Design and Testing of a Helical Insert for the Purpose of Affixing Retention Devices Used in the Snow Ski Industry

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ABSTRACT

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The purpose of this project is to design and test a helical insert that will be used in the snow sports industry to affix retention bindings to downhill snow skis. The goal is to produce a product that will exceed the current tensile strength standard for the industry as well as provide greater freedom to the consumer. ASTM International provides several standards for the testing of sports equipment that were used as the basis of this research. My project is accomplished through combining research in ski design and manufacturing, emphasis coursework in manufacturing engineering and business management, and experimental procedures learned from physics. The product was tested on cross-section samples of snow skis that consist of sandwiched layers of plastic and composites wrapped around a core material of wood, foam, or a combination of both with epoxy resin. A variation of ASTM Standard F474-98 was used to verify the results. The results of this research proved that both goals were attained.

Keywords: ASTM, standard, F474-98, insert, ski, industry, binding, retention, tensile, strength

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I would like to give special thanks to my wife, Dani Hoagland, for her years of patience as I have obsessed over the topic of ski and snowboard construction as well as the product tested in this project. I thank my parents, Dennis and Mary Hoagland, who have provided the support which allowed me to gain the depth of knowledge required for this subject. I thank the Manufacturing Engineering Technology department at Brigham Young University for the resources and instruction that I received, which made this project and my current career possible.

Sincerely,

David W. Hoagland

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1. Introduction

The term R&D is used in almost every industry and comes up in many conversations. It has become a “buzz word” that is thrown around by marketing teams and sales people to make whatever they are talking about sound highly technical. I had heard it used many times before I knew what it meant. The term stands for Research & Development. It took even longer before I understood what it really meant. The steps of researching an idea so that you can begin to develop it is painstaking and can sometimes take many years. Before beginning the development on my idea, I needed to know how a ski was made.

This introduction is a brief synopsis of the information that I learned through my research. I originally planned on including this information in an appendix, but decided that most people reading this research paper would benefit from learning this information first, as I did. I have formatted this section in a way that will be an easy reference guide as these key terms are encountered later in the paper.

1.1 Definition of Terms for Ski Components

There are several components that make up the whole composition of a snow ski. They are the top sheet, composite, core, base, edge, and sidewall. In this section I will give a brief explanation of each of these terms. Figure 1 shows two skis that have been labeled with terms that correspond to the material type.

1. Top sheet
2. Composite
3. Core
4. Base
5. Edge
6. Sidewall

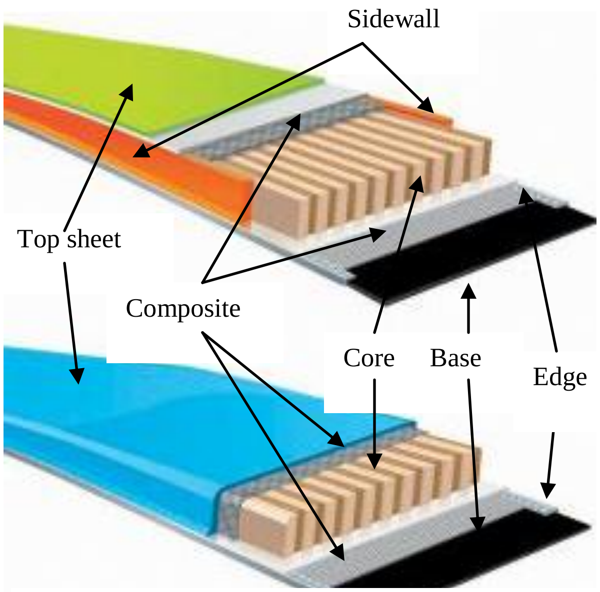


Figure 1: Cross-section of skis demonstrating its various components (Beneski)

1.1.1 Top sheet: The top sheet of the ski is appropriately named, since it is the topmost layer (or sheet) of the ski. The top sheet is a thin piece of plastic that serves as a protection for the inner layers from impact and UV light. The top sheet is also the layer where the graphic for the ski is applied.

1.1.2 Composite: A composite material is a solid material composed of more than one component (Strong, Composites 1). Examples of composites commonly used in the production of snow skis are fiberglass and carbon fiber. Some of the less commonly used composites include basalt and Kevlar. Composite materials are usually a mat fabric that has varying types of weaves. The mats are described by their weight (usually in ounces per yard) and by the direction of the fibers in the weave. The types of weaves are unidirectional, biaxial, triaxial, and quadraxial which contain layers of fibers going in one, two, three, and four directions respectively.

1.1.3 Core: The core is the largest component in the production of a ski and is located in the center, or core, of the ski. The composite is applied to the core, which gives the ski its general shape. The two materials that are typically used for cores are wood and foam. Different species of woods and types of foam will contribute different characteristics to the performance and responsiveness of the ski. Bamboo has become popular as a third material for cores, but is usually used with a combination of wood and is rarely used as the whole core material. It is in the core that inserts are placed prior to manufacturing the ski or snowboard.

1.1.4 Base: The base material is what is used on the bottom or underside of the ski. The base material is almost exclusively made of Ultra High Molecular Weight Polyethylene (UHMWPE), which is a plastic that is made through the process of extrusion or sintering.

UHMWPE is a porous plastic and can be maintained through the application of melted wax. This is where we get the common practice of waxing skis.

1.1.5 Edge: The edge material is made of hardened steel with varying hardness ratings (Rockwell Rating), and it is what allows the ski to grip into the snow and ice.

1.1.6 Sidewall: The sidewall material is used in sandwich construction and is typically adhered to the side of the core to seal it from the elements. It also protects the ski from impacts to the side. It is made of plastic, usually ABS or UHMWPE.

1.1.7 Insert: An insert is a barrel-shaped component with a flanged bottom and threaded inner portion. It is "inserted" into the core and serves as an anchoring device for retention bindings. The flanged bottom prevents the insert from being pulled out of the core. This idea originated with snowboards, but has recently been introduced into telemark skis.

Figure 2: Insert

1.2 Definition of Terms for Basic Ski Construction

In the introduction I talked about two construction methods: sandwich and cap. In this section I will explain the differences between sandwich and cap construction, as well as describe a hybrid construction ski.

1.2.1 Sandwich Construction: Understanding the sandwich construction is very simple. If you cut open a ski and look at its layers, you will see that each layer is stacked on top of the next, like a sandwich. Figure 2 shows a peeled back cross-section of a typical sandwich construction ski. The composite layer gives the ski its flex characteristics, while the core provides the torsional rigidity for the ski. Hard wood is

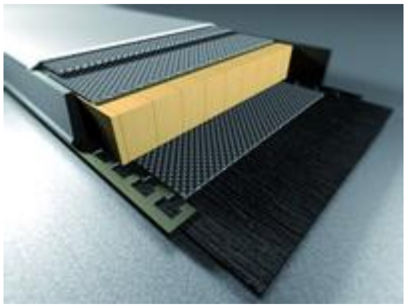


Figure 3: Cross-section of a sandwich construction ski (Rossignol)

almost always used as the core material for a sandwich construction and can be a single species or combination of species.

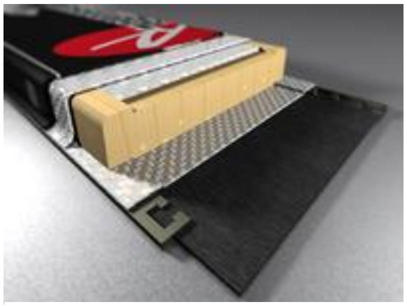


Figure 4: Cross-section of a cap construction ski (Rossignol)

1.2.2 Cap Construction: Also known as monocoque construction, cap construction was made popular by the aeronautical and race car design industry. The idea is that the outer skin (or layer) provides the majority of the structural characteristics and the core, unlike in sandwich construction, doesn't do much in terms of strengthening the ski. You'll notice in Figure 3, that the composite layers wrap around the core forming a cap on the top, and connect to the bottom layer of composite. In cap construction you will find both wood and foam cores. Foam is typically used since it is much lighter and has fewer imperfections than wood does. Also, you will find both fiberglass and carbon fiber in cap construction.

1.2.3 Binding Mounting Area: The binding mounting area is that portion of the top surface of the ski that is intended for mounting bindings (ASTM International S150707, 21). Understanding the two types of construction methods will help to understand the materials that are used for binding retention. Sandwich constructed skis typically used hard wood species, which have great retention strengths for screws, so little reinforcement is needed. Cap constructed skis typically use lighter materials, such as foam, which require greater reinforcement. Typically extra layers of composite and even metal laminates are used to reinforce the binding mounting area.

1.3 How a Ski is Manufactured

Now that I have explained the basic parts of the ski and the construction methods, I will describe how the ski is put together. I am going to define three more terms that are used in the actual making of the skis: layup, mold, and form.

1.3.1 Layup: The layup process is where you put the component parts together to make the ski. This process will be described below. It is a term used in the ski industry and comes from the fact that you lay the materials on the work surface or mold.

1.3.2 Mold: The mold is usually made from aluminum and has some means of aligning the materials, especially the edge to the base. The aluminum sheet is typically hollowed out (milled), so that the edge and base material fit snugly in the shape of the ski. Sometimes the mold will align the core as well, either with locator pins or a deeper piece of aluminum. Figure 5 in an example of a piece of aluminum milled out to the shape of the ski, you'll notice that the ski outline is recognizable.

Figure 5: Ski mold

1.3.3 Form: The form is what shapes the profile of the ski. A ski has a turned up tip, and more recently, a turned up tail as well. When you put two skis together, you'll notice that the middle of the skis arch away from each other and don't touch. This is called camber. The shape of the tip and camber in the ski is determined by the form that is used.

Figure 6: Ski form (Leang, Leang, and Wu)

Earlier I made an analogy to a sandwich, but it is easier to visualize somebody constructing a brick wall. You start with the first layer and apply some mortar before you place the next layer on. The mortar is what holds each layer together. You continue until you reach the top layer, and when it all dries, you have a solid wall.

The edges are temporarily attached to the base material with cyanoacrylate (Super Glue) and are placed in the ski mold. The base and edge comprise your first layer. Like the mortar, a layer of epoxy resin is applied to the base layer until it is completely covered. The next layer, the composite, is now placed on top of the base layer. Epoxy is again applied to the composite layer until it is completely wet. This process is continued with the remaining layers of the core, composite again, and then top sheet, with epoxy resin applied in between each layer.

These layers are then put into a press that applies enough force to squeeze out the excess epoxy. The press is typically heated, so that the epoxy cures faster and with the right characteristics. Figure 7 shows step-by-step pictures of the described process (left to right).

Figure 7: Steps of making a ski (Leang, Leang, & Wu, 2007)

1.4 Snow Ski Binding

1.4.1 Function of the Binding: The binding is designed to be the interface between the skier’s boot and the ski. It has a corresponding toe and heel piece that hold the toe and heel of the boot in place. The toe and heel pieces of the binding each have a spring mechanism that can be adjusted to increase or decrease the force required to release the boot. ASTM F1063-09 provides the standard for determining the release value for a skier based on their height, weight, age, boot sole length, and skier ability (ASTM International S150707). According to this standard, the skier should release from the binding during a fall, so as to avoid serious injury.

1.4.2 How the Binding is Affixed: The binding is affixed (or mounted) to the ski through the use of course thread screws. The manufacturer provides a jig to a certified shop so that their standard hole-pattern can be pre-drilled into the ski. The jig is clamped onto the ski and is adjusted to the length of the boot. A 3.5mm or 4.1mm drill bit is used to drill a hole 9mm deep for adult skis and 7mm deep for children’s skis. A small amount of glue is placed in the hole and then the binding is screwed on.

1.4.3 Reasons for Binding Failure: There are three types of binding failures: when the binding doesn’t release when it should, when it does release when it shouldn’t, and when the binding doesn’t stay affixed to the ski. The content of my research focuses on the last situation. Reasons why a binding can fail to stay attached to the ski can occur due to imperfections in the core material, insufficient composite reinforcement in the binding mounting area, or applying too much torque when tightening the screw into the ski. ASTM F474-98 states that the stripping resistance of the screw/ski interface should be greater than 5 Nm (ASTM International S150702, 71). If more than 5 Nm is applied to the screw, it can damage the surrounding material that is designed to retain the screw, causing the tensile strength (or pullout strength) to decrease.

2. Product Basis

2.1 Background

The snow ski industry is full of advancements and progressive thinking in product design. Companies are coming out each year with different combinations of ski lengths, widths, and shapes. The designs of the skis that are currently being produced are becoming more and more specialized, which makes it desirable, and perhaps necessary, for skiers to own more than one pair of skis, each customized for certain types of skiing conditions. Someone who skis twenty-five or more days a year usually owns at least two pairs of skis. It is not uncommon for avid skiers, who spend fifty or more days a year on the slopes, to own as many as four pairs of skis. Also, different styles of skiing (alpine, telemark, and alpine touring) each require their own type of binding affixed to a dedicated pair of skis.

Retention bindings have been mounted on snow skis the same way since the activity was started. The hole-pattern of the binding is drilled into the ski, the hole is coated with glue, and then the binding is affixed to the ski with a rough thread screw. The bindings typically stay in this some-what permanent state, paired with the same skis, throughout the period of usage. The reason is because continual removal and re-affixing would weaken the structure of the ski and it would eventually fail, causing the screws retaining the binding to be ripped from the ski.

2.2 Motivation

As the snow sports industry evolves and becomes more specialized, many customers have found the need to buy multiple pairs of skis for varying snow conditions. Buying another pair of skis involves the purchase of another set of bindings. It seems obvious that the customer would benefit from being able to use the same pair of bindings on two different pairs of skis or two different bindings on the same pair of skis. This has been accomplished for many years in the snowboard industry and is recently becoming popular in the telemark style of snow skiing. The way this is accomplished is by adding machine threaded binding inserts into the core of the board or ski in the early stages of production. It is then sandwiched inside the plastic and composite materials and heat pressed with epoxy to form the final product. The overlaying materials are then drilled out from above the inserts to expose the female threads. The bindings can be fixed and removed without worry of damaging the core material(s).

There are two reasons why this can be accomplished in snowboards and telemark skis. This is due to standardized hole-patterns and mounting positions. It is for these two reasons that this process cannot be accomplished with downhill skis. Each company has their respective pattern of holes to mount their bindings to the skis. And, varying sizes of ski boots would require that the toe and heel parts of the binding be varying distances apart from each other. The reason why it is possible in telemark skis is because the toe piece of a telemark binding is mounted according to the chord line (or middle of the ski), whereas a downhill binding is mounted according to the middle of the boot. So, the toe of a telemark ski is typically in the same place for all boot sizes and the placement of the heel portion of the binding is less significant since it does not perform any retention in the system.

The only way to use this type of binding insert in an alpine snow ski would be to make a custom ski specifically for each customer. This would require that each ski be made for the certain boot size and binding used by the customer. It is not feasible that a large company could adopt such a process and could only be accomplished by a small, custom manufacturer.

2.3 Context

The idea of having a binding that was transferrable between skis was addressed by one company around 2002, Line Skis. They designed a binding that had a standard hole-pattern that mounted through a plate, which connected the toe and heal portions of the binding. The idea was revolutionary and almost changed the ski and binding industry. Since the binding had a standard hole-pattern and mounting position, the company was able to produce skis with binding inserts in them. Line even received recognition from The Journal of Medicine & Science in Sports & Exercise for its potential reduction in ACL injuries. The whole idea was exciting, but it had some major design flaws. The binding itself was too heavy, the elevation of the boot off of the ski was too high, it was expensive, could only be used on their skis, and it came from a company that had not previously manufactured bindings. They eventually came out with a plate that could be mounted to any ski and adapted it to the bindings system. This only added to the first two problems listed.

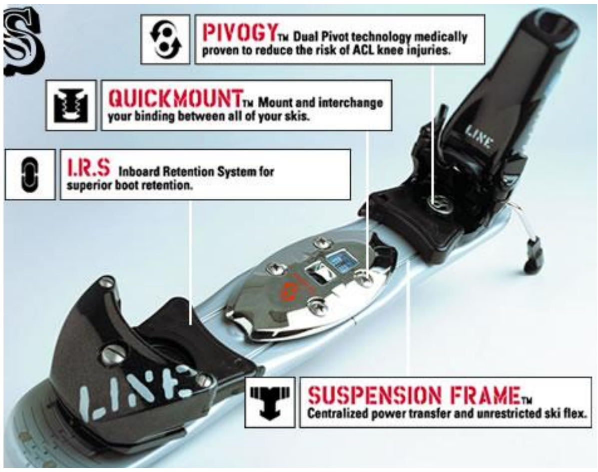


Figure 8: Line Reactor Binding (Skipress World)

The problem was that they focused on the binding itself, instead of the way they are affixed to the skis. My proposed product adapts the traditional method of mounting skis with the use of machine threaded inserts. The hole-pattern can be drilled for any binding and any position. The insert will have a rough outer thread, similar to those currently used to mount downhill bindings, with an inner machine thread, like those used to mount snowboards and telemark skis. The product design is inexpensive and simple, installation is virtually the same, and the applications are limitless. It solves all the problems of the transferrable binding attempt.

3. Methodology

The research question asks: Is it possible to manufacture an insert that will allow a person to mount a single pair of bindings on multiple pairs of skis or multiple bindings on one pair of skis? I have chosen four criteria to choose the material and manufacturing process: strength, durability, manufacturing cost, and production time. Through my research I have determined the different materials and processes that can make this product. I will analyze these options according to the criteria and determine the method that will move on to the testing phase.

3.1 Criteria for Data Analysis

I will use a rating system that was taught by Dr. A. Brent Strong in his Manufacturing 355 class. In this process you choose the four most important characteristics. I have chosen: strength, durability, cost, and time. You assign a weight factor (WF) according to its importance, from one to five, five being the most important. Then, you rank your options from best to worst, worst being one. I will give an example of how this is used in Table 1, where three options will be evaluated according to four criteria.

	Properties								
	Property 1		Property 2		Property 3		Property 4		
		WF= 5	Rank	WF= 5	Rank	WF= 4	Rank	WF= 3	Total Score
		Score		Score		Score		Score	
A	1	5	3	15	2	8	1	3	31
B	2	10	1	5	3	12	2	6	33
C	3	15	2	10	1	4	3	9	38

Table 1: Example of scoring criteria

The weight factor is multiplied by the rank to get a score for each property. The four property scores are then added to get a total score. The option with the highest total score is considered to be the best option according to the four properties. In this example, Option C has the highest total score of 38.

I will explain why I have chosen these characteristics and briefly explain how they will be applied to the evaluation process. They will each be assigned a weight factor and the reasoning given for each value.

3.1.1 Strength: The strength of the insert is the most important factor in the evaluation process. The equipment or process used must be able to create an end result that is at the same level as the current screws used to mount bindings. If the strength isn't as high, then avid users will not consider the product, and it won't hit the whole range of the market. I have assigned the maximum weight factor of five because of its extreme importance.

3.1.2 Durability: Durability can be confused with quality, but there is a subtle difference. Where as quality covers the craftsmanship of the product, durability involves its capabilities. Durability is equally important as strength, since it will determine the amount of use the consumer will get from the product. If the insert has high quality (appearance), but lacks in durability, an expert skier may be inclined to return the product or spread bad publicity through word of mouth. I have assigned a weight factor of five as well to the property of durability.

3.1.3 Manufacturing Cost: The cost to manufacture a product is relevant because it directly relates to the final retail price that the consumer must pay for the product. Higher production costs will either equate to higher retail prices, or a lower profit margin for the business. There are two costs that need to be considered: the initial costs of machines and/or tooling, and the cost of materials that go into each insert that will be sold.

The differences in these costs will be discussed in relation to the construction method that is used, but it is significant enough that a weight factor should be given to each type of cost associated in the manufacturing process. I have assigned a weight factor of four to initial costs, and a weight factor of three to the cost of materials. The reason why I assigned a higher value to initial costs is because it is dealing with equipment that ranges from hundreds to thousands of dollars. The cost of materials won't fluctuate as much per unit. Materials can also be ordered according to product demand, while the initial price to purchase a machine or tooling is decided before production.

3.1.4 Production Time: Production time is important for the overall efficiency of the company. If a company is small, the main concern isn't mass-production. The critical factor is that the time to produce the inserts isn't so long that you can't keep up with demand. If there were a direct relationship between time and cost, there wouldn't be a need for an additional property category. But, since there isn't a proportional correlation and because money is more valuable than time for a start up business, I am assigning a weight factor of two for production time.

4. Material Comparisons

Based on many years of using screws, it was apparent that the length of a screw was a contributing factor to the pullout strength. I had also noticed that longer screws tend to be thicker in diameter. I was not sure, though, whether the increased diameter was to prevent the screw from breaking while it is being driven or if it contributed to the pullout strength. The Forest Products Lab of the US Department of Agriculture provided an equation for withdrawal load or pullout strength of a screw in wood:

Equation 1: P=108.25G^2DL

Where P is maximum withdrawal load (N, lb), G is specific gravity based on oven dry weight and volume at 12% moisture content, D is the shank diameter of the screw (mm, in.), and L is the length of penetration of the threaded part of the screw (mm, in.) (Rammer, 8-10).

This equation confirmed that the diameter (D) of a screw is the key variable when using a material of similar specific gravity (G) and the same length screw (L). This means that using an insert with a greater diameter than the supplied screw, would provide greater pullout strength as long as the screw to insert interface has greater pullout strength. The maple species of wood has the highest specific gravity of the hardwoods typically used in ski cores, which is G=755kg/m^3/(1000kg/m^3)=.755. ASTM F473-96 provides us with the value for L as 8 (mm) and ASTM F475-77 provides D as 4.2 (mm). Using these values we can solve for P.

P=108.28(.755)^2(8)(4.2)=2073.8695N

This value is consistent with ASTM F474-98, which requires the tensile strength of a screw in a ski to be over 2200N.

The two types of materials that are currently used to repair a binding that has been pulled out of a ski are nylon and brass. These parts are shown in Figure 9. I have chosen to evaluate those two materials, as well as stainless steel for potential materials. These three materials will be evaluated according to the criteria stated above.

Figure 9: Ski repair inserts

4.1 Nylon

4.1.1 Advantages: The main advantage of using nylon is that it is inexpensive and easy to work with. Nylon also has high resistance to the elements. It will be easier to manufacture using an injection mold process, which will be fast and relatively inexpensive.

4.1.2 Disadvantages: The main disadvantage is the low resistance to fatigue, so its overall durability will be significantly lower than the other options. Although nylon is inexpensive and the injection process is simple, there is a high initial cost of creating the injection mold for the part.

Advantages	Disadvantages
Cheap material	High mold cost
Fast production time	Fatigue easier
High resistivity	
Light material	

Table 2: Advantages and disadvantages of nylon

4.2 Brass

4.2.1 Advantages: Brass is a non-ferrous material, which makes it is easier to machine. A computer numerically controlled (CNC) lathe can easily machine the outer thread, drill out the middle, and create the inner thread. The other advantage of using a CNC lathe is that the programming to make the part can easily be changed to make slight modifications to the design. Brass is also more durable than nylon.

4.2.2 Disadvantages: Brass is an expensive material, which will increase the per unit cost. Even though the initial set-up costs are low and programming is easy, the CNC machines that will be used are very expensive. The initial costs can be minimized by paying a machine shop instead of purchasing the machine, but hourly machine charges are around $80/hr.

Advantages	Disadvantages
Easy to machine	Expensive machine
Durability	Expensive material
Fast set-up and program changes	Weight

Table 3: Advantages and disadvantages of brass

4.3 Stainless Steel

4.3.1 Advantages: A lot of the advantages for stainless steel are similar to those of brass. It has high strength, durability, and resistance to corrosion. The set-up times and costs are low and changes to the part design can be made very easily.

4.3.2 Disadvantages: Some of the disadvantages to stainless steel are also similar to those of brass. It requires the same type of machine to do the work. Stainless steel is less expensive than brass, but it is a little harder, which means that the cycle times on each part will be slightly higher. It is also heavier than nylon, but not quite as heavy as brass. The specific weight of stainless steel is 7.5 versus 8.5 for brass.

Advantages	Disadvantages
Strength	Production cost
Durability	Production time
Initial Cost	Weight
Fast set-up and program changes	

Table 4: Advantages and disadvantages of stainless steel

4.4 Comparison Chart

There are several benefits and shortcomings of each construction method. The criteria of strength, durability, cost, and time were an excellent way to measure the effectiveness of each method. The only limitation of the weight factor method is that you have to decide on a final rank between the options involved. Since the factors of strength and durability are so important, nylon was easily eliminated from the options. Brass and stainless steel had identical methods of production, so the two criteria of strength and durability again were what set stainless steel apart as the best choice.

Material	Properties										
	Strength		Durability		Initial		Cost of		Production Time		
	Rank	WF Score	Rank	WF Score	Rank	WF Score	Rank	WF Score	Rank	WF Score	Total Score
Nylon	1	5	1	5	1	4	3	9	3	6	29
Brass	2	10	2	10	2	8	1	3	2	4	35
SS	3	15	3	15	2	8	2	6	1	2	46

Table 5: Comparison chart for material according to research criteria

4.5 Material Evaluation

At the beginning of this section we determined that the pullout strength of a standard binding screw is approximately 2000N. According to Equation 1, a screw with greater diameter should have a greater pullout strength in the same material with the same penetration depth. It was decided that if the interface between the insert and machine screw had a higher tensile strength than the pullout strength of the screw, it should be successful. Ultimate tensile strength (UTS) is calculated by dividing the pullout force by the area of the bolt's cross section.

Equation 2: UTS=F/A

I have decided to use a metric M5 bolt, which has a stress diameter of 4.2494. Using 2000N as the force and solving for the stress area, we can solve for the minimum UTS to select the grade of stainless steel.

$$UTS=2000N / (\pi*(.0042494m/2)^2) = 141,087,752.0214N/m^2$$

According to the ASM website stainless steel Type 304 has a UTS of 73200 PSI (505,000,000 N/m^2), which is over three and a half times stronger than what is required.

5. Product Development

Now that the research has been done and the material has been chosen, it is on to the development stage. As an applied project this is where the fun begins. Many hours of research will start to take shape into a tangible product. The next steps are to design the product, create the prototype, and perform testing to evaluate if the research goals have been accomplished.

5.1 Product Design

When I started into my applied emphasis of product development, I had a little bit of experience with computer-aided design (CAD). My wife studied architecture and she taught me the basics of AutoCAD. I became very interested in the usefulness of the program and started to teach myself some of the more advanced skills. As I reached the mid-point of my computer-aided manufacturing (CAM) class, I found it necessary to learn 3-dimensional design. I chose to learn SolidWorks because of its universal use in the design industry. The insert was originally designed with

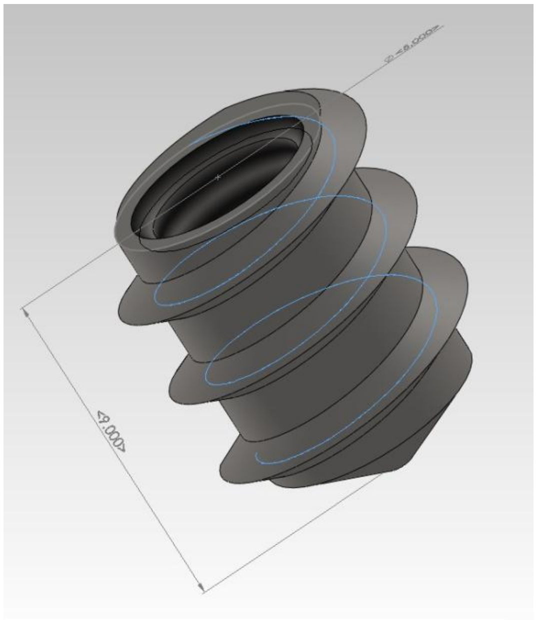


Figure 10: Course thread insert

a very course 9mm outer thread and a M5 machine thread on the inside. This was similar to the brass insert that is used to fix screws that had been previously pulled out of the ski.

5.2 Problems and Changes

It was at this point that I started to question the legal ramification of producing this product. I had worked in a ski shop for several years and there are certifications that you must pass to mount ski bindings. These certifications prove that you know the proper standard procedures to properly mount and adjust ski bindings. When a certified technician mounts and adjusts a pair of bindings, the liability of the product remains with the binding company. If the proper procedures aren't followed or certifications attained, the technician and ski shop are not indemnified against legal suits. Since this product would decrease binding sales, I highly doubted that the binding companies would indemnify anyone using this product.

During this time I also found myself without access to the necessary equipment on campus to product prototypes for testing. My project was at a serious stand still. Fortunately for my research, there was a new turn of events. Another group of engineers started working on a nearly identical product and started selling it to the public. I now had access to a product that I could perform testing on, although I would most likely not pursue the product past the testing phase.

5.3 "Prototype"

The product produced by this company had only one difference to my design. Instead of using a course outer thread, they used a 5/16-18 thread. The outside diameter of the thread is 5/16" (7.9375mm) instead of 9mm. It has a pitch of .0556" (or 18 turns per inch) that equated to approximately 5 revolutions. My design had a .0984" pitch, which had 3 revolutions. The

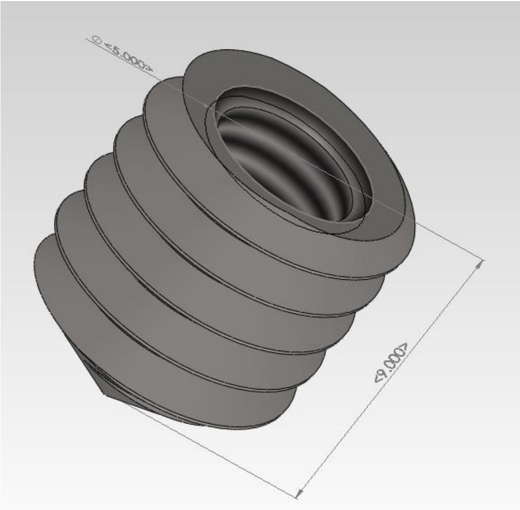


Figure 11: “Prototype” insert

length of the insert was the same due to the standard for mounting depth and the inside was tapped for a M5 bolt. I decided to replicate the CAD drawing of this new design just for visual reference. Although it was not as satisfying to create the test sample myself, it was somewhat gratifying to see that I had a good idea and to physically hold it in my hands. I now had something that I could perform tests on to verify my idea. It will also serve as a reminder to not let a good idea sit too long.

6. Testing

ASTM F474-98 provides instructions on the standard method to test the retention strength of the binding mounting area on a snow ski. This standard was withdrawn in 2004 because of lack of interest. I decided to modify the standard test since I wanted to test the screw itself and not the binding mounting area. The standard lists the following qualifications:

- The screw should be mounted according to the manufacturer’s recommendations
- Drill a hole with diameter 4.1mm to a depth of 9mm
- Tightening torque should be 4 +/-. 05 Nm
- Minimum spacing of 25mm on at least 4 samples
- Loading rate should not be more than 20 mm/min
- No tapping should be performed or lubrication applied

6.1 Test Samples

I chose to test the standard binding screws against the inserts on a matching set of skis at corresponding locations. I used a mounting jig to ensure that the holes were drilled perpendicular to the ski surface. Figure 12 shows the test samples with spacing of 50mm. After they were drilled, they were cut into individual pieces, so the samples wouldn't interfere with each other.

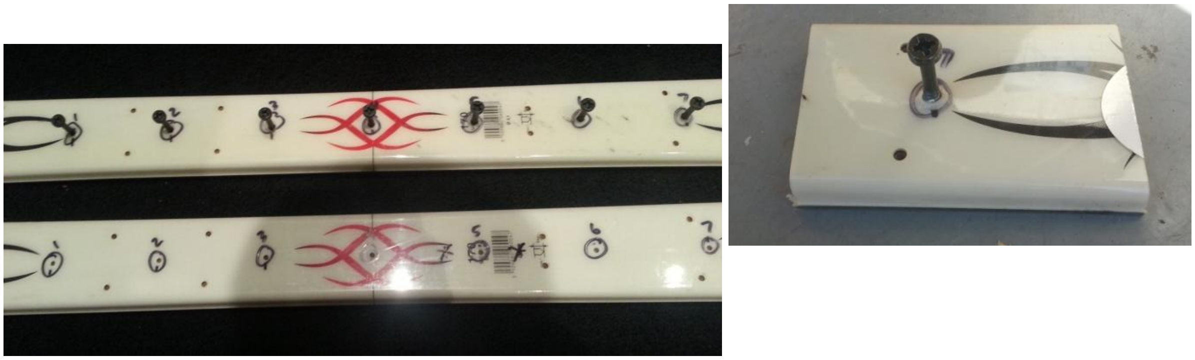


Figure 12: Test samples

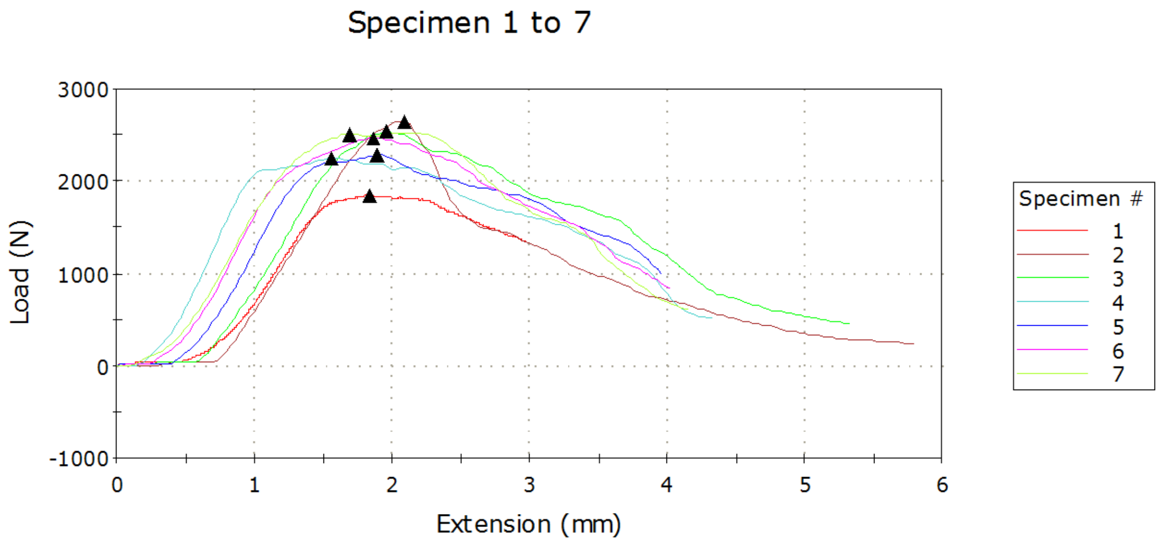
6.2 Test procedure

The lab located in room 160 of the Crabtree Building on Brigham Young University's campus houses an Instron Tensile Tester. I had to modify the top and bottom fixture so that it would hold the sample piece and pull vertically on the screw. Figure 13 shows the fixtures holding the sample piece during the testing process.

Figure 13: Instron testing samples

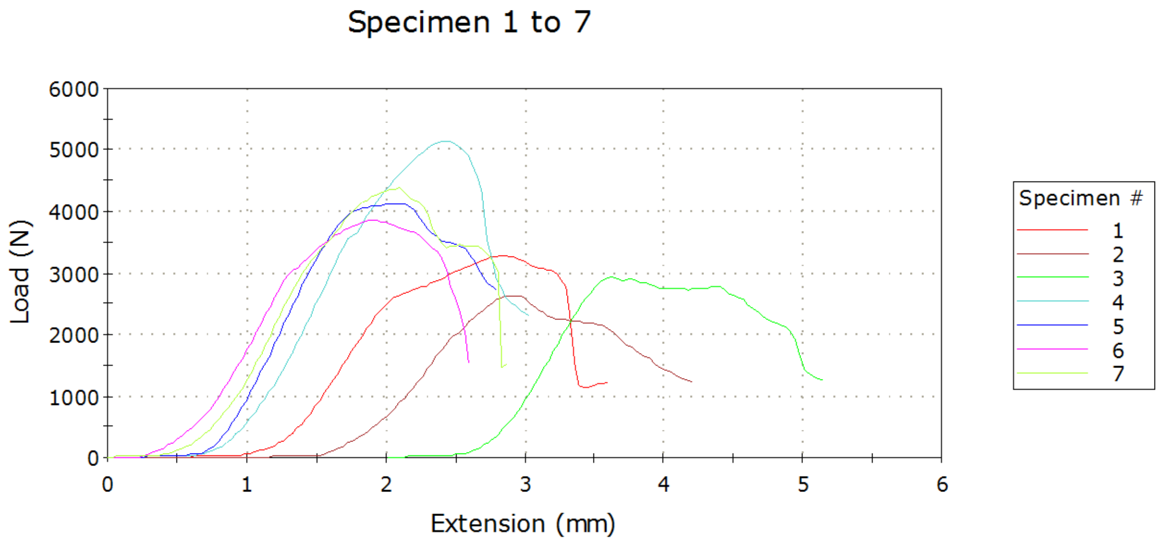
6.3 Results

6.3.1 Binding Screw Results: The first sample tested was an outlier. There are two possible reasons for this. The most probable reason was that the rate was set too low and the subsequent samples were tested at 20 mm/min. The other reason could be that there was an imperfection in the core, which caused the screw to fail prematurely. That is the reason why I performed the test on seven samples instead of the required four. I decided to throw out Specimen #1 because of the difference in the feed rate.



Graph 1: Binding Screw Results

6.3.2 Insert Screw Results: The graph for the insert screw results doesn't look as uniform as the binding screw results. The reason for this was that I didn't re-zero the extension before the first test. Specimen #2 had an unusually low Load value. The reason for this is that I didn't apply a small amount of pressure on the sample before starting the test and its results will be thrown out.



Graph 2: Insert Screw Results

6.4 Conclusion

Table 6 shows the results for the seven specimen samples for the binding screw and insert screw. After throwing out the two outliers that resulted from improper test procedures, I averaged the remaining six samples. The average peak load of the binding screw was 2449.784N and the average of the insert screw was 3953.505N. Equation 1 predicted that the force required to pull out the binding screw would be greater than 2073.8695N, considering there is fiberglass adding to the retention strength of the wood core. It is interesting that the proportionality of Equation 1 held true for the relationship of the binding screw diameter to the insert screw diameter. Holding all other variables constant the strength required to pull out the screws should be proportional to the minor diameter of both screws:

Equation 3: F(insert) / F(screw) = d(insert) / d(screw)

Where F is the force required to pull out the screw (N) and d is the minor diameter of the screw (mm). After completing the samples on the binding screw I could have predicted the force required to pull out the insert by solving for F(insert).

F(insert) = d(insert) * F(screw) / d(screw)

F(insert) = (6.6802mm)*(2449.784N)/4.2mm = 3896.439 N

The result is surprisingly only 57.065N off from the observed average force, which is only a 1.443% difference.

	Binding Screw Load at Machine Peak Load (N)	Insert Screw Load at Machine Peak Load (N)
1	~~1843.788~~	3282.788
2	2647.582	~~2642.689~~
3	2537.711	2931.823
4	2243.683	5137.696
5	2277.045	4132.843
6	2470.542	3848.602
7	2522.142	4387.281
Average	2449.784	3953.505

Table 6: Comparison of Binding Screw to Insert Screw

I can conclusively say that the insert was successful in meeting the goal of exceeding the industry standard for ultimate tensile strength. By design, the product meets the second goal of achieving the freedom to mount a single pair of bindings on multiple skis and also mounting multiple pairs of bindings on a single pair of skis.

6.5 Future Research Directions

I intend to pursue additional testing of this product in my graduate program at Brigham Young University. Once I have the proper resources again, I would like to produce a working prototype of my original design with a course thread that can be compared to the design used in my testing. Also, I would like to perform torque tests on similar samples to verify that the insert meets or exceeds the required value of 5 Nm. As part of that testing I have already designed a variation on the tested sample that incorporates vertical channels in the thread. The reason is that when epoxy resin is applied to the hole when inserting the screw, it might create a channel lock effect that will increase the resistance to fatigue through continuous tightening of the screws when switching out the bindings. Figure 14 is a representation of the new insert design.

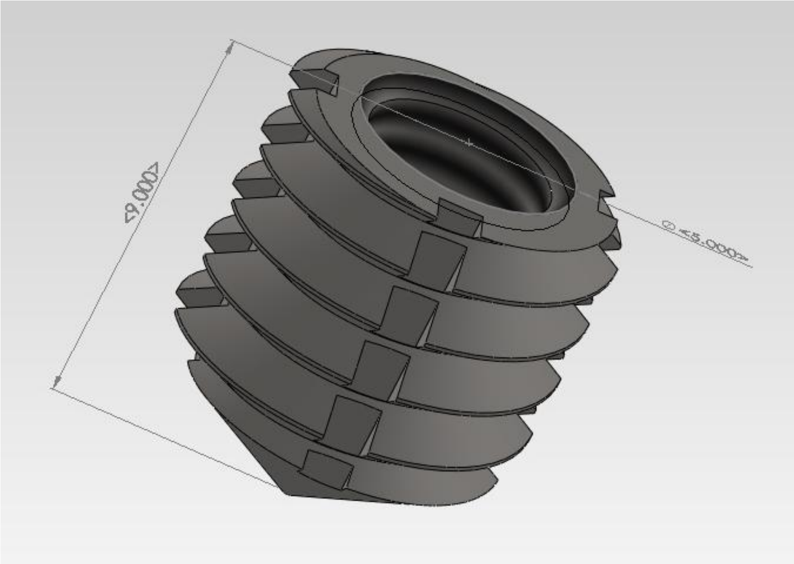


Figure 14: Design for future insert testing

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