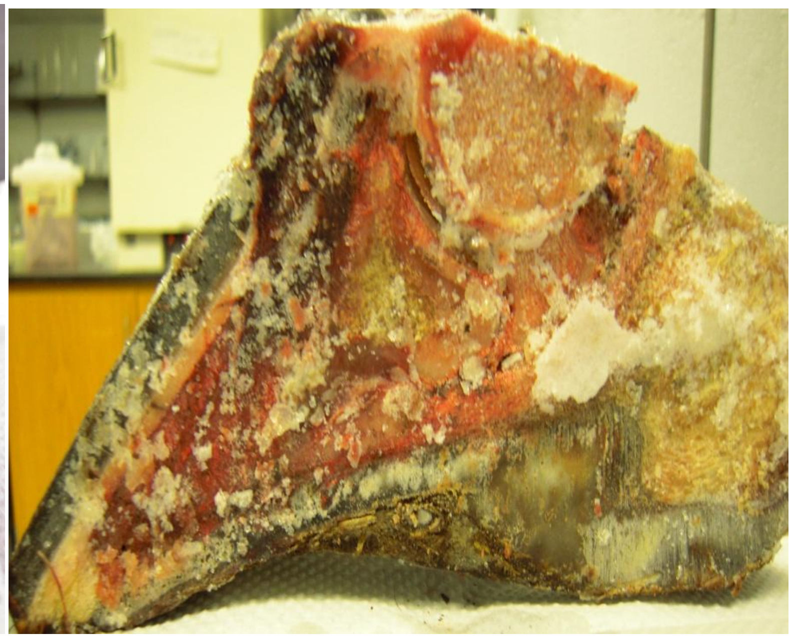
Observations: Both zipper and velcro held the maximum available weight of 5000 grams and showed no signs of distress. It is hypothesized that both components could hold additional weight and further testing needs to be done.

Zipper	Breaking Weight
zipper	5,000 g (max weight) Held for two minutes without breaking bond

Velcro	Breaking Weight
Industrial	5,000 g (max weight) Held for two minutes without breaking bond

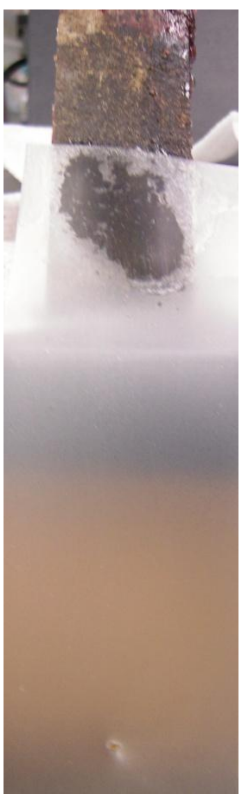
Images:

Hoof

Method:

1. Adhere TPU/Teflon 2. Applied weight until adherence separated from hoof interface

Appendix P: Suffolk Down Communication

Date: February 2, 2010
Time: 3:00pm
Employee: Jessica Paquette, from Suffolk down

Typical Race Information:

- Horse track: 1 mile long
- Typical race: 1 to $1^{1/8}$ mile
- Furlong=1/8 mile
- Horses usually jog in the morning for warm up everyday
- Race 1 week to 1 every 6 weeks