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Mechanical Property Testing of Alpine Skis and Bamboo Ski Cores

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I. Introduction

Prior to starting of this research project, Atomic skis was visited to gain valuable insight on how the ski manufacturing process on a large scale is completed. Also some basic information on how Atomic does research and development on their skis was obtained. Below is a summary of the factory tour taken at Atomic.

Atomic is an international ski brand, based out of Austria, producing skis and ski equipment worldwide founded in 1955. The brand Atomic is owned by Amer Sports, a large scale Finish company, which also owns other ski brands like Salomon, Armada, and Black Crow. The corporation has a yearly turnover of 371 million euros. Each year the production factory in Altenmarkt, Austria produces around 1.1 million pairs of snow skis which accounts for a quarter of the worldwide snow ski production. High quality racing and nordic skis ranging from 800 to 2000 euros in price and they are the primary production focus in Altenmarkt. However, lower quality and less expensive skis are also produced there.

Ski production in Altenmarkt, Austria starts with the sourcing of raw materials. Poplar and Beech, obtained from Central and South Europe are used for the different types of snow ski cores used in Atomic skis. Other materials like epoxy and Acrylonitrile Butadiene Styrene (ABS) plastics are purchased from Germany. Atomic does a large portion of material process at their factory in Altenmarkt to ensure the highest quality of ski. There are six main sections of the factory (1) wood processing (2) metal processing (3) graphics (4) layup/pressing (5) finishing (6) quality control, all containing multiple steps leading to a very complex process of manufacturing production. Most of the processes in these areas are automated, but some are completed by hand.

Wood processing starts with large wooden blocks being loaded into an automatic bandsaw and cut down into thinner pieces with a taper design, these will serves as one half of a ski core. Two half cores and then finger jointed and bonded together using epoxy to form an entire core. These cores are then planed, and put on a Computer Numerical Control router to be cut to the desired shape for each specific ski model. After that process, the tips of the ski cores are between two heated rollers to bend the tip into the shape of a snow ski.

Metal processing is similar to wood processing in that the metal needs to be cut into the desired shape and size for a specific ski model. Surface texturing and cleaning also needs to be done to help ensure bonding between the materials is maximized. Titanium and Aluminum are the most commonly used metals in this area of the factory which are used to make the ski stiffer.

Graphic design is something that is becoming more and more important in the ski industry because to the average skier it can be a deciding factor on which pair of skis to buy. For this reason, Atomic does all their own graphic designs in Altenmarkt. This includes top sheet printing of their own designs, along with printing custom designs for customers. It also includes using a Computer Numerical Control on the ABS plastics to cut and create designs on the base of the ski, as well as the top layer.

Once materials are completed in the first three areas of the factory they are sent to the layup/ pressing area. There the materials are laid down in a specific order and more epoxy is applied before being put into a hot press. ABS plastic is used for the base of the ski, then carbon fiber, fiberglass, and metal inserts are added to give the ski the desired flex. Additionally, ABS plastic is added to the tip and tail of the ski to help dampen vibrations when using the skis, especially when riding on firm or icy conditions. Finally, the top sheet with the desired graphic is placed on top. The ski is then ready for pressing. Skis are pressed for 30 minutes at a temperature of 140℃. This method of pressing is called "sandwich pressing" and is used for higher quality skis. Around 40 pairs of skis can be pressed by a single press each shift and there are 19 total presses.

After pressing, the skis are move to finishing. This is where excess material is cut off from around the edges of the ski. Then the ski edges are sharpened before a layer of wax is added to the base of the ski. The skis are then heated to around 50 ℃ to melt the wax of the base and ensure an even layer. Finally skis are cleaned with acetone and a plastic film, that was used to protect the graphic on top, is removed.

Quality control is the final step of the manufacturing process until the skis are ready for sale. Here an employee has measures different dimensions of the skis, like tip radius, thickness, and curvature of the base. Using this information he or she pairs the snow skis together so they are as close as possible to the same dimensions. The employee can even slightly bend the ski to help get it to the correct shape for more identical pairing of the skis. All this work is done by hand and experiences. There isn't a guideline for how it is done. This process takes experience and a good eye. Finally, all information about the ski, for example model and dimensions, are entered into a computer and assigned a serial number. This information is then put onto a Quick Response Code and added onto the skis. This helps Atomic track which ski it is in case of defects or warranty claims.

Overall, the process to make skis contains many steps all which are crucial to producing the high quality skis Atomic has a long history and track record for. Atomic also does many different tests on their skis ranging from friction tests, cyclical tests, bending test, and many more. Unfortunately, these tests are a carefully guarded secret and most employees don't have access to the information. Therefore, this area of the factory in Altenmarkt is closed to the general public.

This research study was done at the Fachhochschule Salzburg University of Applied Sciences in Kuchl, Austria under the Marshall Plan Foundation scholarship with Oregon State University and ON3P as partners. ON3P is an alpine ski manufacturing company based out of Portland, Oregon which produces high quality handmade alpine skis. The testing materials for the study were provided by ON3P, while FHZ Salzburg Campus Kuchl provided the testing equipment machinery and lab space. This study itself and the location were chosen due to the large alpine ski industry based around the Salzburg area and the limited amount of resources available in Portland, Oregon. During the study both the manufacturing sites for Atomic skis and Fischer skis were visited to gain valuable information about the alpine ski equipment industry and how manufacturing and testing of alpine skis is done on a larger scale. Due to privacy of ON3P's products analysis of the differences in properties in the alpine skis and ski cores has been left out of the report. Therefore, the main purpose of this study is to help build a database for small ski companies, gain hands on experiences in testing alpine skis, and develop various test methods for testing alpine skis and wooden ski cores.

Personally, I have been skiing since five years old, but prior to that my parents would take my sister and me to the Sawtooth Mountains in Idaho and snow shoe with us in backpacks. The winter, the snow and skiing has always been a passion of mine. I started out as a young child when my mom would take me to the local mountain in Boise, Idaho and help me point my tips down the slope. This quickly developed into my favorite thing to do during the winter. I would watch the older kids and I always wanted to ski as fast as them or jump as high as them. I never wanted to be left out. Before I knew it, I was joining the school ski clubs, trying make friends with anyone who skied, and begging my mom each weekend to take me skiing. In high-school, my friends and I could finally drive ourselves to the mountain. We would go three times a week at the minimum and it was all we could talk about. Freestyle skiing in the terrain park was my favorite type of skiing from ages 14-20. I would spend all day doing laps on the same 3 runs trying over and over to do new tricks and make the ones I could do look that much better. Once I hit 21 years old I started to become more interested in off piste skiing, especially if there was lots of new powder to be ridden. Transition from park skiing to powdering skiing I was looking for a pair of skis that could float on top of the powder, but had flexibility and play on the slopes. This is when I found out about ON3P who has wide powder skis that were also very flexible and fun to ride. Since then, I was able to gain an internship with ON3P in Portland, Oregon and to learn the ski manufacturing process. Hand crafting skis increased my interest even more about skiing and how skis worked. So, I began to do research on how to tests skis and what types of results were desired. I quickly found that little information was available and so I had to take matters into my own hands by designing my own alpine ski testing methods. With support from the Marshall Plan Scholarship and ON3P I was able to follow my dreams and start learning about how testing alpine skis in a scientific way for the ski industry worked.

ON3P makes alpine skis for freeriding, all mountain, powder and freestyle park skiing by hand in Portland, Oregon. The company started in 2006 in a garage in Tacoma, Washington making skis for friends and family members until the company slowly started to gain traction in the ski industry and ski community. In 2008 ON3P sold 53 pairs of skis built by hand in a garage by the owner and some of his friends. By 2009 ON3P had moved from Tacoma, Washington to a 2400 square foot factory in Portland, Oregon, where the real struggles of making skis for a living began. A third ski press was built in 2010 and it was time to restart the whole production factory from the beginning now that the owner and employees had gained more experience with ski building and how material flow in a factory should operate. Skip forward to 2013, ON3P has moved from a 2400 square foot factory into an 8400 square foot factory upgraded their process in multiple ways and added a CNC machine to their factory. By 2015 ON3P was doing 90 percent of their ski building process in house with all material prep and assembly being done onsite. Now ON3P has grown to be a well known name in the ski industry with products that can compete with any ski manufacture in the world. They make skis in a similar process to Atomic but everything is done by hand work not automated machines. The primary market for the company is freestyle park skiers, all mountain powder skiers, or just skiers who enjoy a lot of flexibility and play in their skis. To continue growth of the company ON3P now is moving into the testing world of skis to try and improve their products not only by experience or trial and error, but by a calculated scientific method. Doing this type of testing will not be easy for ON3P due to the lack of information available online, resources for testing are hard to come by, and cost of testing products and machinery can be high. However, just like all the other bumps along the way, ON3P seems to be determined to solve these problems and come out ahead making a higher quality and better product than ever before.

II. Overview

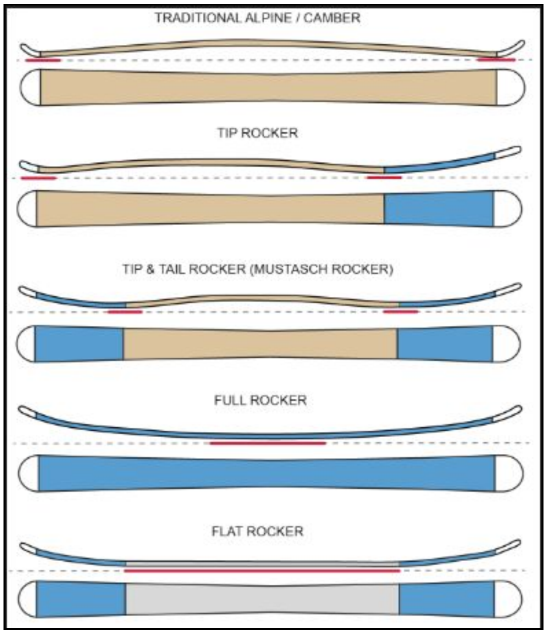
2.1 Background

Perhaps one of the oldest means of transportation on snow and ice is skiing. More than 2000 years ago, it was a classic case of, “necessity is the mother of invention.” The earliest snow skies were rough planks of wood with leather straps nailed on in a crude fashion for securing the skier’s footwear. In the eighteenth century, the sport of skiing evolved and equipment greatly improved. By the mid-twentieth century, skiing become a popular competitive and recreational industry with specialized equipment and clothing, innovative products, and high performing skis. Today, hundreds of companies compete for the market share and having their work stand out amongst fierce competition. Not only in a competition market between professional athletes but also in the recreational market between regular everyday consumers.

Today, the “shaped” skis is the industry standard with tip and tail wider than the middle where the binding are mounted. They provide an easier edging and a shorter turning radius. Alpine skis today are made of several materials along both the length and thickness. The base layer, is polyethylene-plastic. It has high absorption capabilities for gliding on the snow. Steel edges wrap the base layer from tip to tail. A layer of fiber reinforced plastic and/or metal sheet is next, followed by a thicker core of varying wood or foam. To increase the ski’s stiffness, a core a fiber reinforced plastic and/or metal is applied. Some skis may have a rubber material on top to improve the damping characteristics. The final or top layer generally serves for aesthetics and a cap.

Cambered skis, now commonly referred to as “rocker” skis, produce more pressure on the snow at the tip and tail since they have to flex further to achieve this curve. This is caused by a gap in the middle part of the ski between the snow surface and the bottom layer. Without camber the pressure from the skier is distributed on a much shorter length which makes the ski pivot easily. In other words, it behaves like a shorter ski.

“Rocker” on a ski is defined as a prefabricated angle of the ski’s tip and tail parts. It shortens the contact length when riding on a flat area, however when edging the contact length is increase due to the shape of the ski. Full rocker is when a ski does not have a camber part in the middle of the ski and instead there is a direct angle outwards to the ski’s tip and tail. In the photo below are the different shapes and types of skis.



Types and shapes of modern skis

In the backcountry, where the snow is deep, generally softer and ungroomed, skis without camber perform best. They float on the snow. To create a smoother ride in choppy or soft snow some skis are constructed with rocker. A ski can have rocker both in its tip and tail and some skis also have what is called full rocker.

Skis designed for groomed slopes, are often constructed with a binding plate in the middle part of the ski. It serves to help the skier apply extra moment over the ski's edge for better grip while turning. It also allows binding options – where the boot rests - which will vary the ski's stiffness.

To better understand how the mechanical properties of alpine skis impacts the performance and overall feel, testing of mechanical properties need to be conducted. There are many different types of tests conducted on alpine skiing ranging from friction tests, cyclical tests, and bending test. This study will primarily look at the properties obtained from a simple bending test.

Bending is a simple testing method used on wooden materials, however, the mechanical properties determined can be evaluated to solve complex issues with wood. More specifically 3-point bending tests can be used to find values for woods maximum strain, maximum stress, Modulus of Rupture (MoR), and Modulus of Elasticity (MoE). With a deflectometer attached, the total deflection of the wood can also be recorded. 3-point bending is done by applying a force on testing samples at the center of the span of the sample. Testing until sample failure is required to determine the MoR and maximums. However, prior to breaking, other tests like moisture content, torque, and damping ability must be tested before the sample is destroyed beyond use.

The most popular choice for a snow skis core today is wooden. Due to the dynamic properties of wood, a ski can react quicker to a skier, and it has a high durability to withstand the continuous change in applied force. These cores are commonly made up of laminated plywood sheets of bamboo, ash, birch, poplar, maple, and aspen and are shaped on a computer numerical control router (CNC). (Similar to hand-held router used for cutting various hard materials, such as wood, composites, aluminum, steel, plastics, and foams.) Ski manufacturers are producing skis with cores of different width, length, thickness, and species to outperform the competition and produce skis with the desired performance and feel.

The primary goal in ski construction is achieving high performance. High performance means mainly holding an edge while skiing on hard snow and ice, generally at high speeds. This performance criterion is controlled by a ski's torsional rigidity. However, high performance usually comes at a price. A ski that is torsional stiff will have a tendency to be stiff in flexion. Skis that are flexural stiff in nature require much more effort and skill to turn than skis that are soft. The opposite is also true, soft skis perform generally much less well on hard snow and ice than stiff ones, but are less tiring than stiffer variations. Ski manufacturers must find the right balance of stiffness and flex to meet the desired performance of the ski.

2.2 Problem Statement

Large scale ski companies like Atomic, Fischer, Armada, Salomon, K2 and Rossignol have the time, money, and resources to perform ski research and development. However, the information gained from these tests are kept privately within the company or corporation and only a handful of employees know how the testing works or the results. Due to the competitive market there is little exchange between ski companies and users regarding a ski's characteristics, even with top level World Cup skiers[1]. There are also few research publications published in print or electronically on-line about the testing of skis Most of the time a company will partner with a research institution and non-disclosure agreements will be used.

Currently, little information on the mechanical properties of alpine skis and wooden ski cores exists today. This is an issue for smaller ski production operations since equipment and resources to conduct mechanical properties tests can be difficult to find. Without this information companies have to design skis and ski cores based upon experience, non-uniform and non-regulated hand tests, or customer feedback. Designing skis not upon proven testing values can lead to material waste, time waste, and potentially detrimental skis.

2.3 Research Goals

The main goal of this study was to help a small alpine ski manufacturing company start to develop and standardize a database of mechanical properties for its bamboo ski cores and finished skis. This was done by researching current ski testing method, developing a series of mechanical property tests. Having this database could provide a small ski company with critical information about their ski cores and skis to help with future production. With standardized information on core flexure, ski companies can cut down on material waste by purchasing plywood close to the desired thickness of the ski cores. It also can avoid wasting time by reducing the amount of material processing needed to produce a ski core. Finally, by having standardize ski core flexure values, ski companies can produce safer skis for the consumer by allowing the skiing ability of the consumer to fit into the given flexure designed.

Another goal of this study was to provide ON3P with a comparison between the results of the different skis and ski cores to see how the geometry of the ski and ski core impacts the mechanical properties of the final product. However, this will be left out of the report due to privacy reasons of ON3P's products.

III. Materials and Methodology

3.1 Alpine Skis and Ski Cores

The materials that were donated and shipping overseas by ON3P included 14 individual snow skis and 14 bamboo ski cores. The skis ranged in length from 171 centimeter up to 186 centimeter. This was measured from the tip to tail of the ski. The width of the skis ranged from 98 mm to 116 mm measured from the widest part of the ski. Each ski is comprised up of a bamboo core, fiberglass, carbon fiber, Ultra High Molecular Weight Polyethylene plastic, steel edges, VDS plastic, and epoxy. The two models of skis that were tested were the Kartel skis, designed for all purpose and all mountain riding, and the Magnus skis designed to used in the terrain park for freestyle skiing.

The bamboo ski cores are made from a bamboo plywood made in Oregon and cut to shape using a CNC router table. Core lengths ranged from 157 centimeter to 177 centimeter with widths ranging from 88 mm to 112 mm. All cores were measured at 7% moisture content prior to testing by taking a small sample from each ski and weighing it and then putting each sample in an oven set at 103 ℃ and left overnight. The weight of each sample was then recorded the next morning and the moisture content was calculated.

All sample ski and ski core dimensions and information are provided in table 1 and table 2 in the results section. Photos of all skis and ski cores are provided in the figures section of the report (Figures 1-8).

3.2 The Damping Test:

This test was done by attaching one end of the ski to a table and having half the ski overhanging the table edge (shown in Figure 9). The ski's tip was then pulled straight down 20 centimeter until it came to touch the wooden block below the ski tip (This was to ensure the ski tip traveled the same distance down each time). The ski's tip was then released and the amount of time required for the ski to come to a complete stop, after the force was released, was recorded. This process was then repeated 10 times on each ski and an average damping time was recorded. The highest and lowest recorded times were excluded in the average time calculation.

3.3 3-Point Bending:

This test was done using a Zwick /Roell Z250 testing device with a maximum force of 250 kN. Prior to testing, the contact surface of the ski and the ground was determined by laying the ski flat on the ground and sliding a piece of paper under the tip and tail of the ski until the paper would become stuck. The point where the paper stopped was marked near the tip and the tail of the ski and the span of each ski was recorded. This contact surface was the span used for testing the skis. For the ski cores 20 centimeter was measured from the tip and tail of the ski core and was marked. The span between the two markings was the testing span for the bamboo ski cores. Once the span for the skis and ski cores were determined each ski and ski core were loaded individually into the testing machine. The supports to the machine were placed at the end of the contact surface of the ski with the load being applied to the center of the ski (shown in Figure 10). The ramp rate of the machine was set to 20 mm per minute and the applied load was set to 300 N for testing of the skis, this was determined using ISO Standard 5902- Alpine Skis-Determination of the elastic properties [2]. 600 N and 900 N tests were also done to see if the results remained constant but not the skis were tested. A preload force of 20 N was applied to each ski.

For the ski cores, the ramp rate was set at 20 mm per minute and the applied load was set at 100N. A preload force of 20N was applied to each ski core. The total amount deflection of the ski and ski core was measured and recorded once the testing device reached 300 N of applied force.

Another 3-point bending test was conducted on all the skis using the same parameters of 20 mm per minute for the ramp rate, 300 N of applied load, and a preload force of 20 N. The one difference was the span of the testing specimens was done all at the same length of 100 centimeter with the applied load still being on the middle of the ski. The total amount of deflection in each ski was measured and recorded.

Finally, a max strength 3-point bending test was done on the bamboo ski cores with the setup and testing span of the ski cores being the same as the previous 3-point bending test (shown in Figure 13). A preload force of 20 N was applied to each ski core. Due to the time it would take for the ski cores to reach a maximum force the ramp rate was increased from 20 mm per minute to 100 mm per minute and force was applied until the ski core showed signs of deformation. The maximum amount of force each ski core reached was recorded once deformation or material failure was observed.

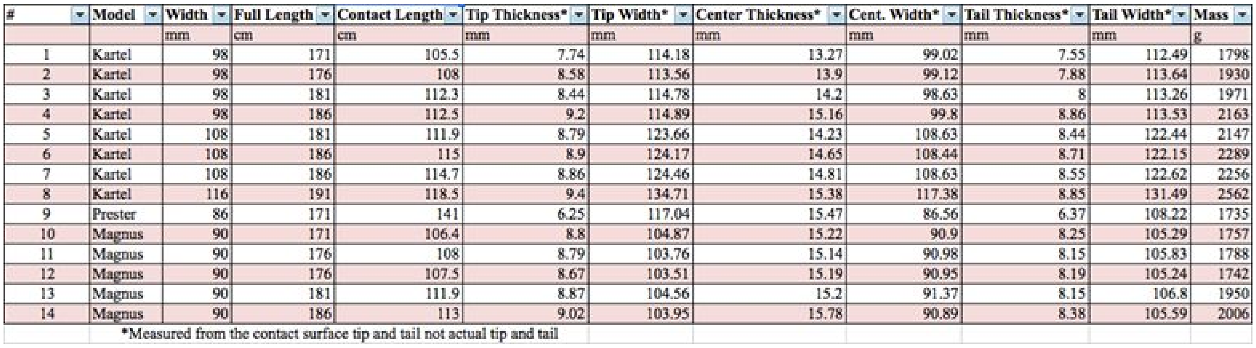
3.4 The Torque Test:

This test was done using a Zwick /Roell Z250 testing device with a maximum force of 250 kN. For the torque test a special stand had to be designed and built to hold the ski into the testing machine so the torque force could be applied correctly. The stand consisted of a wooden wheel that would fit onto the tip of the ski and a place to anchor the ski directly in front of where the bindings would be located (shown in Figure 11). The testing machine would then pull down on the outer rim of the wheel applying a torque force to the ski (shown in Figure 12). The testing span of the torque test was from directly in front of where the binding would be on the ski until where the wooden wheel was attached to the ski. This span was measured at 46 centimeter. The ramp rate for the testing machine was set at 20 mm per minute and the applied load was set at 200 N with a preload force of 20 N. The total movement of the testing machine was then recorded once the testing device reached 200 N of applied force.

IV. Testing Results

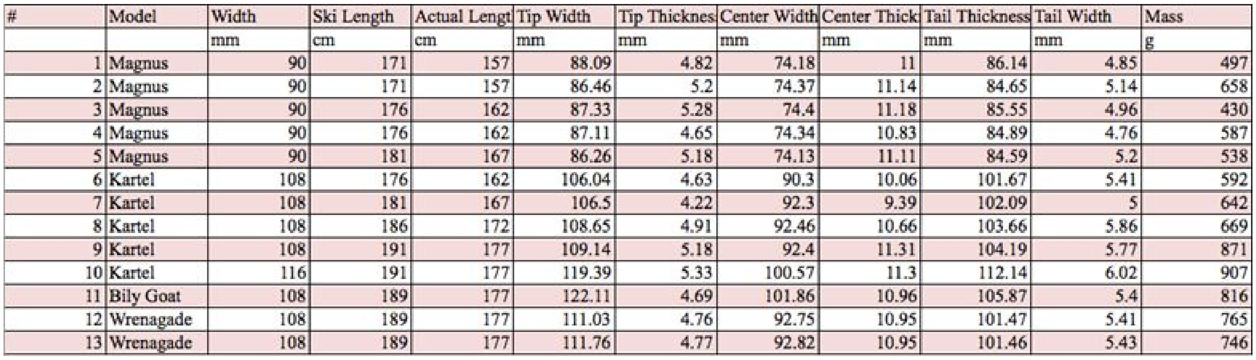
4.1 Test Results:

Prior to testing the model, dimensions, and mass of each ski and ski core was found and recorded into table 1 and table 2 found below. The contact length, tip thickness, tip width, center thickness, and center width were all measured from the start of the tip and tail contact surface, not the full length of the ski.



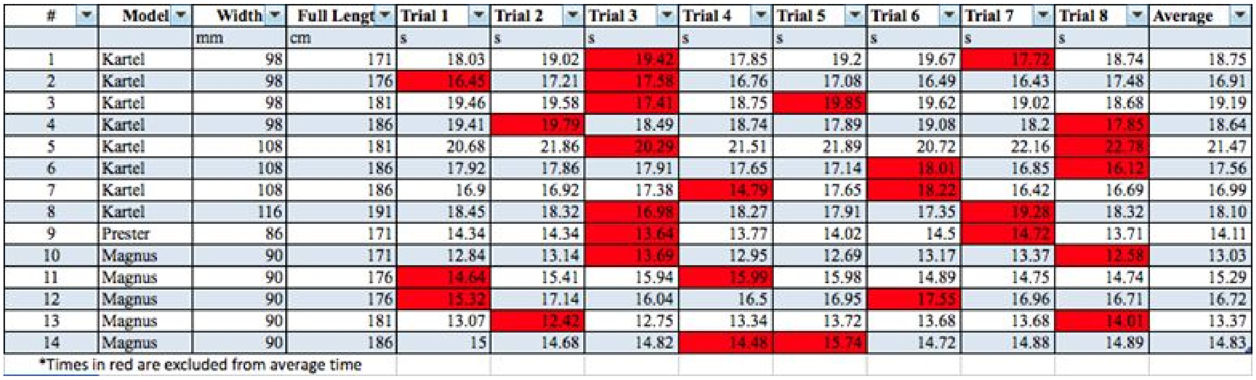
#	Model	Width	Full Length	Contact Length	Tip Thickness*	Tip Width*	Center Thickness*	Cent. Width*	Tail Thickness*	Tail Width*	Mass
		mm	cm	cm	mm	mm	mm	mm	mm	mm	g
1	Kartel	98	171	105.5	7.74	114.18	13.27	99.02	7.55	112.49	1798
2	Kartel	98	176	108	8.58	113.56	13.9	99.12	7.88	113.64	1930
3	Kartel	98	181	112.3	8.44	114.78	14.2	98.63	8	113.26	1971
4	Kartel	98	186	112.5	9.2	114.89	15.16	99.8	8.86	113.53	2163
5	Kartel	108	181	111.9	8.79	123.66	14.23	108.63	8.44	122.44	2147
6	Kartel	108	186	115	8.9	124.17	14.65	108.44	8.71	122.15	2289
7	Kartel	108	186	114.7	8.86	124.46	14.81	108.63	8.55	122.62	2256
8	Kartel	116	191	118.5	9.4	134.71	15.38	117.38	8.85	131.49	2562
9	Prester	86	171	141	6.25	117.04	15.47	86.56	6.37	108.22	1735
10	Magnus	90	171	106.4	8.8	104.87	15.22	90.9	8.25	105.29	1757
11	Magnus	90	176	108	8.79	103.76	15.14	90.98	8.15	105.83	1788
12	Magnus	90	176	107.5	8.67	103.51	15.19	90.95	8.19	105.24	1742
13	Magnus	90	181	111.9	8.87	104.56	15.2	91.37	8.15	106.8	1950
14	Magnus	90	186	113	9.02	103.95	15.78	90.89	8.38	105.59	2006
	*Measured from the contact surface tip and tail not actual tip and tail										

Table 1: model, dimensions, and mass of tested skis



#	Model	Width	Ski Length	Actual Lengt	Tip Width	Tip Thicknes	Center Width	Center Thick	Tail Thickness	Tail Width	Mass
		mm	cm	cm	mm	mm	mm	mm	mm	mm	g
1	Magnus	90	171	157	88.09	4.82	74.18	11	86.14	4.85	497
2	Magnus	90	171	157	86.46	5.2	74.37	11.14	84.65	5.14	658
3	Magnus	90	176	162	87.33	5.28	74.4	11.18	85.55	4.96	430
4	Magnus	90	176	162	87.11	4.65	74.34	10.83	84.89	4.76	587
5	Magnus	90	181	167	86.26	5.18	74.13	11.11	84.59	5.2	538
6	Kartel	108	176	162	106.04	4.63	90.3	10.06	101.67	5.41	592
7	Kartel	108	181	167	106.5	4.22	92.3	9.39	102.09	5	642
8	Kartel	108	186	172	108.65	4.91	92.46	10.66	103.66	5.86	669
9	Kartel	108	191	177	109.14	5.18	92.4	11.31	104.19	5.77	871
10	Kartel	116	191	177	119.39	5.33	100.57	11.3	112.14	6.02	907
11	Bily Goat	108	189	177	122.11	4.69	101.86	10.96	105.87	5.4	816
12	Wrenagade	108	189	177	111.03	4.76	92.75	10.95	101.47	5.41	765
13	Wrenagade	108	189	177	111.76	4.77	92.82	10.95	101.46	5.43	746

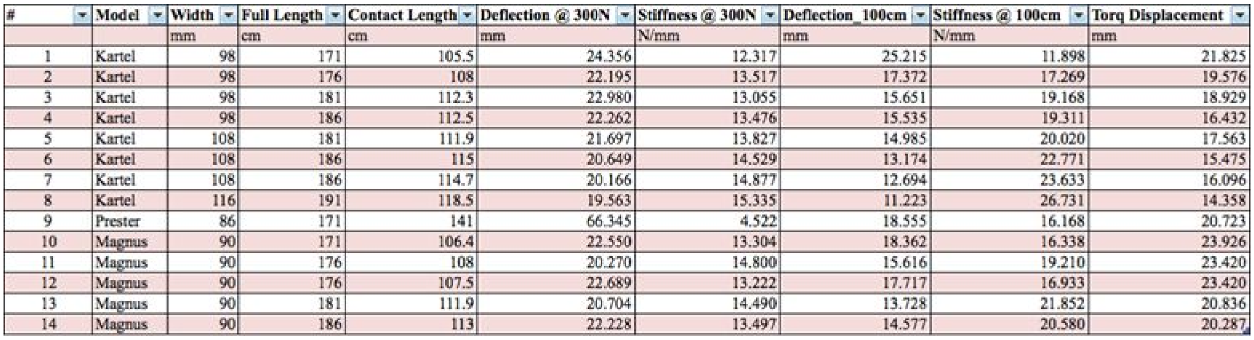
Table 2: model dimensions and mass of tested bamboo ski cores



#	Model	Width	Full Lengt	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Average
		mm	cm	s	s	s	s	s	s	s	s	
1	Kartel	98	171	18.03	19.02	19.42	17.85	19.2	19.67	17.72	18.74	18.75
2	Kartel	98	176	16.45	17.21	17.58	16.76	17.08	16.49	16.43	17.48	16.91
3	Kartel	98	181	19.46	19.58	17.41	18.75	19.85	19.62	19.02	18.68	19.19
4	Kartel	98	186	19.41	19.79	18.49	18.74	17.89	19.08	18.2	17.85	18.64
5	Kartel	108	181	20.68	21.86	20.29	21.51	21.89	20.72	22.16	22.78	21.47
6	Kartel	108	186	17.92	17.86	17.91	17.65	17.14	18.01	16.85	16.12	17.56
7	Kartel	108	186	16.9	16.92	17.38	14.79	17.65	18.22	16.42	16.69	16.99
8	Kartel	116	191	18.45	18.32	16.98	18.27	17.91	17.35	19.28	18.32	18.10
9	Prester	86	171	14.34	14.34	13.64	13.77	14.02	14.5	14.72	13.71	14.11
10	Magnus	90	171	12.84	13.14	13.69	12.95	12.69	13.17	13.37	12.58	13.03
11	Magnus	90	176	14.64	15.41	15.94	15.99	15.98	14.89	14.75	14.74	15.29
12	Magnus	90	176	15.32	17.14	16.04	16.5	16.95	17.55	16.96	16.71	16.72
13	Magnus	90	181	13.07	12.42	12.75	13.34	13.72	13.68	13.68	14.01	13.37
14	Magnus	90	186	15	14.68	14.82	14.48	15.74	14.72	14.88	14.89	14.83

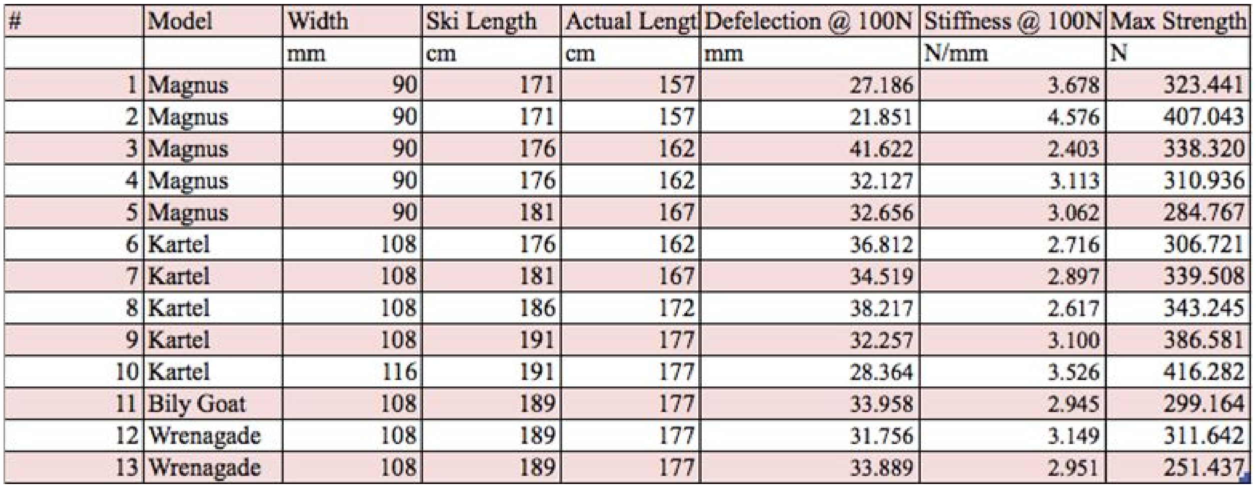
*Times in red are excluded from average time

Table 3: Results from damping test on all skis



#	Model	Width	Full Length	Contact Length	Deflection @ 300N	Stiffness @ 300N	Deflection_100cm	Stiffness @ 100cm	Torq Displacement
		mm	cm	cm	mm	N/mm	mm	N/mm	mm
1	Kartel	98	171	105.5	24.356	12.317	25.215	11.898	21.825
2	Kartel	98	176	108	22.195	13.517	17.372	17.269	19.576
3	Kartel	98	181	112.3	22.980	13.055	15.651	19.168	18.929
4	Kartel	98	186	112.5	22.262	13.476	15.535	19.311	16.432
5	Kartel	108	181	111.9	21.697	13.827	14.985	20.020	17.563
6	Kartel	108	186	115	20.649	14.529	13.174	22.771	15.475
7	Kartel	108	186	114.7	20.166	14.877	12.694	23.633	16.096
8	Kartel	116	191	118.5	19.563	15.335	11.223	26.731	14.358
9	Prester	86	171	141	66.345	4.522	18.555	16.168	20.723
10	Magnus	90	171	106.4	22.550	13.304	18.362	16.338	23.926
11	Magnus	90	176	108	20.270	14.800	15.616	19.210	23.420
12	Magnus	90	176	107.5	22.689	13.222	17.717	16.933	23.420
13	Magnus	90	181	111.9	20.704	14.490	13.728	21.852	20.836
14	Magnus	90	186	113	22.228	13.497	14.577	20.580	20.287

Table 4: Results from 3-point bending test, stiffness calculations, and torque test of all skis



#	Model	Width	Ski Length	Actual Lengt	Defelection @ 100N	Stiffness @ 100N	Max Strength
		mm	cm	cm	mm	N/mm	N
1	Magnus	90	171	157	27.186	3.678	323.441
2	Magnus	90	171	157	21.851	4.576	407.043
3	Magnus	90	176	162	41.622	2.403	338.320
4	Magnus	90	176	162	32.127	3.113	310.936
5	Magnus	90	181	167	32.656	3.062	284.767
6	Kartel	108	176	162	36.812	2.716	306.721
7	Kartel	108	181	167	34.519	2.897	339.508
8	Kartel	108	186	172	38.217	2.617	343.245
9	Kartel	108	191	177	32.257	3.100	386.581
10	Kartel	116	191	177	28.364	3.526	416.282
11	Bily Goat	108	189	177	33.958	2.945	299.164
12	Wrenagade	108	189	177	31.756	3.149	311.642
13	Wrenagade	108	189	177	33.889	2.951	251.437

Table 5: Results from 3-point bending test and max strength test of all bamboo ski cores.

4.2 Discussion:

Damping test of Alpine ski samples:

Looking at the results of the damping test on the ski samples, the average range of time it took each ski to come to a complete stop was between 13 second and 21.5 seconds. The ski that had the greatest damping effect was ski Number 13 the Magnus 90 with full length of 181 centimeter. The ski with the lowest damping ability was ski Number 5 the Kartel 90 with full length of 181 centimeter. There was a wide range of results in the damping test for the skis. This was believed to be primarily due to human error in the testing methods. Since the results were so varied, this testing method was determined to be inaccurate and not usable for future testing and comparison of final ski products. To improve on this method an apparatus, or simple machine needs to be built that pulls each ski down the exact same distant and releases it with the same force each time. There also needs to be a more accurate way of determining when the ski has come completely to rest since visual determination by the tester is inaccurate of leads to a large range of values. Using some type of vibration sensor or visual movement sensor might be a way around the inaccuracy of human while conducting this test.

3-point bending ski samples:

After completing testing it was decided that the results from ski Number 9 would be mentioned in the results, but excluded from the comparison between skis since it was a much older model. It had little similarities to the other skis tested. Since two types of skis were tested (Kartel and Magnus) the comparisons will first be between skis of the same model. Then the maximum and minimums of one ski model will be compared to the other ski model. Due to privacy of ON3P and their products, the reasoning between the differences in skis has been left out of this report. The method and results for the 3-point bending tests were determined to be accurate and usable data for future testing and comparison of final product skis. The first test can be used to help determine the stiffness behind a ski based upon the materials used and the geometry of the ski (length, width, thickness, mass). Meanwhile, using the first 3-point bending test results paired with the 100 centimeter span bending test, the geometry of the ski can be excluded in the comparison and a more accurate reasoning for how only the material in the ski affects stiffness can be concluded.

Looking at the results of the first 3-point bending test conducted on the skis with 300N of force applied and the contact surface of the ski being the testing span, the range of deflection for all the skis varied between 19.5 mm and 24.3 mm with the stiffer skis deflecting less and the more flexible skis deflecting more. The deflection values for all the skis then translated into a stiffness values for the skis ranging between 12.3 N/mm and 15.3 N/mm with the stiffer skis having a higher value. Looking at the Kartel group first, for this test the stiffest ski was ski Number 8 the Kartel 116 with a full length of 191 centimeter and a stiffness value of 15,335 N/mm. The most flexible ski in the Kartel group was ski Number 1 the Kartel 98 with a full length of 171 centimeter and a stiffness value of 12.317 N/mm. The average stiffness for the Kartel group was 13.198 N/mm with a standard deviation of 2.537.

For the Magnus group, the stiffest ski was ski Number 11. The Magnus 90 with a length of 176 centimeter and a stiffness value of 14.8 N/mm. The most flexible ski in the Magnus group was ski Number 12 the Magnus 90 with a length of 176 centimeter and a stiffness value of 13.222 N/mm. This variation in ski Number 11 and 12 is due to the fact that ski Number 12 is an older demo model that has been used to ride on, or ski on, multiple times. While ski Number 11 is a brand new model from production this year that has never been used.

100 centimeter span test:

The next test was done with all the skis having the same testing span of 100 centimeter and an applied force of 300 N. The stiffest ski in the Kartel group for the 100 centimeter span test was ski Number 8. The Kartel 116 with a length of 191 centimeter and a stiffness value of 26.731 N/mm. The most flexible ski in the Kartel group for the 100 centimeter span test was ski Number 1 the Kartel 98 with full length of 171 centimeter and a stiffness value of 11.898 N/mm. Stiffness in the skis increased from the shortest skis having the lowest stiffness and the longer skis having a higher stiffness during the 100 centimeter span test. This increase is due to the difference in material weight and composition between the shorter skis and the longer ski. For the Kartel group the range of stiffness values was much larger than that of the Magnus group which had a much smaller range of stiffness.

This 100 centimeter span test was determined to be accurate and usable for future testing of skis. The results from this test paired with the results from the previous test can help to determine the difference in stiffness based upon the different materials used in each ski. This is due to the fact that you can calculate the stiffness based upon geometry and materials from the previous 3-point bending test. Then using those results you can calculate just how the material in the ski contributes to the stiffness.

Torque test:

Overall, the torque test was difficult to conduct due to a lack of proper equipment. However, after building a stand to hold the skis in the testing device accurate results were able to be obtained. Since the same amount of force was used to twist each ski and the testing span of each ski was the same length, the best way to compare the torsional stiffness of each ski would be to look at the displacement of each ski during the test.

Looking at the results from the torque test, the best way to accurately compare the torsional stiffness in a ski would be just to compare which ski had the most displacement during the torque test and which ski had the least amount of displacement. Overall, the values ranged from 14 mm to 24 mm of displacement. The ski with the least amount of displacement and the highest amount of torsional stiffness from the Kartel group was ski Number 8 the Kartel 116 with length of 191 centimeter, this ski moved 11.223 centimeter during the test. The ski with the most amount of displacement and the least amount of torsional stiffness from the Kartel group was ski Number 1 the Kartel 98 with a length of 171 centimeter. Kartel skis with a width of 98 all had similar torsional stiffness with the shorter length skis having the least amount of torsional stiffness and increasing in stiffness as the length of the ski increases. Kartel skis with a width of 108 also had similar torsional stiffness between skis of the same width. The shorter length skis had the least amount of torsional stiffness while the longer skis had a higher torsional stiffness.

For the Magnus group of skis the results were much closer together than the Kartel skis with the total displacement of each ski ranging from 20.2 centimeter to 24 centimeter. The skis with the highest torsional stiffness was the ski Number 14 the Magnus 90 with length of 186 centimeter with a total displacement of 20.287 centimeter. Meanwhile, the ski with the lowest torsional stiffness was ski number 10 the Magnus 90 with length of 171 centimeter and a total displacement of 23.926 centimeter. Torsional stiffness increased as the ski length increased the same as the Kartel ski group. However, the Kartel skis on average displaced approximately 5 centimeter less than the Magnus skis.

To improve upon this testing method for future testing, a new stand needs to be designed that allows for the testing span of each ski to change based upon the length of the ski. Another improvement would be to use an electronic angle gauge to read the angle the ski twists when 200N of Torque force is applied. This would lead to better values for comparison of torsional stiffness between the skis.

Since bamboo plywood has very little torque resistance and the majority of the torque stiffness comes from other materials in the ski, the bamboo plywood ski cores were not testing for their torque stiffness.

Bamboo core 3-point bending test:

The range of stiffness values for the bamboo ski cores found from this test were between 2.6 N/mm and 4.6 N/mm with the majority of the values hovering around 3.0 N/mm. The average stiffness for the ski cores was 3.13 N/millimeter with a standard deviation of .529. There appears to be little difference between the ski cores used for the Magnus skis and the ski cores used for the Kartel skis. For the bamboo ski cores the longer the core was the less stiffness it provided. Therefore, the stiffness in the longer skis discussed in the previous tests must be coming from materials other than the ski core.

This test method and results were determined to be accurate and usable for future testing. To improve upon the results, multiple bamboo ski cores with the same parameters should be tested to confirm these results remain constant between all the ski cores used to produce skis.

Bamboo core maximum strength test:

Results from the max strength test of the bamboo ski cores ranged from 300 N to 420 N with an average max strength of 332N and a standard deviation of 45.8. Similar to the 100N test, there was no consistent difference between the bamboo cores used from the Magnus skis and the bamboo cores used for the Kartel skis. Due to the high flexibility of the bamboo ski cores it is believed that other material failure will happen prior to core failure, if this same test was conducted on finalized skis.

This test method and results were determined to be accurate and usable for future testing. To improve upon the test, multiple test samples of the same parameters need to be tested. Also, a test device with higher span supports need to be used because as seen in Figure 13. It illustrates that the load apparatus ran out of space and the test had to be stopped prior to the core completely failing. Testing was stopped manually a few millimeters prior to the ski core touching the bottom of the testing device. Fortunately, each core did reach a maximum force as shown in the graph below and permanent deformation of the bamboo cores occurred.

V. Future Work

Future work in area needs to be done to continuously improve the testing methods and results from testing alpine skis. The first big challenge to overcome if more testing is to be conducted is the lack of materials and high cost of testing. For all future testing accurate results need to be obtained from testing only one or two samples for each category of test. This will help to keep the cost of conducting these tests lower. Both completed alpine skis and wooden ski cores should be tested to not only see how the wooden ski core impacts the final alpine ski but also to ensure that the cores are being made consistently. Tests that will help determine the mechanical properties of alpine skis and wooden ski cores are cyclical tests, max strength tests of the alpine skis, high speed bending tests, and surveys of high level alpine skiers. The cyclical test would be done by loading the alpine ski or wooden ski core into the testing device. A constant load would be applied back and forth on the alpine ski or wooden ski core until the sample break or deformation of the sample is too great. This type of test will give insight to how long a ski can last before the integrity of the ski is compromised and becomes unsafe to ride. A cyclical test can also show the relationship between the wooden core duriablity and the geometry of the core. Unfortunately, this type of test takes a long time to complete on just one sample and the sample will be broken or useless after testing is complete. A high speed bend test would be similar to that of the 3-point bending done in this study. However, the major difference would be the rate at would the force is applied to the ski. Since skiing is such a dynamic sport, the skis often take high amounts of force along the ski at a very high rate. To see how this high speed force impacts an alpine ski or wooden ski core a high speed snap test would need to be conducted. Finally, another good way to see how the performance of the ski compares to other skis and ski brands would be to conduct a survey asking about the performance of the ski. This would require many high level alpine skiers to ride on the skis multiple times and then complete a survey with regards to how the ski feels, performs, and even look since all these things impact the overall sales of the skis. Overall, more testing can always be completed if more testing materials were found. However, until the cost of testing is somehow reduced and resources become more available, small scale alpine ski production companies will find testing to be not worth it. This give large scale alpine ski production companies a huge advantage during ski production since these companies have the time and resources to complete these types of tests. For now small scale alpine ski production companies will have to rely on experience, trial and error, and customer feedback to improve on the physical and mechanical properties of their skis.

VI. Conclusion

Throughout this study many challenges and problems arose that had to be solved. For example, a shortage of materials, non-disclosure agreements from companies, and lack of information from other sources. However, even with all these complications, three out of the four tests were determined to be a valid methodology to test alpine skis and ski cores for ON3P or any small scale ski production company. The damping test was the only test that didn't produce accurate enough results to provide any real information on the alpine skis or ski cores. To improve this test and obtain more accurate results a precise way of measuring when the ski comes to a complete stop after the force is released is needed to avoid human error. Also a mechanism or device needs to be build to release the skis all at the same distance and force. The 3-point bending tests and parameters were a good way to determine the stiffness of a ski and ski core. Also, 3-point bending could be used to find the maximum strength of an alpine ski or ski core. One improvement that needed to be done was a testing machine with higher supports so the samples could have been broken. Testing all the same span of 100 centimeter on the skis allowed for an analysis of how the different material in the skis impacted the overall stiffness. Finally, the torque test provided results on how the torsional stiffness increases as ski length and width increases. Two improvements for the torque test would be able to change the length of the testing span and measure the angle along with the deflection of the ski when a torque force is applied. Overall, this study was able to start a database for ON3P to test their alpine skis and ski cores, provide a starting ground for small scale production ski companies for how to test their products with limited resources, and give the tester hands on experience testing the mechanical properties of alpine skis and wooden ski cores. However, more testing is required to continuously build and improve upon the database for ski testing. Tests like cyclical loading, high speed bending, and surveying all need to be completed for expansion of the database and to help small ski companies improve their products.

The overall experience of the research project and knowledge of the alpine ski industry, was greatly enhanced by University of Salzburg field trips to the following corporations before, during and after the research testing: Binderholtz, plywood production; Team 7, high end, European furniture manufacturer; Wintersteiger, a machine developers for wood products and ski testing; Storra Enso, a CLT production facility of cross laminated timber; and along with Atomic Ski Manufacturing, Fischer Skis. Additionally, a particle board project was conducted dealing with improving the mechanical properties of particle board by testing different additives. The particleboard project was partnered with Kaindl where we replicated their production process for particle board and then added different additives the company received. The purpose of this was to test if these products received from other companies were worth incorporating into their normal production process and if it was possible with their current machinery.

Also, the following courses were completed:

International wood trade; study includes learning key features of national and international forestry and forest products, as well as to make students familiar with non-European wood species and their most important characteristics. Students gain insight into international wood trade markets, beginning with raw material supply, demand structures and the export trade for the specific wood markets. In addition, students are informed about meaning of sustainability certificates and the international rules for imported wood.

Two week intensive German A1 level; a daily, eight-hour course to learn the national language.

Wood manufacturing process analysis; a class where students have the ability to develop innovative materials and products optimized for individual companies and their targeted market. Equipped with advanced proficiencies and knowing the general technical conditions the students are aware of the practical implementation based on the properties of wood.

VII. References

[1] Wikerman Fredrik (2016) Characterization of Alpine Skiing

[2] ISO5902: Alpine Skis- Determination of the Elastic Properties

[3] Truong J, Brousseau C, Desbiens A (2016) A Method for Measuring the Bending and Torsional Stiffness Distribution of Alpine Skis.

[4] Mastrogiuseppe P (2007) The effects of core material and thickness on the performance and behavior of a ski

[5] ISO6265: Alpine skis -- Determination of deformation load and breaking load

VIII. Figures

Figure 1: Ski 1 & 2 Top/Base

Figure 2: Ski 3 & 4 Top/Base

Figure 3: Ski 5 & 6 Top/Base

Figure 4: Ski 7 & 8 Top/Base

Figure 5: Ski 9 & 10 Top/Base

Figure 6: Ski 11 & 12 Top/Base

Figure 7: Ski 13 & 14 Top/Base

6.2 Ski Cores

Figure 8: All Bamboo Plywood Ski Cores

6.3 Testing Photos


Figure 9: Damping Test Setup

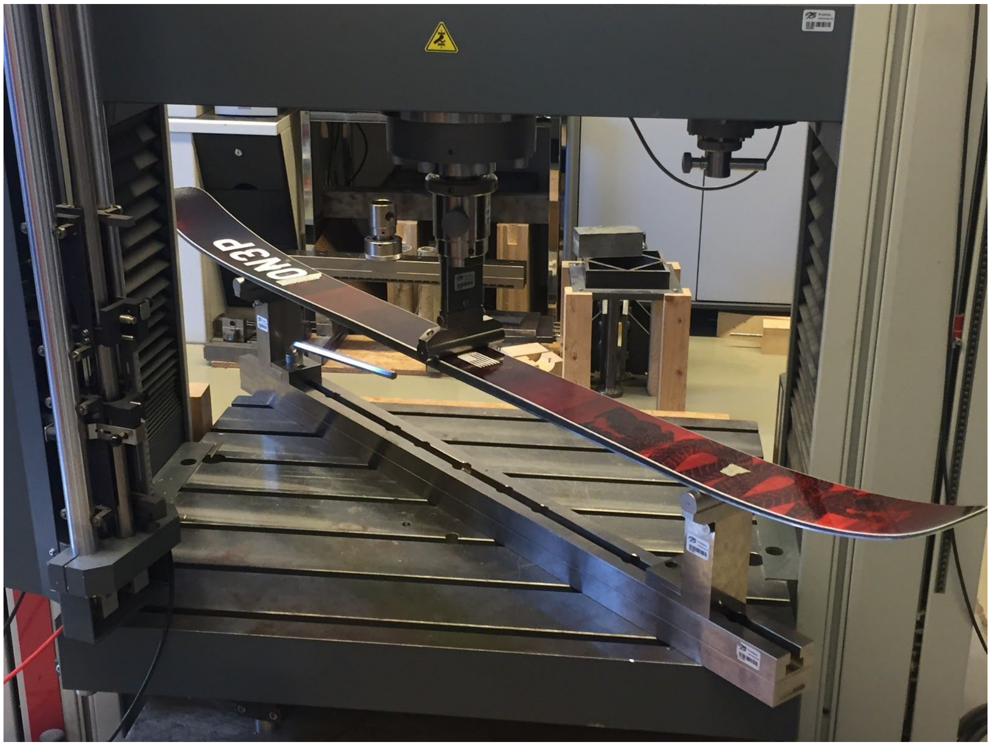


Figure 10: 3-Point Bending Test Setup

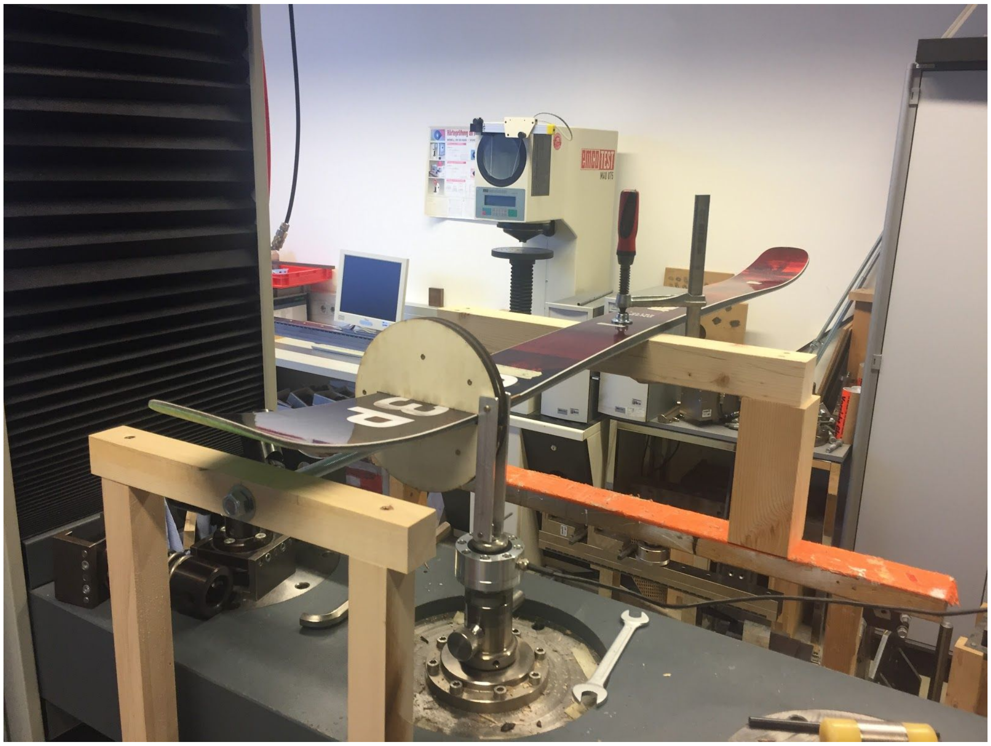


Figure 11: Torque Test Setup

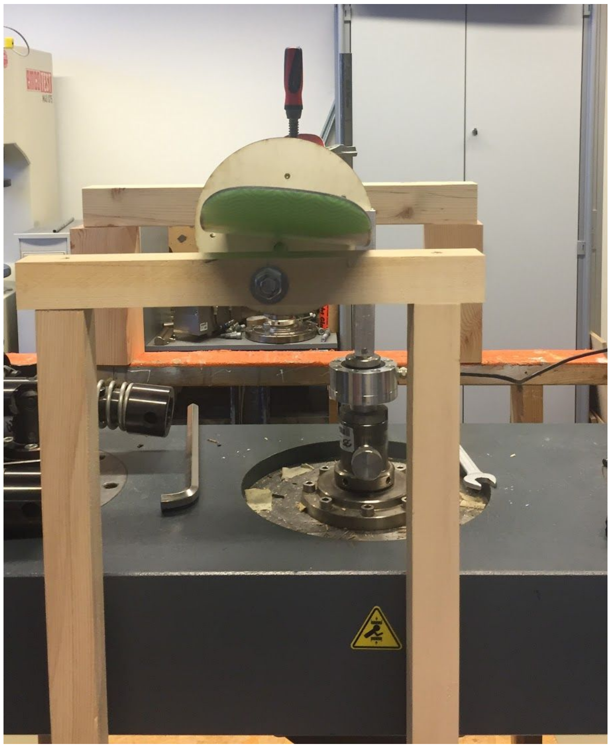


Figure 12: Torque Test in Progress

Figure 13: Max bending test on bamboo ski cores