# The effects of core material and thickness on the performance and behaviour of a ski

Philippe Mastrogiuseppe

McGill University
Department of Civil Engineering and applied Mechanics

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Abstract

The behaviour of a ski is directly related to its longitudinal flex pattern and damping properties, and the performance of a ski depends mainly on its torsional rigidity. These characteristics depend mostly on core material and thickness. A direct correlation between the stiffness of the core and stiffness of a ski cannot be made, due to the composite nature of a ski. This paper analyses the contribution of the core material and thickness to the final stiffness of the ski, by comparing the flexural stiffness, damping properties, and torsional rigidity of 5 skis with various core thicknesses and materials.

*Fig. 0.0.1 The homemade ski press*

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*Fig. 0.0.2 The 5 test skis*

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# *1 – Introduction*

## 1.1- Ski Construction

Skiing has a very long history, which dates back around 4000 years ago[1]. However, ski construction has remained quite constant for the vast majority of its existence, where straight wooden planks were used. In 1949, Howard Head introduced the first commercially successful metal ski[2]. 10 years later, Freg Langdorf and Art Molnar created the first usable fiberglass ski[2]. From that point on, ski construction has steadily improved and changed, to the point where construction methods are chosen for their distinct characteristics rather than their durability or quality.

Six (6) different skis were chosen, cut, and inspected to analyse the different methods and materials used by different ski companies. There are essentially three (3) main different methods used to build skis.

- Sandwich: This method involves simply superimposing layers of different materials. This method is easily identifiable on skis that have sidewalls to protect the inner core. There are no composite materials of metal in a vertical position between the core material and the sidewalls.


*Figure 1.2.1 – Examples of Sandwich construction*

- Torsion-box : This method involves wrapping the core material in fiberglass or carbon fiber.

*Figure 1.2.2 – Example of Torsion-box construction*

- Cap or Monocoque: In this method, the outer wrapping material of the ski serves a structural purpose. This material can be either fiberglass, graphite, or metal, or any combination of those materials. On the ski pictured below, the topsheet of the ski is made of aluminum.

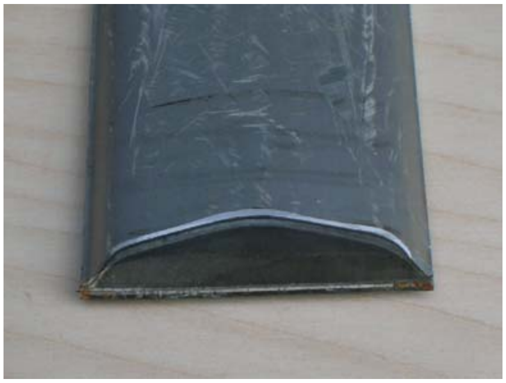

*Figure 1.2.3 – Example of Monocoque construction with a foam core*

These 3 methods represent the vast majority of skis built in the world today. However, there are a few odd designs on the market. For instance, Volant skis use a peculiar hybrid construction design. It is a cross between a monocoque and a sandwich ski.

*Figure 1.2.4 – Example of cap-sandwich hybrid construction*

This particular ski has a complete fiberglass cap on top of a regular sandwich ski, with an added layer of stainless steel on top of the cap. The main core material is wood, but near the edges the core is made of a foam material. The foam was probably used to save weight and cut costs.

Although different, all construction methods have something in common: either there is a torsion-box around the core, or there are top and bottom structural layers of metal or composite material, separated by the core material. The core material serves as both a separator, and also as a damping element[1]. However, some speculate that the core material is in fact the main contributor to a ski's behaviour[4]. Since the core's contribution to flex is moot, this study attempts to demonstrate its contribution to flexural rigidity.

## 1.2- Ski performance and behaviour

The primary goal in ski construction is achieving high performance. High performance means mainly good edge hold on hard snow and ice. This performance criterion is controlled by a ski's torsional rigidity.

However, high performance usually comes at a price. A ski that is torsionally stiff will have a tendency to be stiff in flexion. Skis that are flexurally stiff 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 stiff ones[4]. Hence the conundrum: easy turning skis, or high performance skis?

This is actually an optimisation problem, where each performance criteria is weighed differently depending on the type of skier the final product is aimed at: race skis are stiff and heavy but hold very well on ice, whereas beginner skis, where performance is not the primary goal, are soft and light.

## 1.3- Objectives

The objectives of this study are to evaluate the effects of core material of a ski on its final performance and behaviour. The performance of a ski is based mainly on its torsional rigidity, whereas its behaviour is governed by the ski's stiffness and damping properties. These characteristics are tested in each ski to compare the effects of the core materials.

## *2- Methodology*

### 2.1- Used Construction Method

The method used is essentially a simplified version of sandwich construction. Whereas ski companies use sidewalls to protect the innards of their skis, this step was eliminated due to the fabrication complications that it entailed.

All the skis made have certain parameters in common. The layup (successive layer configuration) for all skis is the following, from bottom to top:

- P-tex 2001 grade material base (UHMW polyethylene), 1.5mm thick
- 2mm steel edges glued onto the edge of the P-tex base
- Vibration absorbing rubber
- 2 layers of 10 oz bi-directional fiberglass
- Wood core
- 2 layers of 10 oz bi-directional fiberglass (totalling 4 layers in the ski)
- Cosmetic fabric

The bonding agent used is Ciba Araldite AW 8594 epoxy in a 3:1 ratio with the Ciba HY 5049 hardener. No metal was used in the layup process due to bonding issues. The skis are pressed to ensure optimal bonding. The recommended pressure needed for ski construction is between 30 psi and 60 psi[4]. To achieve this pressure and distribute evenly over the length of the skis, a pneumatic press using a pressurised bladder is used. Th pressurised bladder is a 5” water pump hose. The water goes through a closed cycle which contains a water heater. The purpose of having a water heater is to help cure the epoxy. The water’s temperature is about $55^{o}$ Celsius.

All layers are put into a mold successively. Each successive layer is covered with epoxy. Then, all the layers are pressed.

*Figure 2.1.2 – Press and mold layup process. From top left: empty mold, then the black p-tex base is added, then successive layers, until the bladder and top mold are placed. Bottom right: the all parts of the press are put into place, and the pressure is raised in the bladder hoses, evenly distributing the pressure along the ski.*

## 2.2- Ski Design

The only difference between the skis made is their core material or thickness. For the first part, all skis have the same wood core thickness profile, but are made of different woods. The 3 different woods are:

- Yellow Birch (Betula Alleghaniensis), Young's Modulus: 19505 MPa
- Spanish Cedar (Cedrela Odorata), Young's Modulus: 9800 MPa
- Jatoba (Hymenaea Courbaril), Young's Modulus: 30515 MPa

*Figure 2.2.1 – Rough cut wood samples, from left to right: Jatoba, Spanish Cedar, Birch*

These woods were chosen for their Young's modulus. Spanish Cedar is quite flexible, Jatoba is quite stiff, and Yellow Birch falls in the middle. The moduli values were obtained through testing. Compared to literature, these values are realistic[3]. However, the research conducted was not made on the wood itself. The only importance of these values is their relation to each other.

All cores are laminated, to avoid irregularities in the wood structure, such as knots. The laminations are about 1" wide, and are bonded together using Elmer's PU Ultimate Glue. This glue was chosen for its high shear strength (above 3500 psi) and because it is waterproof. The identical cores are 12mm thick underfoot (the middle of the ski), and 2mm thick at the ends (tip and tail).

The other different cores are made of Yellow Birch, and their thicknesses are adjusted to have the same stiffnesses (EI) as the cores made of Spanish Cedar and Jatoba. Since all skis have the same width, 'b' can be ignored.

$$EI = E\frac{bh^3}{12} \qquad E_1 I_1 = E_2 I_2 = E_1 \frac{b_1 h_1^3}{12} = E_2 \frac{b_2 h_2^3}{12} \qquad \frac{h_1^3}{E_2} = \frac{h_2^3}{E_1}$$

The Birch core made to have the same stiffness as the Jatoba core has a thickness of 14mm underfoot and 2.3mm at the tip and tail. The Birch core made to have the same stiffness as the Spanish Cedar core has a thickness of 9.5mm underfoot and 1.6mm at the tip and tail.

## *3- Testing*

### 3.1- Flexural Stiffness

The ski is simply supported on 2 stands, spaced 5' (152.4cm) apart. Then, individually, three weights of 20 lbs (9.09kg, 89.17 kN), 30 lbs (13.63kg, 133.71kN), and 40 lbs (18.18 kg, 178.35 kN) are placed on the binding mounting center of the ski. This center is measured 36" (91.44cm) from the point where the tip starts to curve upwards. The deflection is measured from the ski's initial position. The measurements are done with a Leica DISTO$^{TM}$lite[5] laser measuring tool, placed under the ski on the ground. The initial height of the bottom of the ski is measured from the ground, then the weight is applied to the ski, and the distance is again measured. The deflection is then obtained by subtracting the final distance from the initial position.

*Figure 3.1.1 – Flexural Stiffness test*

## 3.2- Torsional Stiffness

An apparatus was constructed to apply a moment force in the longitudinal axis of the ski. The ski is clamped down at its tail, and a lever is attached 4" (10.16cm) behind the point where the tip starts to curve upwards. The lever is placed so that there a moment force is created without having any undesired upward or downward forces. Two different moment forces were applied to the skis, a 15.85 kNm force, and a 23.78 kNm force. The height from the bottom of lever to the ground is measured using a Leica DISTO$^{TM}$lite[5] laser measuring tool. Once the moment force is applied, and the lever has twisted, the distance from the ground is measured again. Knowing how far from the center point of the lever the measuring tool is, it is possible to calculate the angle created by the twisting.

*Figure 3.2.1 Torsional Stiffness test. The right weight is hung on a sliding pulley, assuring the force applied is perfectly vertical.*

## 3.3- Damping

To measure the damping characteristics of a ski, the ski is held in position with its tip acting as a cantilever 30" (76.2cm) long. A force is applied at the tip, bending the ski, and then the ski is rapidly released. The time is measured until the ski stops vibrating. The magnitude of the deflection or force is not important in determining the amount of time the ski will vibrate. The deflection or load will only affect the amplitude of the vibrations. Since the test involves more human error than the previous ones, it is done 8 times and the highest and lowest values are ignored.

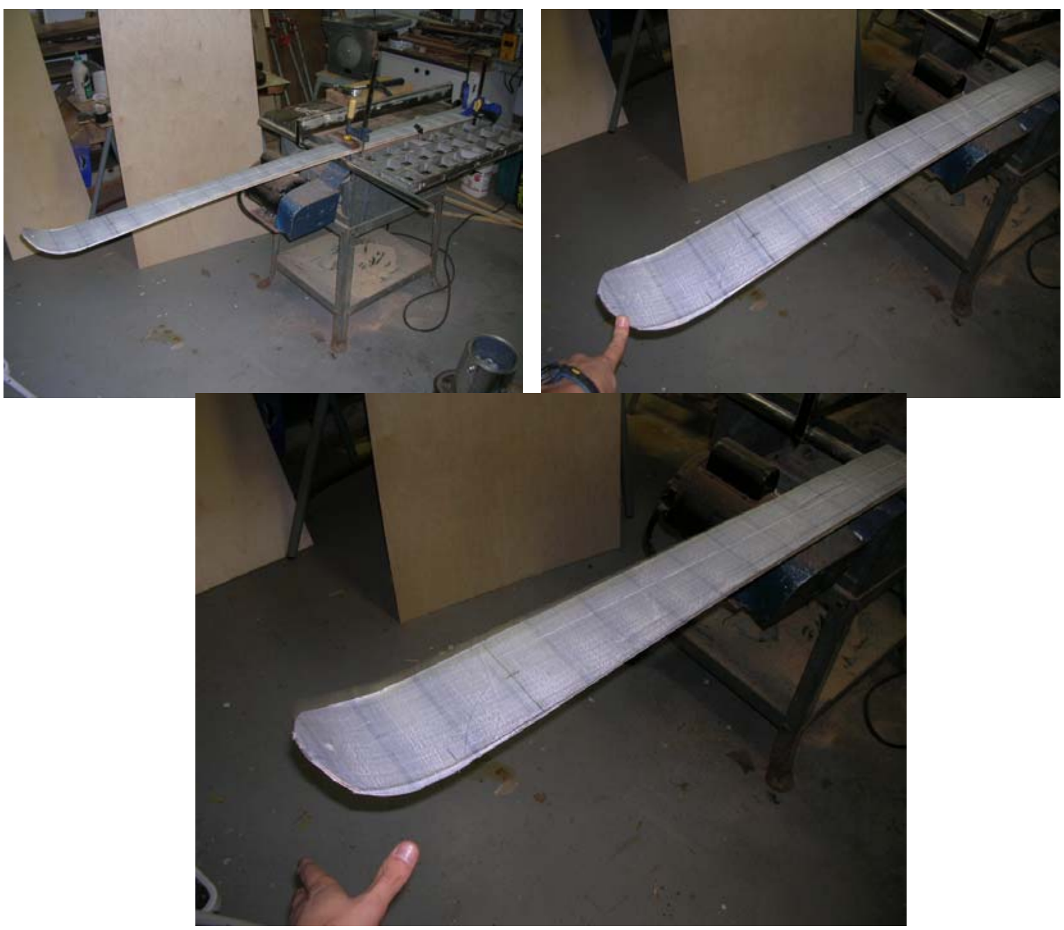

*Figure 3.3.1 Damping test*

# *4- Analysis and Comparison*

## 4.1- Materials

Here, a comparison is made between the results obtained for all the skis made with the same thickness profile, but with different core materials. The analysis will start with the flexural stiffness test results.

| Ski | Deflection (cm) | | |
|---|---|---|---|
| | 89,17 kN | 133,71 kN | 178,35 kN |
| Birch 12mm | 2,1 | 3,1 | 4,1 |
| Sp. Cedar 12mm | 2,1 | 3,2 | 3,9 |
| Jatoba 12mm | 1,4 | 2,1 | 2,7 |

*Table 4.1.1- Flexural stiffness test results*

By comparing the identically shaped cores, we can determine the core material's contribution to the flexural stiffness of a ski.

The 12mm Jatoba ski is 50% stiffer than the 12mm Birch one, whereas the core itself is 60% stiffer. In this case, the core represents nearly 85% of the ski's flexural stiffness. The other 15% comes from the base material and fiberglass.

The 12mm Spanish Cedar ski is 5% stiffer than the 12mm Birch ski. However the Spanish Cedar core is theoretically 50% softer than the Birch core. The Spanish Cedar, which is a very porous wood, has absorbed a non-negligible amount of epoxy in the top and bottom layers of the core during the pressing. The epoxy has hardened inside the top and bottom layers' wood pores and has hence stiffened and strengthened the wood. These layers act like flanges in a W beam.

To further this analysis, another soft but non-porous wood should be used in the place of the Spanish Cedar.

Now here are the torsion test results.

| Ski | Torsion angle (degrees) | |
|---|---|---|
| | 15,85 kNm | 23,78 kNm |
| Birch 12mm | 15,1 | 19,2 |
| Spanish Cedar 12mm | 18,7 | 26,3 |
| Jatoba 12mm | 13,0 | 17,5 |

*Table 4.1.2- Torsional stiffness test results*

By comparing the Spanish Cedar ski with the Birch one, the Birch ski is 30% stiffer torsionally than the Spanish Cedar ski. However, the Birch core is about twice as stiff as the Spanish Cedar core. The epoxy-stiffened top and bottom layers of the Spanish Cedar core do not have as much effect on torsional rigidity compared to flexural rigidity, which is why in this case the Birch core is stiffer. The core's contribution to torsional stiffness is about 30%.

Between the Jatoba ski and Birch ski, the Jatoba ski is only a 12% stiffer, even though the core is 60% stiffer. Its contribution to stiffness would only be about 20% in this case.

Here are the damping test results.

| Ski | Damping test result (seconds) | | | | | | |
|---|---|---|---|---|---|---|---|
| | test 1 | test 2 | test 3 | test 4 | test 5 | test 6 | Average (s) |
| Birch 12mm | 16,12 | 16,83 | 16,84 | 16,75 | 16,37 | 17,19 | 16,7 |
| Jatoba 12mm | 17,20 | 17,50 | 17,14 | 17,67 | 16,00 | 16,68 | 17,0 |
| Sp. Cedar 12mm | 15,62 | 16,64 | 15,65 | 15,78 | 16,21 | 16,52 | 16,1 |

*Table 4.1.3- Damping test results*

By observing these results, it seems that core material has a very light effect on a ski's damping properties. The lighter softer wood, Spanish Cedar, seems to have slightly better damping properties than the other woods.

## 4.2- Thickness

Here, comparisons are made between each pair of skis with identical longitudinal stiffness, i.e. the 12mm thick Jatoba core ski is compared to the 14mm thick Birch core ski, and the 12mm thick Spanish Cedar core ski is compared to the 9.5mm thick Birch core ski. Also, the 3 different Birch cores can be compared between themselves.

Here are the longitudinal stiffness results.

| **Ski** | **Deflection (cm) at loads (kN)** | | |
|---|---|---|---|
| | 89,17 | 133,71 | 178,35 |
| Sp. Cedar 12mm | 2,1 | 3,2 | 3,9 |
| Birch 9,5mm | 3,6 | 5,4 | 7,1 |
| | | | |
| Jatoba 12mm | 1,4 | 2,1 | 2,7 |
| Birch 14mm | 1,7 | 2,5 | 3,2 |
| | | | |
| Birch 12mm | 2.1 | 3.1 | 4.1 |

*Table 4.2.1- Flexural stiffness test results*

Once again, the 12mm Spanish Cedar ski is much stiffer than expected, and much stiffer than the 9.5mm Birch ski. This can be attributed to the epoxy being absorbed into the porous Spanish Cedar, as explained in the previous section. The Spanish Cedar ski is in this case 82% stiffer.

The 14mm Birch ski is softer than the 12mm Jatoba ski. The Jatoba ski is in fact 21% stiffer. The plausible cause of this discrepancy would be imprecision in the 14mm core's construction, it being slightly undersized.

Comparing the 3 Birch cores, the 12mm core is 73% stiffer than the 9.5mm one, whereas the core is twice as stiff. This means that in this instance, the core's contribution to stiffness was about 73%, which is quite important.

However, the 14mm Birch ski is only 25% stiffer, whereas the core is about 60% stiffer. This would also tend to indicate that the core was not properly manufactured.

Here are the torsional stiffness results.

| **Ski** | **Torsion angle** | |
|---|---|---|
| | 15,85 kNm | 23,78 kNm |
| Sp. Cedar 12mm | 18,7 | 26,3 |
| Birch 9,5mm | 21,2 | 30,6 |
| | | |
| Jatoba 12mm | 13,0 | 17,5 |
| Birch 14mm | 15,0 | 21,0 |

*Table 4.2.2 Torsional stiffness test results*

The difference in torsional stiffness between the 12mm Spanish Cedar ski and the 9.5mm Birch ski is less important than for the flexural test. The difference in torsional stiffness here is only 15%, compared to the 82% discrepancy in flexural stiffness.

Between the 12mm Jatoba and 14mm Birch skis, the difference in torsional rigidity is about 17%, whereas in flexion the difference is 24%.

Here are the damping test results.

| Damping | Damping test result (seconds) | | | | | | |
|---|---|---|---|---|---|---|---|
| | test 1 | test 2 | test 3 | test 4 | test 5 | test 6 | Average |
| Birch 9,5mm | 25,43 | 24,1 | 23,71 | 23,64 | 25,67 | 23,54 | 24,3 |
| Birch 12mm | 16,12 | 16,83 | 16,84 | 16,75 | 16,37 | 17,19 | 16,7 |
| Birch 14mm | 15,54 | 16,06 | 16,32 | 16,02 | 16,07 | 16,12 | 16,0 |

*Table 4.2.3 Damping test results*

Here, all 3 Birch core skis are compared. Compared to core material, core thickness seems to have a slightly more important part to play in a ski’s damping properties. However, if the correlation between the 9.5mm ski and the 12mm ski, then the 14mm ski should be damper. This result tends to indicate that the 14mm core might be undersized.

## *5- Conclusion*

The results show that the core material has a certain importance in flexural stiffness. A more thorough analysis should be done to assure consistent results. However, by comparing the 12mm Jatoba ski and the 12mm Birch ski, we can conclude that in a ski with a similar layup configuration, up to 85% of the final ski's flexural stiffness may depend on the core material; the other 15% depends, in this case, upon the other materials used, mainly fiberglass. The wood/epoxy combination also may play an important part in a ski's flexural stiffness. The ski made with Spanish Cedar, a very porous wood, was stiffer than initially expected. This is probably due to the wood absorbing and combining with epoxy in a manner similar to composite materials such as fiberglass.

The study between core thickness and ski flexural stiffness has been somewhat inconclusive. It is obvious that thickness has an important part in controlling a ski's flexural rigidity, and therefore its behaviour, but whether the core itself adds the stiffness to the ski, or rather adds stiffness by increasing the distance of the stiff outer layers (usually metal or composite materials) from the centroid, like flanges in a W section do, is still unknown. Improved quality control over many steps of the ski building process and more extensive building and testing would be needed to thoroughly understand the function of thickness in a ski. Unfortunately, the author was limited to 5 skis for financial and temporal reasons.

The torsional stiffness, however, does not mainly depend on the type of neither core material nor its thickness. Composite braided materials such as fiberglass cloth or carbon fiber are much more likely to dictate the amount of torsional stiffness a ski has. In this experiment, the core’s contribution to torsional rigidity was as low as 20%. By comparing the torsional rigidity of the stiffest and softest skis, the 12mm Jatoba ski and the 9.5mm Birch ski, the difference is around 47%, whereas in flexion, the Jatoba ski is more than two and a half times stiffer.

Core material seems to have little effect, if any on a ski’s damping properties. Softer woods seem to be slightly damper and absorb vibrations more rapidly than hard stiff woods. Core thickness seems to play a more important part in a ski's damping characteristics. A thicker ski absorbs vibrations more quickly, making a thick ski damper than a thin one. By using softer woods and thicker cores, damping can be optimised.

Also, although it has not been mentioned before, core material has a large impact on a ski’s weight. The 12mm Spanish Cedar ski weighs 1587g, compared to 1730g for the 9.5mm Birch ski. The 12mm Jatoba ski weighs 2467g, and the 14mm Birch ski, made to be as stiff as the Jatoba one, weighs 2126g. Hence, making a thicker core of softer wood would be advantageous to reduce the weight of a ski.

Knowing this information, it is possible to say that ski behaviour depends on core material selection and thickness, whereas performance depends mostly on other parts of a ski, its composites mainly, to control torsional rigidity.

However, even though a thick soft wood core may seem preferable to a thin stiff wood core, other aspects of ski performance not observed here may prove otherwise. For instance, although Spanish Cedar provides ample flexural stiffness and is lightweight, it is extremely soft. It is possible that the wood is not hard and/or strong enough to prevent binding tear out in actual skiing conditions. Durability may also be an issue with softer woods.

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