Trabajo Fin de Master:
Analysis, modelling and design of a snowboard by reverse engineering

Student: Jules Antoine
Supervisor: David Jeronimo Busquets Mataix

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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Abstract

This study aims to improve current snowboards through the technique of reverse engineering. Reverse engineering is the process of finding improvements for the snowboards of the future based on current boards using computer software. For this, the use of the finite element software Abaqus was necessary. As a first step, an extensive introduction to the subject was carried out. It retraces the history of the discipline, its evolution over time, the elements and materials that make up the boards and the different shapes that these boards can adopt. Next, digital bending and torsion tests were carried out on 3 different types of snowboards. The first board, called the reference board, serves as a reference for all the other boards. This board is made from the materials currently used in the manufacture of freeride boards, which are glued laminated ash wood for the core and a layer of epoxy fibreglass [0°,90°] in taffeta weave for the skins. For the other boards, the core will remain the same and only the skins will vary in order to study the variation of a single parameter. The second board is a triaxial board [0°,45°,-45°] in epoxy glass fibre, and the third board is made of biaxial linen fibre [0°,90°] also in taffeta weave. The mechanical tests carried out on these boards show that the triaxial board has a much stiffer torsional behaviour than the 2 others, $469MPa$ against more than $1099MPa$ for maximum stresses, which does not make it an advantage for freeride practice. The flax board has a more adapted bending behaviour with a more uniform bending stress distribution within the board. Finally, a discussion was held on these different boards to determine the advantages and disadvantages of each, before making a selection of the best candidates.

Key words: snowboarding, finite element method (FEM), bending, torsion

Resumen

Este estudio tiene como objetivo mejorar las actuales tablas de snowboard mediante la técnica de ingeniería inversa. La ingeniería inversa es el proceso de búsqueda de mejoras para las tablas de snowboard del futuro basado en las tablas actuales utilizando un software de ordenador. Para ello, fue necesario el uso del software de elementos finitos Abaqus. Como primer paso, se llevó a cabo una extensa introducción al tema. En ella se recorre la historia de la disciplina, su evolución a lo largo del tiempo, los elementos y materiales que componen las tablas y las diferentes formas que estas tablas pueden adoptar. A continuación, se realizaron pruebas digitales de flexión y torsión en 3 tipos diferentes de tablas de snowboard. La primera tabla, llamada la tabla de referencia, sirve de referencia para todas las demás tablas. Esta tabla se fabrica con los materiales que se utilizan actualmente en la fabricación de tablas de freeride, que son madera de fresno laminada encolada para el núcleo y una capa de fibra de vidrio epoxídica [0°,90°] en tejido de tafetán para las pieles. Para las demás tablas, el núcleo seguirá siendo el mismo y sólo las pieles variarán para estudiar la variación de un único parámetro. La segunda tabla es una tabla triaxial [0°,45°,-45°] en fibra de vidrio epoxi, y la tercera tabla es de fibra de lino biaxial [0°,90°] también en tejido de tafetán. Las pruebas mecánicas realizadas en estas tablas muestran que la tabla triaxial tiene un comportamiento torsional mucho más rígido que las otras dos, $469 MPa$ contra más de $1099 MPa$ por tensiones máximas, lo que no la convierte en una ventaja para la práctica del freeride. La tabla de lino tiene un comportamiento de flexión más adaptado con una distribución más uniforme del esfuerzo de flexión dentro de la tabla. Por último, se celebró un debate sobre estas diferentes tablas para determinar las ventajas y desventajas de cada una de ellas, antes de hacer una selección de los mejores candidatos.

Palabras claves: snowboard, método de los elementos finitos (MEF), flexión, torsión

Resum

Aquest estudi té com a objectiu millorar les actuals taules de surf de neu mitjançant la tècnica d'enginyeria inversa. L'enginyeria inversa és el procés de cerca de millores per a les taules de surf de neu del futur basat en les taules actuals utilitzant un programari d'ordinador. Per a això, va ser necessari l'ús del programari d'elements finits *Abaqus. Com a primer pas, es va dur a terme una extensa introducció al tema. En ella es recorre la història de la disciplina, la seua evolució al llarg del temps, els elements i materials que componen les taules i les diferents formes que aquestes taules poden adoptar. A continuació, es van realitzar proves digitals de flexió i torsió en 3 tipus diferents de taules de surf de neu. La primera taula, anomenada la taula de referència, serveix de referència per a totes les altres taules. Aquesta taula es fabrica amb els materials que s'utilitzen actualment en la fabricació de taules de *freeride, que són fusta de freixe laminada encolada per al nucli i una capa de fibra de vidre epoxídica [0°,90°] en teixit de tafetà per a les pells. Per a les altres taules, el nucli continuarà sent el mateix i només les pells variaran per a estudiar la variació d'un únic paràmetre. La segona taula és una taula triaxial [0°,45°,-45°] en fibra de vidre epoxi, i la tercera taula és de fibra de lli biaxial [0°,90°] també en teixit de tafetà. Les proves mecàniques realitzades en aquestes taules mostren que la taula triaxial té un comportament torsional molt més rígid que les altres dues, $469MPa$ contra més de $1099MPa$ per tensions màximes, la qual cosa no la converteix en un avantatge per a la pràctica del *freeride. La taula de lli té un comportament de flexió més adaptat amb una distribució més uniforme de l'esforç de flexió dins de la taula. Finalment, es va celebrar un debat sobre aquestes diferents taules per a determinar els avantatges i desavantatges de cadascuna d'elles, abans de fer una selecció dels millors candidats.

Paraules claus: surf de neu, mètode dels elements finits (MEF), flexió, torsió

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1 Introduction

1.1 Purpose of the study

This study aims to produce a complete synthesis on current snowboards in an attempt to improve these objects through the technique of reverse engineering. This technique consists of using the snowboards used today, establishing the hypotheses of mechanical calculations, making sure that these boards are sufficiently resistant to mechanical stress and trying to improve the current boards based on these results.

To do this, it is first necessary to model the board from a numerical point of view to ensure that the selected boards actually withstand the stresses determined in the calculation assumptions. The use of Abaqus finite element (FE) software will be required to carry out this project. Based on these results, the objective is to improve future boards from different points of view such as weight, mechanical behaviour or price by playing on different parameters such as the dimensions of the board or the materials of which it is made. This step is also carried out digitally. Finally, the last step consists in manufacturing samples of new boards previously digitally imagined to check the coherence of the computer and experimental results.

This is the total principle of reverse engineering for a snowboard. However, this year, because of the Covid-19, this study will only take place on computer and the last part with the realization of samples and their mechanical characterization will not take place. In fact, due to the health crisis that is hitting the world in this year 2020, the part in the laboratory had to be suspended.

1.1.1 Motivation

The improvement of snowboarding boards is in the world of sport a highly coveted research topic for workers in the field. From a personal point of view, this study makes it possible to reconcile passion for winter sports with scientific research. Moreover, the study of such a technologically complete sandwich composite material offers a great source of inspiration. The complexity par excellence of this sandwich material from the point of view of its composition to respond to such a particular mechanical behaviour allows imagination and creativity without limits. The growing influx of people for the practice of this discipline is also a powerful motivating factor. From an economic point of view, it is necessary to push research in this sector in order not to give in to the competition. Moreover, following the example of the discovery of parabolic skis at the end of the 20th century, the discovery of a potential revolutionary snowboard with an extraordinary mechanical behaviour also pushes scientific research in this field. Finally, technology for men's leisure activities has never ceased to evolve, providing ever greater comfort, which is also the case for the practice of winter sports.

1.1.2 Justification

The practice of snowboarding in winter sports resorts is growing every year all over the world. More and more people are trying out snowboarding as a leisure activity. This study is then necessary to try to improve current snowboards to make this practice even more enjoyable, accessible and therefore to reach an even wider audience. Throughout history, objects have never ceased to evolve. As far as snowboarding is concerned, the history of this object is very recent and has developed exponentially. The introduction of new materials and the working of the shapes of the board have led the snowboard to become more and more successful throughout history. It is therefore necessary to continue on this path, especially as the number of snowboarders is increasing all over the world. The improvement of snowboarding boards allows us to push back the limits of snow sports by innovating more and more to offer a more pleasant feeling and better performance to those who practice the sport.

Moreover, this study also allows us to imagine snowboards shaped differently, with materials and manufacturing methods that are more respectful of ethics and the environment. Today's society is becoming aware of the current stakes in terms of global inequalities and climate change, which pushes companies to produce in a more eco-responsible way, hence the importance of carrying out these studies.

1.1.3 Objectives

The aim of this study is to improve current snowboards from the point of view of materials and design. In order to achieve this goal, the study is being carried out using Abaqus software. The aim is to simulate a snowboard digitally using finite element software in order to have a reference data base, and then to try to improve the mechanical properties necessary for snowboarding.

This improvement is achieved by playing with the shape of the snowboard, the thickness, the number of layers and the orientation of the fibres that make it up, while keeping the current materials, but also from the point of view of the materials of which they are made by trying to use new materials that are coming onto the market.

Finally, it must be kept in mind that all these changes made to the manufacture of snowboards are only there to try to improve these current objects from the point of view of weight, mechanical behaviour, costs and finally respect for the environment.

1.2 State of the art of Snowboard

1.2.1 History

Snowboarding is a gliding sport rich in thrills. It is practiced using a snowboard, a pair of bindings and a pair of adapted boots. This sport was born from the meeting of two ancestral practices, skiing (of Scandinavian origin) and surfing (of Hawaiian origin). The position of snowboarders on their boards is directly inspired by that of surfers: in profile, with their feet one behind the other (Unknown, 2009). Throughout its history, snowboarding has undergone various transformations from the point of view of the materials used or the shape of the board in order to improve it. Accompanied by its particular vocabulary and lifestyle, snowboarding developed during the 20th century to become a gliding sport that is booming today.

The origins of snowboarding could go back in United-States to the late 1920s (Wikipedia, 2020c). At that time it was a simple game consisting of sliding on snow while standing on a board. The first appearance of "snowboard" as it is known today took place in 1929. The snowboard was composed of a piece of wood to which the user attached his or her feet with leather straps.

The Second World War then greatly hampered research and development of snowboarding. It was only in 1965 that Sherman Poppen (Wikipedia, 2020b) continued to develop this activity by inventing the "snurfer". The idea was to assemble two skis together to form a single board on which a rope is attached to the front for steering. His invention was then patented a few months later under the name of "surf-type snow ski", later renamed "snurfer".

The 1970s marked the beginning of a new area for snowboarding. In 1970, the improvement of snowboards continued with the use of a surfboard on which metal edges were attached to the sides of the board. These edges are used to provide a better grip of the board in the snow when making turns. In the same year, the grip of the board is also improved. In order to prevent the snowboarder from falling when using the object, the idea was to add materials such as crushed glass or gravel to the pile side (air side) of the board in order to increase the roughness. This roughness makes it easier for the user to stand on the snowboard. In addition, the straps that were otherwise made of leather were replaced by the first nylon straps that year.

The year 1974 marks a revolution in the way feet are attached to boards with the appearance of spoilers. Spoilers are rigid bindings that are attached directly to the board, allowing for optimal foot support. In addition, the precision and ease of turning was greatly improved. The rigid part of the spoiler located at the back of the calf allows the transmission of stress from the user to the board during a backward turn. It is thanks to this invention that backside turns have been greatly facilitated.

A further improvement was introduced in 1976. The first swallowtail snowboards are born. The advantages of this new form of snowboard are many. First of all, swallowtail snowboards reduce the lift at the back of the board. This reduction will inevitably cause the back of the snowboard to plunge into the snow, which will naturally lift the front of the board. Lifting the front of the board therefore allows the snowboarder to have better lift in powder snow without sinking. In addition, swallowtail snowboards remove material from the board and therefore save weight, which also makes it easier to lift on the snow. Swallowtail snowboards, however, are less effective in torsion due to the reduced amount of material. This type of board is therefore used for a certain activity and is not suitable for all types of riding.

It was in 1979 that snowboarding officially made history. Jake Burton Carpenter democratised the discipline throughout the American continent. He is officially recognized as the father of the discipline. Author of numerous patents, he improves the already existing snowboard prototypes such as Sherman Poppen's snurfer (Bright, 2020), thus democratizing snowboarding and taking advantage of the opportunity to create his own trademark: "Burton Snowboards".

In the decade that followed everything accelerated: snowboards were now made from the same materials as the skis of the time. In fact, the gliding activity being relatively similar, snowboard manufacturers decided to use the same manufacturing techniques as skis, which were more advanced and popular at that time.

Then at the beginning of the 1990s snowboarding was divided into 3 distinct categories (FFS, 2020). It is the appearance of freestyle, freeride and alpine snowboarding. These 3 activities require the use of very different snowboards to excel in each of them. It is therefore the arrival of the first asymmetric boards to excel in some of these areas.

It was at the Olympic Games in Nagano, Japan in 1998 that snowboarding made its debut in the world's best-known sporting competition. It was the introduction of two events for snowboarding: the giant slalom (which will be transformed into a parallel giant slalom in 2002) and the half-pipe.

Finally, in 2006, snowboarding had a new birth in the same competition: the introduction of the Snowboardcross event at the Winter Olympic Games in Turin, Italy (FFS, 2020).

1.2.2 Different types of snowboard

Snowboards evolved in the 1990s into 3 distinct categories. Among these categories are alpine, freestyle and freeride snowboards. Each of the snowboards in these categories have very different characteristics and properties for the practice of these disciplines. Among these properties are the stiffness, the side-cut radius and the width of the snowboard. These 3 properties will vary drastically from one discipline to another to leave room for very different mechanical behaviour depending on the type of snowboard desired.

i Alpine snowboard

Alpine snowboards are made for competitions on packed snow. These competitions can be parallel giant slalom or snowboardcross. In these 2 competitions, the objective is to go down as fast as possible down a marked out course to win. In the case of snowboardcross, the riders start 4 by 4 on the same course with jumps and obstacles, whereas in the parallel giant slalom, only 2 riders start at the same time on two independent but identical courses. Anyway, the objective in these 2 cases is to finish the race as fast as possible.

These 2 races are done on hard and compact snow, so the stiffness of the snowboard is then the main characteristic to take into account. Indeed, during a race, the snowboarder will deform the board during each turn to turn and follow the materialized course, and when exiting the turn, the board will return to its initial shape. This is the return. And it is this return of the board at the exit of the turn that will allow acceleration and thus save time for the user. In order to exploit this reaction, the objective is to make boards with a very high stiffness. The higher the stiffness, the more the board's deflection will be important and therefore the higher the acceleration created. This is why alpine snowboards are the stiffest boards on the market.

The side-cut radius is also suitable for this type of board. It reflects the ability of a snowboard to turn more or less quickly during a turn. The higher the sidecut radius, the longer the turn and the more stable the board will be. Otherwise, the turns will be shorter but the board will lose stability. Most of the turns to be made in these competitions are small turns with a small curve radius, so the side-cut radius of the alpine boards must also be take in account. That is why a small sidecut radius is preferred for this type of board where turns have to be done quickly.

Finally, the width of the board is also important for this type of discipline. Indeed, a narrow board favours a better grip and precision, which is necessary to make tight turns and to anticipate with precision the best trajectory on the slope.

Most of the time alpine boards are asymmetrical. As snowboarding is practised with a "strong" foot at the front, all alpine athletes keep their favourite foot at the front of the board without changing direction. This allows the manufacture of asymmetrical boards by trying to work on the shapes of each part of the board in order to optimise the properties in the direction of sliding.

ii Freestyle snowboard

Freestyle snowboards are used to perform competitions consisting of acrobatic tricks in the air. Among these disciplines are the Half-pipe and two other non-Olympic disciplines which are slope style and big air. The half-pipe, as its name suggests, is half a tube in which snowboarders move from one side to the other to perform tricks in the air. The slope style is an non-materialized descent consisting of jumps and ramps on which athletes perform a series of tricks, and the big air is a huge bump on which snowboarders try to perform the most impressive trick.

In order to establish a ranking in all these disciplines, the athletes are submitted to a jury to determine the winner. Therefore the quality required here is style and precision in the figures rather than speed. Thus a rigid board is of no use in this discipline. Moreover, in certain situations, the board can be brought to deform considerably (bad reception of a jump, elastic deformation on a slide bar). If the board is too rigid, the return will be very powerful which can destabilise the athlete in his or her performance. Moreover, the curves and turns for these practices are not imposed and chosen by the snowboarder himself, which implies having a medium sidecut radius. Finally, as these disciplines are practised on packed snow, it is not necessary for the board to be excessively wide to increase lift. A narrow board is required to maintain a more precise trajectory.

The big difference between freestyle boards and other types of snowboards is in the symmetry. A freestyle board has to be symmetrical. In fact, freestyle boards consist of rotations in the air, so the snowboarder is often brought to land in "fakie", which means slipping upside down with the wrong foot in front. So the user must be able to use his board with the "strong" foot in front or the "weak" foot in front in the same way, and therefore the freestyle board must have the same characteristics and properties in front and behind. Finally, freestyle boards should be as light as possible in order to facilitate rotation in the air.

iii Freeride snowboard

Freeride snowboards are used for off-piste snowboarding in powder snow. It is this type of board in particular that is the focus of this study. Freeride snowboarding is not yet recognised at Olympic level but it has several international competitions such as the ”Freeride World Tour”.

Freeride snowboarding requires special characteristics to excel in this discipline. The principle being to ride down virgin slopes, the board is exposed to powdery snow. This snow is very soft and does not react at all in the same way as packed snow. The snowboard sinks under its own weight when leaning against it. It is therefore impossible to get the return of the board in this kind of snow. This is why the freeride board tends to have a low stiffness. However, the curve radius should be as large as possible. Snowboarders have no choice but to make large curves on a freeride run. The snow is so special and the slope so steep that it is impossible to make a succession of small turns at low speed. The descent is made at high speed with long turns, so it is necessary to ensure stability during these long turns. This is why the sidecut radius must be large.

The width of the board is also a characteristic to be taken into account here. The freeride board must be very wide to ensure maximum lift in powder snow, to float on top of the snow and not sink from underneath.

Finally, as freeriding is mostly done with the ”strong” foot in front, the board can be asymmetrical as in the case of alpine boards. This is one of the reasons why swallowtail freeride boards have made their appearance for this type of discipline.

Figure 1: The different disciplines of snowboarding. From left to right and from top to bottom: Parallel Giant Slalom (Alpine), Half-Pipe (Freestyle), Freeride downhill (Freeride) and a current snowboard.

1.2.3 Snowboard components

Snowboards are composite objects made by assembling several layers of different materials (Snowboardpascher™, 2020). This is called a composite sandwich material. These layers can be natural or synthetic in nature depending on their role and position in the snowboard. All layers have a particular use within the object and the removal of any one of them will result in the malfunctioning and inability to use the snowboard.

i Core

The core is truly the soul of every snowboard (Unknown, n.d.) (Snowboardpascher™, 2020). It is most often made of wood, but it can also be made of polyurethane foam. The most common woods used in snowboard design are poplar, ash, beech, red birch and red cedar. These lightweight woods are known to be very resistant to twisting and bending. Wood is a composite material in its own right. Composed of cellulose, hemi-cellulose and lignin, wood is a natural composite material with exceptional properties. The cellulose fibres are particularly resistant mechanically and the cohesion of the fibres is ensured by a natural agent present in wood, lignin. This particular composition gives wood a remarkable mechanical composition, sometimes close to that of steel. Moreover, wood is a light material, easy to machine, cheap and its presence in the snowboard makes it more rigid and allows the absorption of vibrations. On the other hand, they have moderate tensile and shear strength. Polyurethane foam can also be used for the core of snowboards. The high density of the foam, combined with strong facings, allows polyurethane to develop in applications with high mechanical stress. It resists fairly high torsion and bending. Polyurethane foam is also an open-cell foam.

There are 3 main types of core for making a snowboard, the monolithic, the horizontal glulam and the vertical (Unknown, n.d.).

<u>The monolithic:</u>

The monolithic core is a core made from an open-cell polyurethane foam. As shown in the figure 2, it is an isotropic material that lies at the centre of the snowboard sandwich. This high density foam is also combined with reinforcements (carbon particles) to give it better mechanical behaviour. However, this type of core is the least efficient of all. Cracks quickly appear as a result of the material's unsatisfactory performance against mechanical fatigue. Once these cracks appear, the snowboard loses all rigidity and becomes soft, making it very little usable. As a result, the mechanical stresses applied during the use of the snowboard will contribute to multiply and enlarge the cracks that already exist before the board breaks completely.

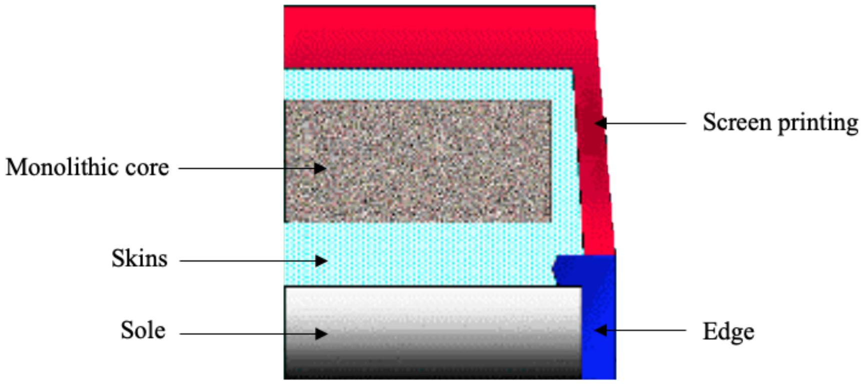

Figure 2: Schematic representation of a monolithic core.

The horizontal glulam:

Horizontal glulam is a succession of thin layers of wood stacked on top of each other. As shown in the figure 3, the layers of wood are thin and the same width as the board. In order to increase the mechanical properties of such a stack, the wood fibers in the layers are alternately crossed at 0° and 90°. This process thus improves the torsional strength of the core. However, this manufacturing technique is not optimal. For layers oriented at 0° the wood fibres are in the direction of the board, which is not a problem. On the other hand, for layers oriented at 90°, the direction of the fibres is perpendicular to the board, and these layers are not in one piece. In fact, layers of the order of 1m50 in length must be used, which makes it difficult to find plates of such a length with fibres oriented at 90°. It is therefore necessary to assemble several small plates oriented at 90° to obtain a single plate. However, the assembly weakens the structure and presents points of weakness at the gluing points (Cognard, 2005) (Becue, 2015). Although there are different techniques for assembling wood, such as making notches in the wood like finger joints for example, even if this technique allows the solidification of the joints between the different pieces, the wood always proves to be weakened in these places. Moreover, these brittleness appear perpendicular to the snowboard, as the torsion and bending forces are applied in this plane, the mechanical behaviour of the snowboard will be greatly modified. For these reasons, this manufacturing technique is not the most optimal.

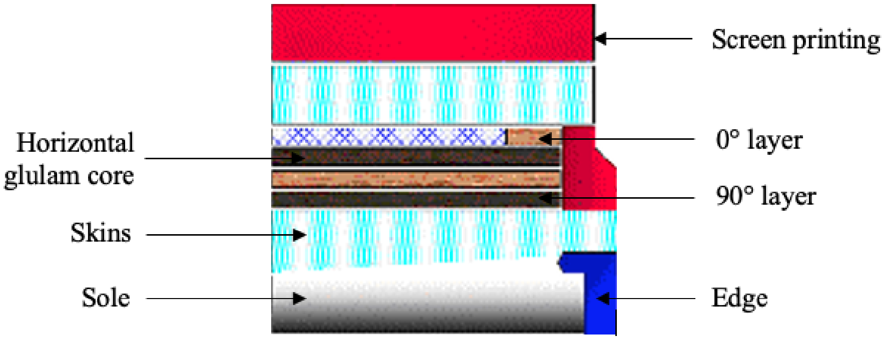

Figure 3: Schematic representation of a horizontal glulam core.

The vertical glulam:

Vertical glulam is an assembly of slats the length of the thickness of the board but with a small width (see figure 4). The laths are cut in the direction of the fibres and are in one piece, unlike horizontal glulam. The laths are assembled next to each other with an alternating fibre direction as shown in figure 4: this particular fibre orientation gives the vertical glulam an unprecedented tensile and torsional strength because the fibres cover the entire stress plane. Furthermore, although the slats are glued together, the gluing points do not weaken the board during mechanical stress because the gluing is carried out along the length of the board, which does not disturb the torsion and bending forces that it applies during the activity. As far as gluing is concerned, the choice of glue should also be studied. Not all glues are compatible with all types of wood (Becue, 2015). This depends on the absorbency of the wood, its hardness, whether it is softwood or hardwood, the pH of the species... For ash wood, one of the most used woods for snowboard making, it is a softwood, acid and very absorbent (Cognard, 2005). The glues chosen accordingly will therefore be polyurethane compounds, which can react with the -OH groups of the wood cellulose to form strong bonds, or phenolic resins which cause hydrogen bonds between the -OH groups of the cellulose and those of the phenolic resin.

In this study, the vertical glulam is used for the manufacture of the snowboard.

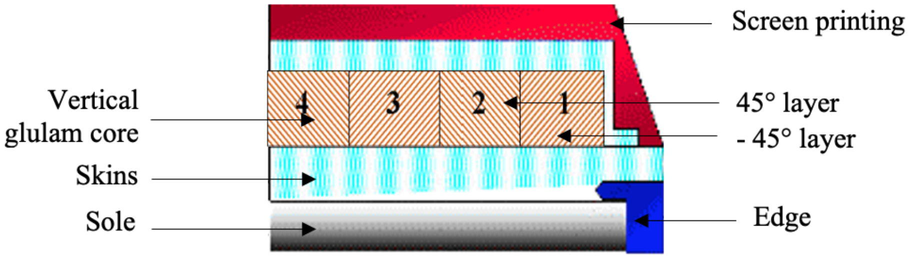

Figure 4: Schematic representation of a vertical glulam core.

ii Skins

The skins of a snowboard are the 2nd most essential elements of a snowboard. They are the ones that will ensure the mechanical structure of the snowboard (Puget, 2011) (C. Agouridas and Rigny, 2014) (Y. Rémond, 2011) (D. Lind, 2002). They are placed above and below the core of the board. These skins have multiple uses in a snowboard: first of all, and this is their main use, they will contribute to the maintenance of the structure following the mechanical stress of the board. Secondly, they will protect the core from any contact with the outside. As snowboarding is an outdoor sport, practised in winter, the environment in which the board evolves is particular: thermal expansion due to temperature variations, exposure to humidity, UV rays... The skins are therefore there to protect the core, which can be sensitive to this type of environment. For instance, a wood core can swell under the effect of humidity. If the water produced by the snow reaches the wood core, the core can swell and deform until the board is shattered. In addition, if the core is not UV-protected, the wood can work causing irreversible deformations in the structure of the board, making the snowboard unusable. The skins are then a crucial element for the longevity of the snowboard over time.

The skins of a snowboard can be composed of different materials and different structural organisations. This depends on the type of snowboard used. As far as materials are concerned, most of the time the skins are made of a glass-fiber/epoxy composite material. The choice of these materials is not random and each material is carefully selected according to the desired properties.

Glass fibres are chosen for their good mechanical behaviour, because fiberglass combines a large strain-to-failure value with low cost, it is the most frequently used structural element in making snowboards (D. Lind, 2002). As snowboards are subject to very high mechanical stress, materials must be chosen accordingly. Glass meets these requirements. The type of fibre chosen is fibreglass E. These fibres have sufficient mechanical properties for snowboarding. The S and H fibres are glass fibres with high mechanical resistance, these fibres are then too rigid for the practice of snowboarding (A. Berthereau, 2008), especially for freestyle or freeride where rigidity is a characteristic studied closely. Moreover, E fibres, unlike S and H fibres, are not sensitive to water and are the easiest to machine and produce. In addition, their low cost also becomes an advantage for the production of efficient snowboards at lower costs.

It may happen that for some snowboards, such as very high level alpine snowboards, the use of high strength fibre is required. In this case S or H glass fibres or carbon fibres can be used. However, the ultra rigid nature of these fibres gives the snowboard a very different behaviour from traditional snowboards, which makes the use of this type of fibre very marginal in the general production of snowboards.

Whatever the type of fibre used, the sizing operation is a necessity to ensure a good cohesion between the fibre and the matrix. This operation consists in improving the cohesion between these 2 materials by mechanical or chemical processes. Mechanical sizing consists in making microscopic grooves along the glass fibres in such a way as not to modify the mechanical properties of the fibre, while increasing its specific surface area. This increase then allows a better increase in the chemical bonds between the molecules of the matrix and the molecules that make up the glass fibre. In this way the mechanical stresses are better transmitted to the fibres and the risk of detachment between the fibres and the matrix is reduced. Chemical sizing is also used to reinforce this cohesion. For this, at the interface between the fibre and the matrix, a bridging agent is placed to ensure a strong chemical bond between the agent and the fibre, and between the matrix and the bridging agent. This technique also improves the cohesion between fibre and matrix which improves the transfer of loads and therefore the mechanical behaviour of the material.

The matrix, for its part, is also very scrupulously chosen. And it is the epoxy resin that is chosen. These advantages are multiple (Bardonnet, 1992). Initially, this resin is compatible with glass fibres and carbon fibres, which is not the case with all polymer matrices. This compatibility means that chemical bonding occurs when this resin and the fibres come into contact, without which the transfer of mechanical stresses would be impossible. This is the case, for example, between polyester matrices and carbon fibres, which are naturally incompatible. Again in comparison with unsaturated polyester matrices, epoxy resin is waterproof, which excludes unsaturated polyester for snowboard making. Epoxy matrices are very chemically stable and provide optimum core protection against external aggression. Moreover, as its glass transition temperature is around 120°C, the temperature range for the use of this polymer is widely respected for snowboarding. This resin is also an excellent thermal insulator, which protects the wood core from sudden temperature changes. This material also has very good mechanical properties, far superior to polyester resins. However, here the mechanical resistance is provided by the fibres, which makes this characteristic derisory. Moreover, due to their 3D cross-linking by their thermosetting aspect, epoxy resins have excellent adhesive properties which makes them particularly well suited to the formulation of composite materials. Finally, this high cross-linking density allows the epoxy resin to have a low shrinkage during its solidification, which ensures the structural stability of the board following its manufacture. It is for all these reasons that epoxy resin is the ideal candidate for the manufacture of skins for snowboards.

iii Edges

The edges are two metal edges placed on either side of the snowboard allowing the board to hang in the snow to make a turn. They are necessary to make cut turns, i.e. without skidding, which greatly improves the snowboarder's speed in turns. The edges are made of Nickel-Chromium stainless steel with a chromium content of around 10% (Snowboardpascher™, 2020). The presence of chromium makes the edges resistant to corrosion Mainly composed of iron, in contact with water, the iron present in the steel will oxidize and turn into rust. It is therefore essential to add nickel as well as chromium to give the edges the stainless character necessary for snowboarding on snow. In addition, the edges must also be very hard. In contact with hard snow or ice, the edges must be able to sink into this hard material and not the other way round. Chromium also improves hardness, so adding chromium to the stainless steel used to make the edges has a dual purpose. Finally, the edges must still remain easily machinable during the life of the snowboard. Because to increase the performance of snowboarders, the edges must be sharpened evenly at a precise angle, ranging from 90° to 85° for professionals. This is because the edges are subject to repeated fatigue and friction which removes the material, eventually breaking the initial angle. Using a material that is too hard would then make this preparation of the edges impossible, which is why the edges must not exceed 10% chromium in their composition.

iv Sole

The sole is the part in contact with the snow, it is this layer of the sandwich that will ensure the snowboard's good glide. More precisely, this glide takes place between the sole and the water. As the snowboard passes over the snow, the friction created between the molecules of the sole and the snow molecules will locally increase the temperature until the snow melts. This snow is then transformed into water which allows the board to slide.

The sole of the snowboard boards is then composed of High Density Polyethylene (HDPE) in which fine carbon particles are added (Snowboardpascher™, 2020). HDPE can be used in many ways. The paraffin surface of high density polyethylene ensures a low friction coefficient (Penu, 2016). The molecular structure of HDPE, composed only of alkane, limits any kind of possible bonding such as hydrogen bonds or Van der Waals bonds between the sole and the water that could slow down the snowboard. In addition, HDPE also has a naturally hydrophobic character. It is also a material with a relatively low hardness. It can be scratched with a simple human fingernail. This low hardness allows for the presence of micro scratches on the sole of the snowboard, thus allowing for better water evacuation and therefore better gliding. In addition, this material has very good resistance to cold shocks due to its very low glass transition temperature (Tg = -110°C), ideal for the practice of winter sports. Finally, HDPE is a thermoplastic material, easy to process and very cheap.

The presence of fine carbon particles also plays a major role in optimising the glide. Carbon particles, which are also hydrophobic in nature (Puget, 2011), tend to repel water molecules. Moreover, these same particles also allow the evacuation of the electrostatic energy created during friction. The conductive nature of the carbon then allows the dissipation of energy which can oppose the movement of the snowboard and consequently slow it down.

Finally, the micro-arrays present in the high-density polyethylene material also allow the possibility of adding an external molecule in the interstices: paraffin. During the regular preparation of the material, paraffin plays a major role in optimising the glide. By definition, paraffin is also a material composed solely of alkane, which has very little affinity with other materials (Wikipedia, 2020a). The addition of paraffin in the micro grooves of the HDPE allows the reduction of the abrasive character of the board by further reducing its friction coefficient, so as to have an even more optimal glide.

v Screen printing

The upper side is a transparent polymeric sheet (Snowboardpascher™, 2020) decorated on the underside (so the pattern is preserved from wear and tear), which guarantees the protection of the sandwich structure, which is very sensitive to water. It is made from Acrylonitrile Butadiene Styrene Sheet (ABS). The use of this polymer belonging to the styrenic polymer family allows the protection of the snowboard (Vandom, 1978). It has very interesting anti-shock properties and can therefore protect the snowboard from any shock that may occur on the front surface of the board (contact on the slopes or in queues, when storing equipment...). Moreover, it is a transparent polymer, which allows the graphic designers to express their creativity for the silk-screen printing of the product. However, this elastomer tends to yellow when exposed to ultra violet radiation. It is therefore regularly combined with transparent protective screens against UV rays to limit this physical ageing.

1.2.4 Snowboard shape

The shape of the snowboard is also a criterion of choice in the optimisation of performance. There are several ways of working with the shape of the snowboard. The first one consists in working on the shape of the board itself by working on its dimensions: its length, its width, the distance from the ”nose” (front of the board) and from the ”tail” (back of the board) in relation to the centre, width of the ”nose”, width of the ”tail”. All these dimensions are not left to chance and vary according to the type of discipline performed. The symmetry of the board is not a necessity and in most cases snowboards are absolutely not symmetrical.

The second important shape of the snowboard is called the camber. The camber defines how the lower surface of the snowboard is in contact with the snow. It is defined in the plane perpendicular to the snow and in the longitudinal direction of the board. It can have different shapes: standard camber, inverted camber, W camber, rocker... There is a whole selection of different shapes that give the snowboard different behaviour.

Finally, the last shape to be taken into account is that of the fibres present in the skins of the board. They can also be of different shapes: woven, non-woven, long, short, in one, two or three dimensions... which naturally varies the properties of snowboards.

i Global shape

The overall shape of the snowboard varies according to 8 elements (Burton™, 2020) as shown in Table 1. The first of these is the length of the snowboard. The longer a board is, the more stable it will be at high speed, but the more difficult it will be to handle. Another criterion that leads to the same consequences is the side-cut radius. A low side-cut radius means a board's ability to make small turns, increasing its manoeuvrability. However, it also means a decrease in stability at high speeds. These two characteristics, which are linked together, therefore influence the handling of the snowboard.

The width of the board in the skate, i.e. in the middle of the feet, reflects the board's lift. The wider the board is, the higher the contact surface in powder snow and the less the board will sink. This is also true for the width of the nose and tail. The wider the nose and tail, the greater the lift in powder snow will be, but this characteristic leads to a loss of accuracy on packed snow. In addition, the difference in width between the width of the skate and the width of the nose and tail is directly related to the side-cut radius. These characteristics also change another dimension of the board: the side-cut depth. The effective length is the length of the board in contact with the snow. The side-cut depth is the length of the board in contact with the snow, as the tips are raised so that the entire length of the board is not in contact with the snow. This is why the introduction of a new length, the effective length, is important in defining the snowboard. This length will affect the manoeuvrability of the board in the same way as the total length of the board. Finally, the last dimension to be taken into account is the stance. The stance represents the distance between the 2 feet of the snowboarder. It will evolve according to the morphology of the rider, to try to keep a natural distance between the feet equal to the width of the pelvis.

Table 1: Table of the different dimensions of a snowboard board.

Board Size (mm)	Effective Edge (mm)	Side-cut Radius (mm)	Side-cut Depth (mm)	Waist Width (mm)	Nose Width (mm)	Tail Width (mm)	Stance Width (mm)
1560	1180	7400	21.1	248	295.2	285.2	560
1620	1240	7800	22.2	254	303.4	293.4	560
1680	1295	8200	23.2	260	311.5	301.5	560

ii Camber

The camber is one of the most important properties in the shape of the snowboard. It offers a totally different way of sliding depending on the type of camber chosen. Still according to the Burton™ brand (Burton™, 2020), there are 6 different types of camber all referenced in figure 5.

- Traditional camber: A symbol of powerful turns and dynamic precision, the camber embodies the essential values of a snowboard. Offering an energetic suspension, the camber distributes the weight evenly along the entire length of the snowboard for smooth and continuous edge control from tip to heel.
- Directional camber: The front rocker causes the spatula to lift and the camber under both feet maintains movement and stability in deep curves and variable conditions.
- PurePop camber: An evolution of a traditional camber shape, our PurePop camber profile features subtle flat zones just outside your feet to amplify pop and add playfulness to the snap and response of camber. Early rise tip and tail sections spin and float with a catch-free feel.
- Flying V™: A blend of camber and rocker performance, Flying V™ offers the best of both worlds. Rocker overall, including between and outside your feet, enhances playfulness and float. Underneath your feet, subtle camber zones focus edge-control for crisp snap, added pop, and powerful turns.
- Flat Top: Rising rider or seasoned pro, keep your game high and tight with Flat Top. A flat profile between the feet means stability, better balance, and continuous edge control. The tip and tail kick up with an early rise outside the feet for the catch-free, loose feeling you'd expect from rocker.
- Directional Flat Top: A flat profile overall with a rocker nose for the steady stability and effortless float demanded by deep days and surfy terrain.

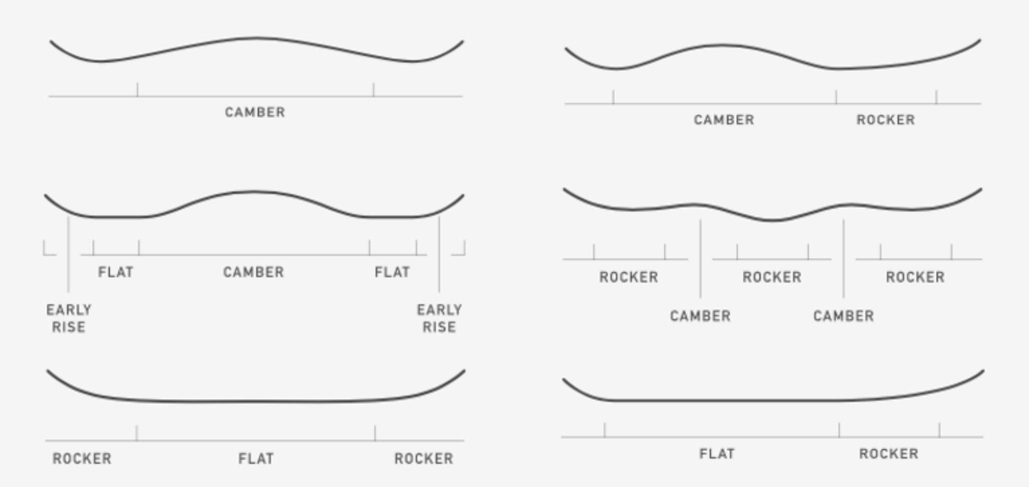

Figure 5: The different types of cambers. From left to right and from top to bottom: traditional camber, directional camber, PurePop camber, Flying V™ camber, Flat top camber and directional Flat top camber.

iii Fiber shape

The majority of snowboards are manufactured in the same way as today's skis in terms of the composite layers that make up the skins. Composite layers are made from resin-impregnated unidirectional fibres, which are laminated around the core of the ski in strips, diagonal or triaxial braids (D. Lind, 2002).

The choice to use continuous, oriented and woven fibres results from the mechanical behaviour of this type of fibre. Indeed, the snowboard must have a similar mechanical behaviour in flexion and torsion to give the snowboard the desired performance. It is for this reason that skewed fibre structures or rectangular tubular configurations are chosen. These configurations provide the highest torsional stiffness with optimal bending behaviour (D. Lind, 2002). In addition, a woven fibre configuration offers material and weight savings compared to disordered fibre mats for equivalent mechanical strength (Y. Rémond, 2011). However, weight is a criterion of choice for the design of snowboards, so it is natural that the fibres in the skins are of a continuous, oriented and braided nature. Finally, the most commonly used weave for this type of object is the Taffeta weave, which provides the appropriate mechanical properties and is also the easiest to use.

1.2.5 Theory of composites

As seen previously in part 1.2.3.ii, the glass fibres used for the manufacture of snowboard skins are long fibres, woven and oriented in the 2 directions of the plane.

However, the numerical modelling of these skins can be carried out in different ways. The calculation of the elastic properties of the fabrics used in composite materials differs according to several models (F. Dal Maso, 1998). For two-dimensionally woven fabrics, several analytical micro mechanical models have been presented:

- The analogy to a laminate [0°/90°]
- The mosaic in series and in parallel
- 1D corrugations
- 2D series-parallel and parallel-series corrugations.

These models all attempt to represent, more or less close to reality, the results following mechanical constraints applied to a woven composite material.

Results are obvious: finding experimental results from a theoretical model is not easy. Indeed, the complexity of the weaving process has a huge influence on the results obtained, which distances the models from reality.

To begin with, the analogy of a laminate [0°/90°] is the model furthest from reality, but it is also the easiest model to implement. This model does not take into account the undulations of the fibres during weaving, which makes it approximate. Moreover, the assumption of a collage between the 2 superimposed layers also influences the result.

The mosaic in series or in parallel consists in neglecting the undulation of the fibres by assuming that they are discontinuous. On the basis of these assumptions, the fabric is discredited as a set of paving stones, consisting of two asymmetrical cross-plies [0°/90°] and [90°/0°]. As with the previous model, ignoring ripple seems particularly critical. Furthermore, the local coupling between bending and extension does not affect the modulus in the parallel mosaic model and therefore leads to results with too high values.

The 1D corrugation model takes into account the corrugation and continuity of the fibres along the considered axis. The results show that the 1D corrugation pattern is close to the experimental values in the case of the carbon fabric, but clearly overestimates the values for glass E fabrics. This is because the geometric characteristics of the warp and weft threads are identical. This leads to an overestimation of the modules in the weft direction. This type of model is therefore not suitable for snowboards made of fibreglass.

Finally, the 2D wave model is an improvement of the first 1D model. It takes into account the weaving in both dimensions, as well as the spaces between neighbouring yarns. It is this model that provides the best estimated module values. However, the complexity of this model to set up is a hindrance to its use.

Here are the results of their experiences compiled in Table 2:

Table 2: Table of tensile moduli calculated with micro-mechanical and experimental models.

Material	Thickness (mm)	Experimental Moduli (GPa)	laminate [0°/90°]	Mosaic	1D Wave	2D Wave
Carbon/Epoxy	0.16	60.3	58.2	60	54.7	58.8
Glass/Epoxy	0.15	14.5	21.2	-	23.1	14.9
	0.20	18.1	21.2	-	24.1	21.5
	0.50	14.8	21.2	-	24.4	21.6

From the results in Table 2, it is clear that the most complex model, the 2D corrugation model, offers the most accurate results. However, it is also noticeable that the results of the [0°/90°] stratified analogy remain to a lesser extent close to reality. Moreover, the simplicity of this model makes it a criterion of choice for its use. It is for this reason that the [0°/90°] analogy model will be used for the rest of this study.

1.2.6 Mechanical properties

The practice of snowboarding requires the board to withstand various types of stress. The first constraint to be taken into consideration is the normal stress on the board. This stress, brought by the weight of the snowboarder, will apply a force to the board and deform it: this is the bending stress. This stress is very important to take into account because the majority of movements linked to the snowboard will deform the board according to a bending test. Therefore, the board must be able to withstand high bending stresses, otherwise snowboarding would not be possible. In addition, the snowboard is subjected to a torsional stress field. The snowboarder, mainly at the exit of a turn, will apply a torsional stress on his board and deform it elastically, which will tend to return to its initial shape. During this step, the board will release the accumulated energy necessary to deform it previously: this is the return. This return will then be exploited by the snowboarder to convert it into kinetic energy and thus create acceleration with his board. Torsional stress is therefore an important characteristic to take into account. Finally, bending and torsional stresses are the 2 main stresses to be taken into account (C. Agouridas and Rigny, 2014).

Shear stresses are also present in snowboarding. However, these stresses are only secondary and their intensity is only marginal compared to the others. The shape of the snowboard and the choice of materials according to the bending and torsional stress largely covers the expectations to resist shear stresses, so it is not necessary to study them. This is also the case for compressive stresses which are very low compared to bending and torsional stresses. Finally, the snowboard is subjected to stresses coming from all directions and of different natures, but only the study of torsional and bending stresses is sufficient to establish a model of whether a snowboard is stable or not.

1.3 Organisation of the work

The work for this study is organised as follows. The first step is the realisation of the state of the art of snowboarding. This step allows us to establish a synthesis of all the research that has been done on snowboarding in order to carry out this study with all the knowledge and sufficient technical baggage on this subject. Then comes the step of computer modelling of the current board. It is the reference snowboard. All comparisons to improve the object will be made in relation to the results obtained with this reference board. For this, the choice of dimensions as well as the materials used depends on the technology currently used for snowboards. This modelling is of course based on research carried out during the state of art in order to get as close as possible to reality. Then the mechanical tests are applied on the digital model to obtain results. These results will then be processed and discussed to establish the mechanical stresses applied during the practice of snowboarding and therefore determine the minimum mechanical properties for the production of this type of object. Finally, the last step will be to improve the snowboard boards based on the results previously obtained. By modifying the materials used, the shape of the board, or the number of layers present in the material, the aim is to optimise the mechanical characteristics while trying to make improvements from a performance, cost or ecological impact point of view.

1.4 Budgeting

The purpose of this section is to determine the budget needed to carry out such a study. This section is composed of 3 sub-sections. The first sub-section lists the gross prices of all the elements used to carry out the project. The second sub-section corresponds to the actual budget for the study carried out, while the third part also includes the price of the physical implementation of the project.

This project requires the use of a specific machine as well as special software to carry it out. However, the price of the machines and software must be calculated according to the time of use in relation to their purchase price, as well as in relation to the depreciation price of such an asset, on a proportional basis. The budget for the use of the machines and software for this project can then be calculated according to the equation 1 :

$$Preal = \frac{t * C}{A} \tag{1}$$

With t the actual usage time for this project, A the amortisation time of the machine/software, and C the actual purchase cost of the machine/software.

For reasons of approximation, large machines and software will be depreciated over 10 years, while small tools will be depreciated over 5 years.

Finally, the calculation that budgets for this project takes into account the direct costs such as labour, raw materials or the price of machines and software, but it is also necessary to consider the overheads supposed to be equal to 10%, the taxes on know-how also supposed to be equal to 10%, and finally the value added tax (VAT) at 21%. All these taxes are to be taken into account when calculating the total price of the project.

1.4.1 Real prices

The following tables provide information on the gross price of the elements required to complete the project.

Table 3: Table of the price of workforce

Units	Description	Unit Price (€)
h	Project Manager	25.00
h	Researcher	25.00
h	Material engineer	20.00
h	Laboratory assistant	15.00

Table 4: Table of the price for Raw Material

Units	Description	Unit Price (€)
u	Ash wood core 190x14cm	24.00
u	Snowboard edge 1.95m	10.99
m	Glass fabric E taffeta [0°,90°] 200g/m^2	5.35
m	Glass fabric E triaxial [0°,45°,-45°] 750g/m^2	7.62
m	Linen fabric taffeta [0°,90°] 115g/m^2	9.78
kg	Epoxy resin	16.66
kg	Wood glue	14.70

Table 5: Table of the price for Tools

Units	Description	Unit Price (€)
u	Electric planer	59.99
u	Electric router	65.99
u	Jigsaw	42.95
u	Belt sander	59.95
u	Drill	55.99
u	Precision balance	16.99
u	Vacuum pump	230.00
u	Extension cord	5.50
u	Cutter	2.80
u	Clamp	4.50
u	Brush	1.70

Table 6: Table of the price for Devices and Software

Units	Description	Unit Price (€)
u	Laptop computer	1000.00
u	Abaqus software	65000.00
u	Pack office	50.00

Table 7: Table of the price for Protective Equipment

Units	Description	Unit Price (€)
u	Latex gloves	0.02
u	Cotton blouse	12.99
u	Protective goggles	7.98
u	Gas mask	26.99
m	Protective cover	0.2

1.4.2 Actual study budget

The table 8 provides information on all the elements contributing to the direct costs of carrying out this project.

Table 8: Effective budget for the computer modeling of a snowboard

Units	Description	Unit Price (€)	Quantity	Total (€)
	Snowboard modeling			
h	Project manager	25.00	10	250.00
h	Laptop computer	1000.00	350	3.99
h	Abaqus software	65000.00	200	148.40
h	Pack Office	50.00	100	0.06
			Total price	**402.45**
			10% Overhead costs	40.25
			10% Know-how	40.25
			21% V.A.T.	84.51
			Investment Budget	**567.46**

Table 8 then gives the final price of the study conducted without the material manufacture of the snowboards. The price of the study is then **Five hundred and sixty seven Euros and forty six cents : 567.46€**

1.4.3 Study budget with physical design

The table 9 estimates approximately the total price for the physical realisation of this project, in addition to computer modelling.

Table 9: Effective budget for the modeling and fabrication of the 3 types of snowboard

Units	Description	Unit Price (€)	Quantity	Total (€)
	Snowboard modeling			
h	Project manager	25.00	10	250.00
h	Laptop computer	1000.00	350	3.99
h	Abaqus software	65000.00	200	148.40
h	Pack Office	50.00	100	0.06
			Total price	**402.45**
	Snowboards fabrication			
h	Project manager	25.00	10	250.00
h	Researcher	25.00	3	75.00
h	Material engineer	20.00	5	100.00
h	Laboratory assistant	15.00	10	150.00
u	Ash wood core 190x14cm	24.00	6	144.00
u	Snowboard edge 1.95m	10.99	6	65.94
m	Glass fabric E taffeta [0°,90°] 200g/m^2	5.35	2	10.70
m	Glass fabric E triaxial [0°,45°,-45°] 750g/m^2	7.62	2	15.24
m	Linen fabric taffeta [0°,90°] 115g/m^2	9.78	2	19.56
kg	Epoxy resin	16.66	3	49.98
kg	Wood glue	14.70	1.5	22.05
h	Electric planer	59.99	1	0.02
h	Electric router	65.99	1	0.02
h	Jigsaw	42.95	1	0.01
h	Belt sander	59.95	1	0.01
h	Drill	55.99	0.5	0.01
h	Precision balance	16.99	0.5	0.01
h	Vacuum pump	230.00	2	0.12
u	Extension cord	5.50	1	5.50
u	Cutter	2.80	1	2.80
u	Clamp	4.50	18	81.00
u	Brush	1.70	3	5.10
u	Latex gloves	0.02	3	0.06
u	Cotton blouse	12.99	1	12.99
u	Protective goggles	7.98	1	7.98
u	Gas mask	26.99	1	26.99
m	Protective cover	0.2	5	1.00
			Total price	**1046.09**
			10% Overhead costs	104.61
			10% Know-how	104.61
			21% V.A.T.	219.68
			Investment Budget	**1474.99**

According to the table 9, the final budget with material design of the 3 different snowboards would then amount to **One thousand four hundred and seventy-four Euros and ninety-nine cents : 1474.99€**

2 Material and methods

2.1 Material selection

2.1.1 Laminated ash wood

Glued laminated ash wood is the type of wood used to make the core of the reference snowboard. As mentioned above (1.2.3.i), glued laminated wood is ideal for the manufacture of snowboard hearts. And for this study, ash wood will be used. Its high torsional and bending strength makes it the ideal candidate for the manufacture of snowboard cores. Ash is also a tree species with high resilience. This characteristic should be taken into consideration for the manufacture of snowboard boards that may be subject to severe impact. This high resilience is due to its high density and hardness. However, ash is one of the only hardwoods to be relatively light, yet it retains very interesting mechanical properties (Walsh, 2019). Finally, this species is easily machinable and does not absorb water very easily, which is an advantage for outdoor snowboarding on snow. This limits the risks of swelling and explosion of the board.

The mechanical properties such as Young's modulus E or shear modulus G of glued laminated ash wood are not obvious to determine. Indeed, the literature on the subject says that mechanical properties depend on many criteria, such as the moisture content of the wood, its origin, the way in which the glued laminated timber is assembled, etc. In order to have Young's modulus and shear modulus values for this study, a selection of works has been made to estimate the values for these characteristics as accurately as possible. According to the work of *S. Rahili Khorasan* (Khorasan, 2012) who studied glulam beams with the finite element technique, he used the mechanical properties of the Table 10. These values will also be used for the calculations in this study.

Table 10: Mechanical constant values to express elastic behaviour of glulam.

E_1 (MPa)	E_2 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
12000	240	0	720	720	72

2.1.2 Glass fiber / Epoxy

As seen previously (1.2.3.ii), the materials that make up the skins for the reference snowboard are fibreglass and epoxy resin. According to 1.2.5, the simple superposition of layers [0°,90°] is sufficient to establish a model close to reality. Thus it is sufficient to consider only the unidirectional mechanical properties to obtain values for numerical calculations.

In the work carried out by *F. Wolfsperger et al.* (F. Wolfsperger, 2016), a finite element modelling was carried out for an alpine ski. As the ski is relatively similar to the snowboard, it is then possible to use the values used in their study to carry out this project. The values of the mechanical constants of the unidirectional fibreglass / epoxy material are then listed in the Table 11.

Table 11: Mechanical constant values to express elastic behaviour of fiber/epoxy composite material.

E_1 (MPa)	E_2 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
32000	8000	0.32	2500	3000	3000

According to the values in the tables 10 and 11, it is clear that the mechanical behaviour is mainly ensured by glass-fibre / epoxy composite layers, which have mechanical properties far superior to those of wood. This remark will have an impact on the core fibre arrangement.

2.2 Reference snowboard design

2.2.1 Shell construction

In order to get as close as possible to reality, the design of the snowboard on Abaqus was based on an existing snowboard. For this purpose, the study is based on the "Men's Burton Flight Attendant Camber Snowboard" model (Burton™, 2020) of a snowboard from the brand Burton™. This board is a snowboard used for freeride. It therefore has special characteristics. First of all, it is asymmetrical with the "nose" bigger than the "tail". In addition, the width of the nose is also wider than the width of the tail. These 2 characteristics combined allow the board to have an optimal lift in powder snow. The choice of the camber, which is a standard camber, also allows the board to adopt an adequate mechanical behaviour for the practice of snowboarding in fresh snow. This board was initially designed on Abaqus according to the manufacturer's dimensions shown in the figure 6.

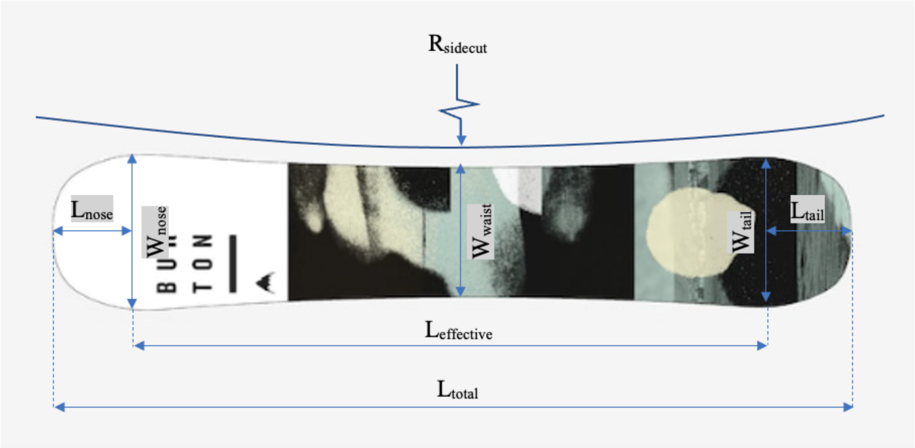

Figure 6: Specific lengths for snowboard design.

In addition to these dimensions, the dimensions in the plane perpendicular to the snow, the XY plane, must also be considered. In this plane are the dimensions of the camber $Camber$, the height of the spatulas $h_{spatula}$, as well as the total thickness of the board t_{total}.

All these dimensions useful for the manufacture of the snowboard are listed in Table 12

Table 12: Table of the different dimensions of a snowboard board.

L_{total} (mm)	$L_{effective}$ (mm)	$R_{sidecut}$ (mm)	L_{nose} (mm)	L_{tail} (mm)	W_{nose} (mm)	W_{tail} (mm)	W_{waist} (mm)	$Camber$ (mm)	$h_{spatula}$ (mm)	t_{total} (mm)
1590	1210	7600	205	175	298.3	288.3	560	-8.2	100	16

The figure 7 present the pattern for the production of the reference snowboard. This pattern only concerns the general shape of the board. The total thickness of the snowboard, the individual layers and the fibre orientation will be defined later in the computer construction.

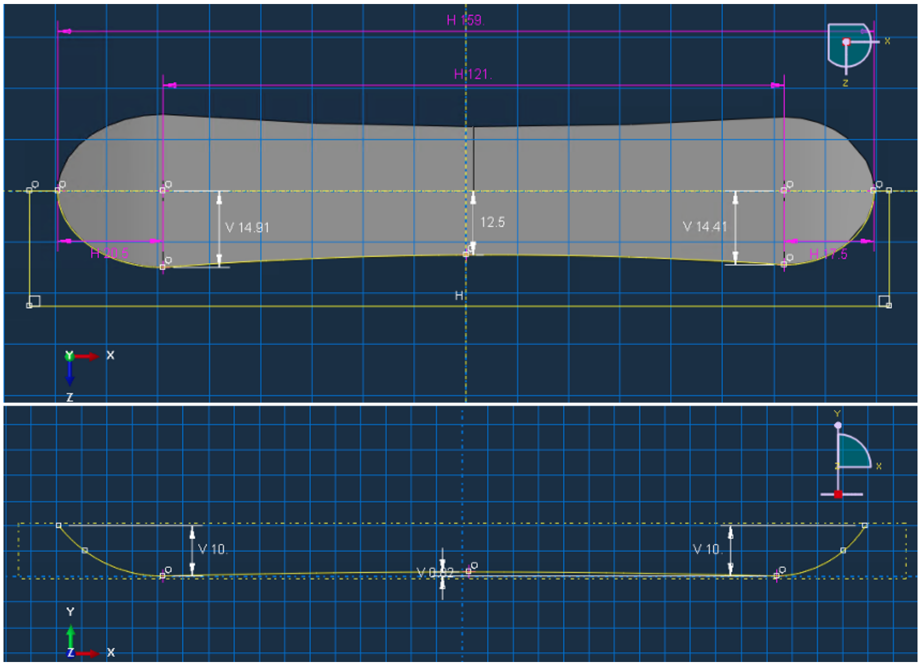

Figure 7: Pattern for the construction of the reference snowboard on Abaqus.

2.2.2 Layers assembly

The assembly of the different layers inside the previously manufactured snowboard shell is carried out directly on the Abaqus software. The manufacture of a layup composite with a supposedly perfect bonding is possible directly via a tab in the software. According to the point 1.2.5 seen in the introduction, a simple [0°,90°] joint is sufficient to model a woven composite. As the composites used for snowboard skins are woven glass fibres in taffeta, this method is acceptable. In addition, this study aims to simply determine the mechanical behaviour of the snowboard. As the sole, the edges and the upper surface do not play any role in the mechanical resistance of the object, these layers will not be modelled during the mechanical tests carried out. Finally, according to the research carried out on glued laminated ash wood, it is possible to consider the core of the board as a unidirectional material with the mechanical characteristics of a previously determined glued laminated wood.

The composition of the board will therefore be as follows:

- 2 top layers of fibreglass / epoxy, with 0° and 90° orientation to resemble taffeta weave. Each of these layers is 1mm thick (F. Wolfsperger, 2016), so a total of 2mm.
- 1 layer of unidirectional glued ash laminate 1.2cm thick (Unknown, 2020) that will make up the heart of the board.

- 2 lower layers of fibreglass / epoxy with 90° and 0° orientation, to be the exact symmetry of the upper layers. These layers are also 1mm thick for a total of 2mm.

Finally, the snowboard is therefore composed of 5 layers for a total thickness of 1.6cm. The organisation of the layers is shown in Figure 8.

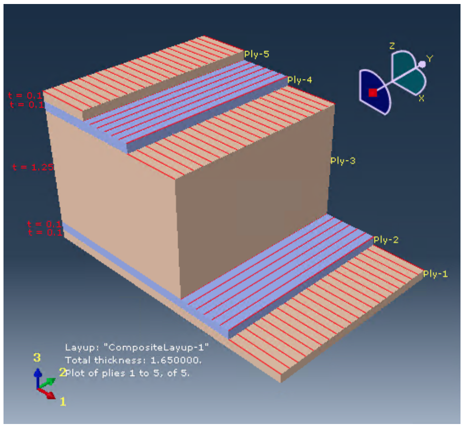

Figure 8: Organisation of the different layers inside the snowboard.

2.3 Mechanical tests

During this study, 2 mechanical tests were carried out: the 3-point bending test and the torsion test.

2.3.1 3-Point bending test

In the 3-point bend test, the snowboard was supported at the beginning and end of the effective part of the snowboard which corresponds with the contact points of the nose and tail (Figure 9 left). The board was loaded in the centre to a force of $327N$ (N. Scott and Osada, 2007) which is closest to reality. For greater accuracy, a coefficient of friction of 0.1 was added between the non-deformable cylinders and the snowboard.

2.3.2 Torsional test

A torsional test was carried out for the front and rear body of the snowboard (Figure 9 right). The snowboard was rigidly fixed in the middle of the board, between the rider's 2 feet, while an opposing force torque of $100N$ was applied.

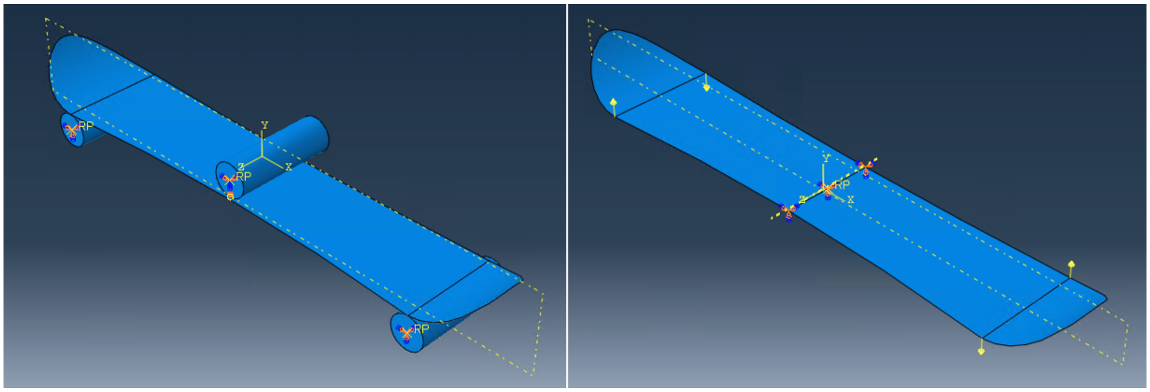

Figure 9: Mechanical tests carried out. From left to right: 3-Point bending test and Torsion test.

2.4 Experimental snowboards design

In this study, 2 innovative snowboards will be compared to the reference snowboard, composed of a glued laminated core of ash wood and skins made of fibreglass / epoxy composite. These two new boards will be different in terms of the materials used and the overall shape of the board.

2.4.1 Experimental shape

First experimental board will be made from the same materials as the reference board, i.e. it will consist of a core of glued laminated ash wood and fibreglass/epoxy skins. However, the shape of the skins will be different. Instead of the two-dimensional laminate [0°,90°], this experimental board is equipped with a three-dimensional laminate [0°,45°,-45°] as shown in Figure 10. The mechanical stresses applied when using a snowboard justify the orientation and arrangement of these new plies within the laminate. Although the addition of an extra layer of fibre may add weight to the structure, this weight will be minimal compared to the mechanical performance gains provided by this additional ply. The digital study of this board will allow us to determine whether the change in mechanical behaviour due to the new type of laminate used will be favourable or unfavourable to freeride snowboarding.

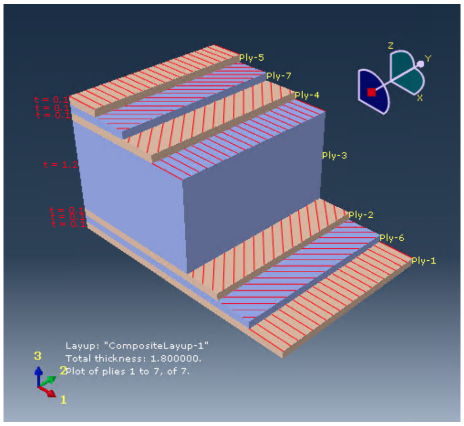

Figure 10: Organisation of the different layers for the triaxial laminate inside the snowboard.

2.4.2 Experimental material

The second experimental snowboard is made of totally different materials than the reference board. In order to vary only one parameter, the core of the board remains glued laminated ash wood, but the skins are now made of flax fibre in an epoxy matrix. The choice of these materials was not made at random. Flax was chosen for its mechanical behaviour very close to that of fibreglass, so the mechanical responses of the flax board will be similar to the mechanical responses of the reference board. Moreover, flax has a lower density than glass ($d_{flax} = 1.4g/cm^{-3}; d_{glass} = 2.5g/cm^{-3}$), its use will allow a weight saving of the snowboard. Linen is also an excellent vibration damper which makes it the ideal candidate for the manufacture of a snowboard. Finally, linen is a natural material, so its use in snowboard manufacturing is a first step towards a more eco-friendly manufacturing process. However, flax also has several disadvantages. For example, it can have heterogeneous mechanical properties depending on the quality of the harvest or from one stem to another. It is also dependent on climatic conditions and is not guaranteed every year. It is therefore necessary to remain vigilant in the use of this type of resource.

Epoxy resin has also been carefully chosen. Flax fibres have a very good affinity with epoxy resin, unlike polypropylene resin. The PLA matrix has a better affinity with flax fibres, but has the big disadvantage of being biodegradable. However, one of the main functions of the skins is to protect the core from external aggression. A biodegradable matrix is therefore not conceivable for the manufacture of a snowboard that is constantly exposed to external aggression such as humidity, temperature changes or UV rays. The epoxy matrix is therefore ideal for the manufacture of this new snowboard. Finally, as the flax fibres are fixed in the epoxy matrix, there is no risk of bio-degradation for these fibres despite the external conditions.

The values of the mechanical constants of the flax fibre / epoxy composite are referenced in Table 13 (E. Spārniņš, 2012).

Table 13: Mechanical constant values to express elastic behaviour of flax/epoxy composite.

E_1 (MPa)	E_2 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
26500	2650	0.35	1300	1300	1900

3 Results

Mechanical 3-point bending and torsion tests were carried out on the 3 types of snowboard. In order to exploit the results, numerical calculations were carried out along different paths on the snowboards.

For the 3-point bending test, 3 types of paths were used to obtain results. The first path is transverse to the board, in the middle of the snowboard, where the load is applied. This is where the bending deflection is at its maximum. The second path is in the longitudinal direction of the snowboard, in the middle, from the centre of the snowboard to the rear spatula. Finally, the third and last path is parallel to the second, but on the right side of the board. All these paths have been chosen in order to obtain optimal results that can be used for all 3 snowboards.

For the torsion test, a 4th path in addition to the 3 previous ones is used. This path is, like the first one, transverse to the snowboard and is located at the level of the rear spatula, where the torque is applied.

Figure 11 shows the paths on which the numerical calculations were performed.

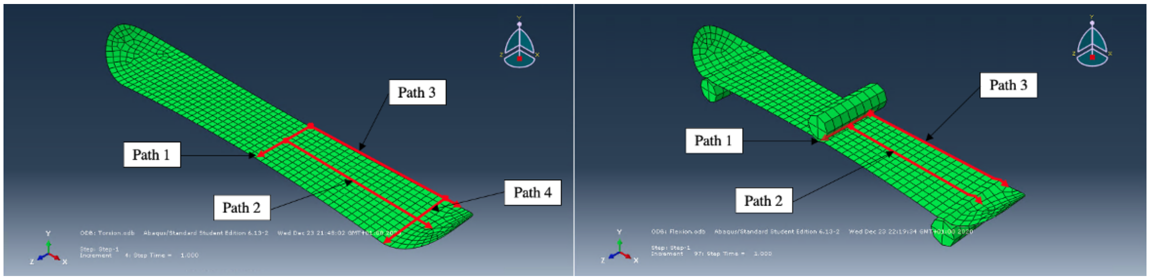

Figure 11: Paths used for the numerical calculations. From left to right: paths for torsional test and paths for 3-point bending test.

When carrying out the calculations on the different snowboards, some results appeared quite surprising with sometimes unexpected values. It should be kept in mind that all calculations were carried out in the same way on all boards and along all paths and therefore the measurement errors, if any, are the same for all results obtained. The results therefore allow comparisons to be made between different paths within the same board or between the same different board paths, but the eigenvalue of some results may not make physical sense.

3.1 Reference board

The calculations carried out on the reference board will be the basis for comparison with all other snowboards. It is from these results that the conclusions on the other board types will be drawn.

Figure 12 shows the results of the two mechanical tests carried out on the reference snowboard for the different paths. On the graph of the torsion test, we can see that the maximum torsion of this board reaches a value of $1099MPa$ on paths 1 and 3. This maximum value is produced in the middle of the board on the 2 edges. Path 1 also shows a decrease in torsional stress at the centre of the board to a value of $153MPa$. Path 2 shows a slight increase in torsional stress along the board before going down again. Path 2 shows an evolution of the torsional stress in the form of a flattened bell. At point 0, the torsional stress is $153MPa$, then goes through a maximum at $32.79cm$ with a value of $299MPa$, and finally ends at $168MPa$ at the end of the path. This means that the torsion at the centre of the board in the longitudinal direction increases as it moves away from the centre, before decreasing again as it approaches the spatula. This behaviour is completely opposite to the behaviour of path 3. Torsion according to path 3 is maximum at the beginning of the path with a value of $1099MPa$, before decreasing to a value of $194MPa$ at a distance of $32.79cm$ from the centre of the board, before increasing again to a value of $441MPa$ at the end of the effective edge. Finally, path 4 shows a similar behaviour to path 1, to a lesser extent. The maximum torsional stress along this path starts at point 0 with a value of $441MPa$, before decreasing to the centre of the board in the transverse direction ($15.72cm$) at $181MPa$ then this value increases to $441MPa$ at the end of the board at $28cm$. Since path 1 is the recessed area for the calculations, it is normal to find higher torsional stress along this path than along path 4.

The bending results show that the maximum bending stresses are applied in the centre of the board at the point of force application. This perfectly logical result shows a maximum bending stress of nearly $2.5 \times 10^8 MPa$ (the value of this result may be somewhat erroneous due to its incredibly high value). However, the observations on path 1 show that the bending stress on the ends of the board in the transverse direction are slightly lower than the bending stress applied at the centre. On the ends, the board is subjected to bending stresses of $2.35 \times 10^8 MPa$ while at the centre in the transverse direction the constraint has a value of $2.48 \times 10^8 MPa$. This difference is due to the presence of the traditional camber in the design of the snowboard. Paths 2 and 3 show that the snowboard follows overall the same mechanical bending behaviour when moving away from the centre of the board towards the rear spatula. The bending stress decreases linearly before dropping to 0 at the point of contact. This result, again logical, shows that the mechanical behaviour of the board in bending does not depend on the transverse position of the board. However, path 3 shows a small subtlety with a slight increase in bending stresses from $2.35 \times 10^8 MPa$ at point 0 up to $2.43 \times 10^8 MPa$ to $6.22cm$. In addition, path 2 has lower constraints than path 3 from $6.22cm$ to $49.35cm$, before reversing the trend in the last few centimetres.

Figure 13 shows the reference snowboard deformed after application of bending and torsional stress. It also shows the bending and torsional stresses in the snowboard in a pictorial manner with a play of colour to establish a scale.

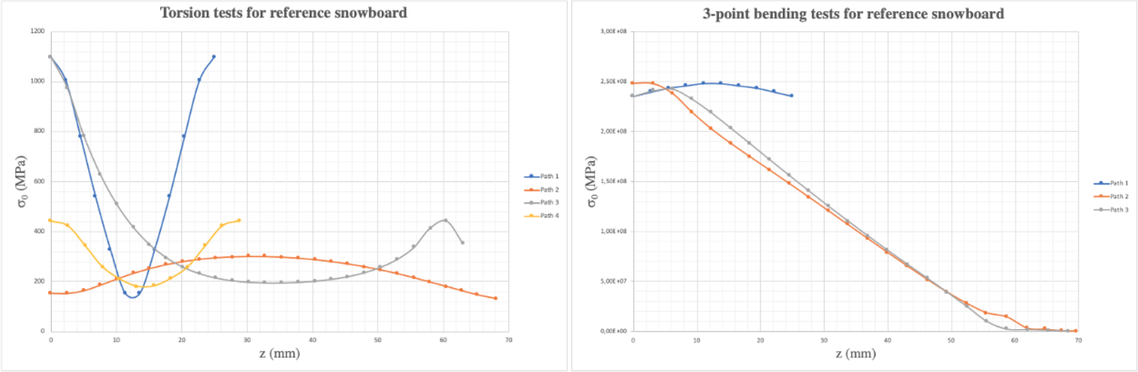

Figure 12: Graph showing the evolution of the constraints for the reference snowboard according to the different paths. From left to right: torsional stresses and bending stresses.

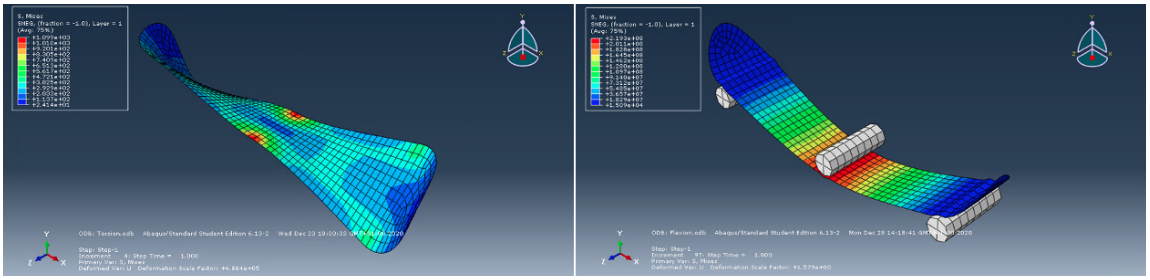

Figure 13: Deformation of the reference snowboard with colour scale for mechanical stress. From left to right: torsional deformation and stresses, bending deformation and stresses.

3.2 Triaxial board

The results obtained for the board with triaxial fibreglass are slightly different from those obtained with the reference snowboard. At first, the general pattern of stresses according to the different paths is similar. Whether in bending or torsion, the mechanical stresses according to the paths follow the same patterns as those for the reference snowboard. As shown in Figure 14, the maximum torsional stress is obtained at the centre of the board on one of the edges as shown in paths 1 and 3, with a maximum value of $469MPa$. The minimum stress according to path 1 goes down to a value of $81MPa$ at $13.62cm$ from the edge, before rising to its maximum on the other side. The maximum stress in path 2 does not exceed $107MPa$ at the top of the bell, and the values at points 0 and 65.19 cm are $81MPa$ and $42MPa$ respectively. The minimum value in path 3 goes down to

$51MPa$ in the middle of the back of the snowboard at $37.84cm$ from the center, when the same path has the maximum torsional stress at point 0. Path 3 shows also an increase in torsional stress up to $216MPa$ at the end of the board. Finally, path 4 shows a low torsional stress following roughly the same pattern as path 1, with values of $216MPa$ at point 0, a minimum of $57MPa$ at $13.10cm$ before rising to $233MPa$ at the other end in the transverse direction.

As far as bending stress is concerned, the triaxial snowboard has a similar behaviour to the reference snowboard. Path 1 shows a maximum stress of $2.48 \times 10^8 MPa$ with lower stresses value of $2.35 \times 10^8 MPa$ on the ends due to the camber of the snowboard. Paths 2 and 3 also show a maximum bending stress at the centre of the board, before decreasing linearly to 0 at the rear contact point. However, path 3 is a little more subtle than this, with an increase in bending stress first, followed by a linear decrease at the same rate as path 2. This small increase in stress from $2.35 \times 10^8 MPa$ at point 0 up to $2.43 \times 10^8 MPa$ at $6.22cm$ shows that the maximum bending stress on an edge of the board does not appear at the point of force application but a few centimetres away. Again, paths 2 and 3 show very similar behaviour but the bending stress values for path 2 are slightly lower than those for path 3 from $6.22cm$ up to $49.35cm$, before reversing the trend over the last few centimetres. All these behaviours are perfectly illustrated by the figure 15.

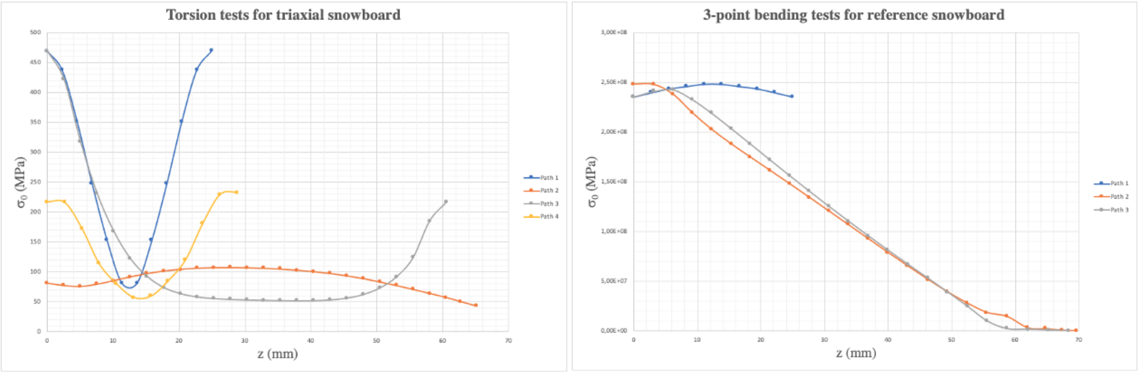

Figure 14: Graph showing the evolution of the constraints for the triaxial snowboard according to the different paths. From left to right: torsional stresses and bending stresses.

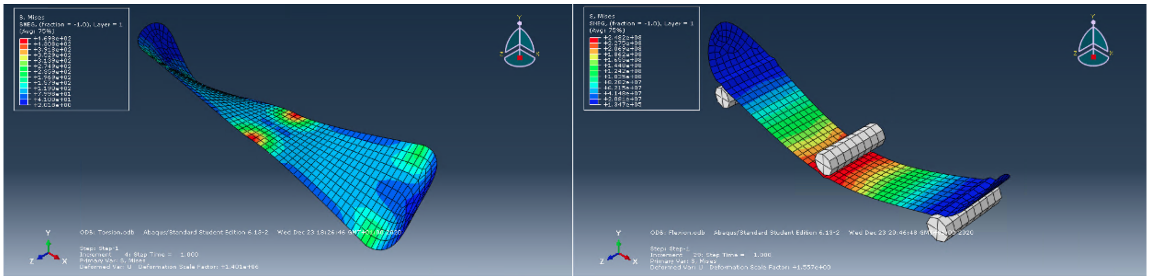

Figure 15: Deformation of the triaxial snowboard with colour scale for mechanical stress. From left to right: torsional deformation and stresses, bending deformation and stresses.

3.3 Flax/Epoxy board

The results obtained for the tests carried out on the snowboard composed of linen fibre and epoxy are shown in the figure 16. Once again, the general appearance of the curves follows the same pattern as for the 2 previous snowboards, with a few differences. The results of the torsion test show that the maximum torsional stress is in the middle of the board on its edges, for a maximum value of $1328 MPa$, determined using paths 1 and 3. Path 1 shows a decrease in stress at the middle of the board, at $13.62 cm$ in the transverse direction, with a minimum stress of $152 MPa$. Path 2 shows an increase in stress up to the middle of the half board starting at $153 MPa$ at point 0 up to $241 MPa$ at $32.79 cm$, before returning to a lower value of $124 MPa$ at the end of the board. Path 3 shows a maximum torsional stress at point 0 of $1328 MPa$ value, before going down to a minimum of $174 MPa$ at around $32.80 cm$ in the longitudinal direction, before finding a peak stress up to $501 MPa$ at $60.55 cm$ from the starting point. Finally, Path 4 follows the same path as Path 1 with much lower stress values, ranging from $501 MPa$ at the ends in the transverse direction to a minimum of $163 MPa$ in the middle of the board at $15.73 cm$. These stress fields can be seen in Figure 17.

For bending stresses, path 1 shows a flattened bell-shaped evolution of the stresses from a minimum of 1.39×10^8 to a maximum of 1.43×10^8 (potentially erroneous values). This small variation can again be explained by the camber of the snowboard. The stresses in paths 2 and 3 decrease linearly from 1.39×10^8 at the beginning to 0 at the support point at the end of the board, with a small offset between path 2 and path 3. The bending stresses are slightly lower along path 2 compared with path 3.

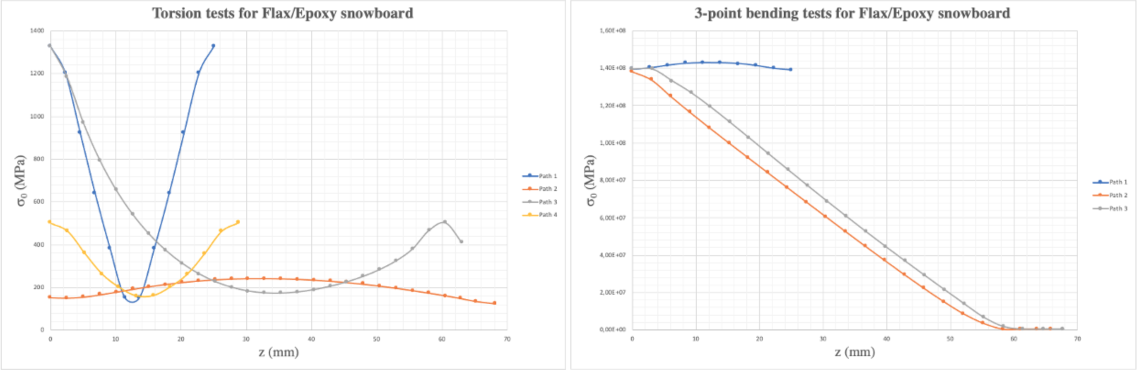

Figure 16: Graph showing the evolution of the constraints for the Flax/Epoxy snowboard according to the different paths. From left to right: torsional stresses and bending stresses.

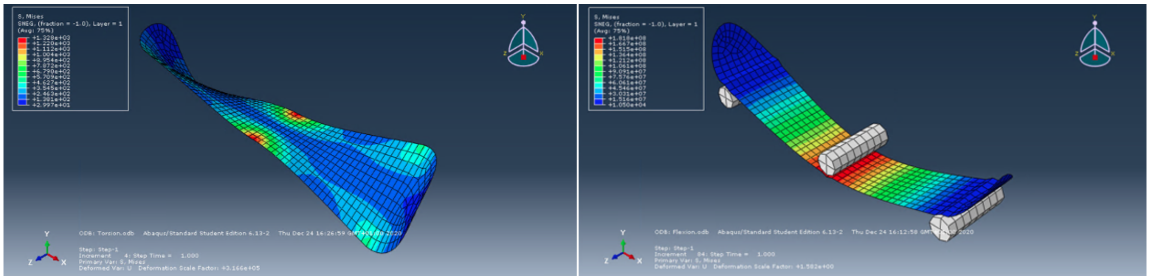

Figure 17: Deformation of the Flax/Epoxy snowboard with colour scale for mechanical stress. From left to right: torsional deformation and stresses, bending deformation and stresses.

4 Discussion

4.1 Torsional test

It is interesting to compare the different snowboards on a single path. The evolution of the mechanical behaviour in torsion of the 3 snowboard boards according to path 1 is visible on Figure 18. This figure first shows that the torsional stresses are much less in the triaxial snowboard than in the other 2 according to path 1. The reference board as well as the board made of flax fibre / epoxy seem to follow a relatively similar mechanical behaviour, but the triaxial board is characterised by much lower torsional stresses. At point 0, the torsional stresses in the triaxial board are 2 times lower than those of the reference board and almost 3 times lower than those of the flax board. In the centre, where the stresses are minimal, these deviations are much smaller but the triaxial board remains better. The other end of the board shows the same results as those obtained at point 0. As far as the comparison between the reference board and the Flax/Epoxy board is concerned, their mechanical behaviour in bending along this path is relatively similar. Indeed, at the extremities, the flax board presents higher bending stresses of nearly $230MPa$, which corresponds to an increase of nearly 20.9%, but at the centre, at $13.62cm$, the torsional stresses are rigorously equal to nearly $1MPa$.

Path 2 shows even different results. As with path 1, the triaxial board offers much lower torsional stresses than the other 2. However, a clear difference between the reference board and the Flax/Epoxy board appears. While the torsional stress seems to be similar for these 2 boards at point 0, the bell-shaped evolution of the reference board is much greater than that of the flax board. The maximum torsional stresses along this path for the reference board reach $300MPa$ at $30.27cm$ from point 0, while the maximum stresses of the flax board are only $240MPa$ at the same location, again a 20% decrease but in the opposite direction this time. Compared to the triaxial board, the maximum torsional stress of this board appears at $27.75cm$ with a value of $107MPa$, almost 3 times less than the reference board. The end stresses along this same path are also much lower for the triaxial board than for the other 2 boards. At point 0, the torsional stresses in the triaxial board are $81MPa$ while for the other 2 boards the stress is $152MPa$.

At the other end of the path, the same conclusions can be drawn. At the end of path 2, the torsional stresses for the triaxial board are $65MPa$, a particularly low value compared to the stresses of the reference board and those of the Flax/Epoxy board which are respectively $131MPa$ and $124MPa$.

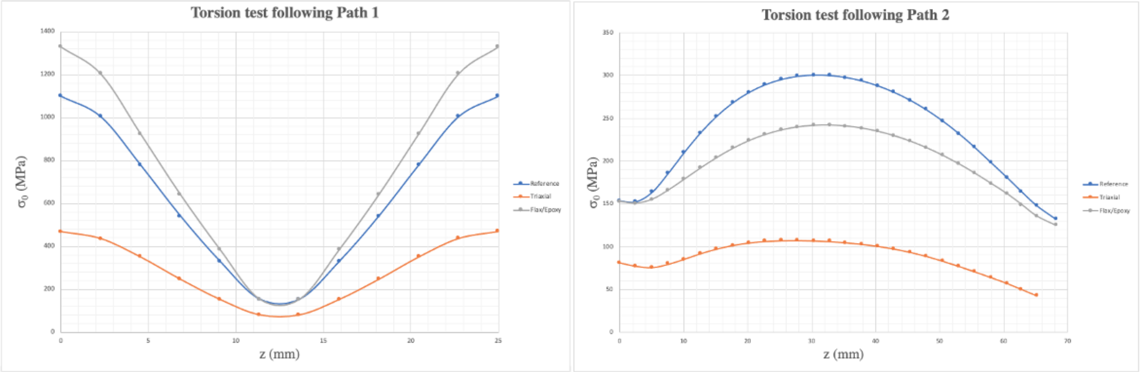

Figure 18: Graph showing the evolution of the torsional constraints according to path 1 and 2 for all types of board. From left to right: path 1 and path 2.

Path 3 confirms once again that the torsional stresses in the triaxial board are much lower than in the other two boards, as shown in Figure 19. For a stress of $469 MPa$ at point 0, the other two boards show a stress of $1099 MPa$ for the reference board and $1328 MPa$ for the Flax/Epoxy board, respectively. The Flax/Epoxy board is therefore the least rigid board with the highest stress. However, when moving along the path, the stresses of the reference board become higher than those of the Flax/Epoxy board from $27.75 cm$ to $45.41 cm$. It is between these two values that the stresses are minimal, but the stresses of the Flax/Epoxy board are lower than those of the reference board: $172 MPa$ at $35.32 cm$ versus $194 MPa$ at the same distance. The minimum stress of the triaxial board is around $50 MPa$ and ranges from $22 cm$ to $45 cm$. Finally, the stress values increase for the 3 boards around the $47 cm$ points, which corresponds to the ratio of the force torque applied at the end of the board, with relatively similar values for the reference and Flax/Epoxy boards ($440 MPa$ and $501 MPa$ at $60.55 cm$) and a much lower value for the triaxial board with a decrease of 50% compared to the reference board.

Finally, Path 4 shows a similar evolution to Path 1. Being also placed in the transverse direction of the board, this type of evolution is rather logical. In contrast to path 1, the torsional stresses along this path are less distant from each other. The reference and Flax/Epoxy boards are only $60 MPa$ different at point 0, and the stresses of the triaxial board at this same point are only $216 MPa$ compared to $441 MPa$ for the reference board. Then, the minimum is again reached in the middle of the board in the transverse direction, at $15.72 cm$, with very close values for the 2 reference and Flax/Epoxy boards and a value 3 times lower for the triaxial board. Note that, as in path 3, the torsional stresses become lower in the Flax/Epoxy board at the centre than those in the reference board at the same location. Finally, the evolution of the curve is symmetrical and the 3 boards adopt the same behaviour as before when approaching the other side.

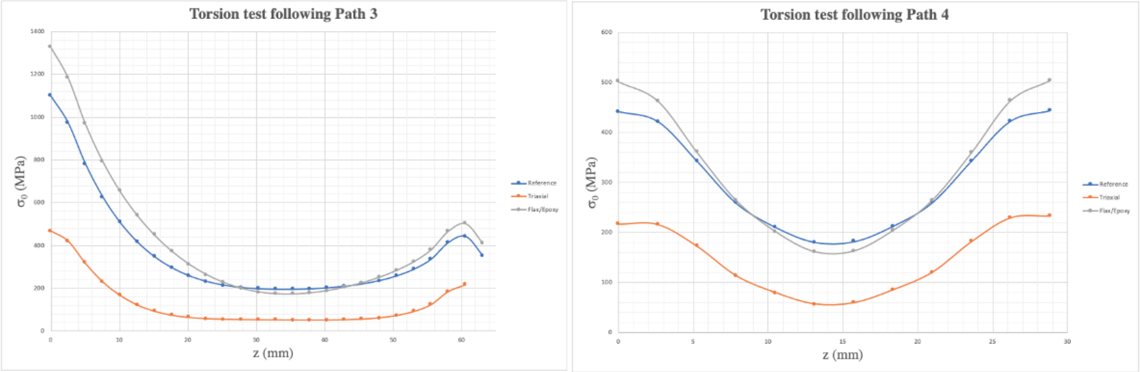

Figure 19: Graph showing the evolution of the torsional constraints according to path 3 and 4 for all types of board. From left to right: path 3 and path 4.

4.2 3-point bending test

It is now time to look at the bending stresses. Depending on the board considered, the results obtained in bending will look quite different from those found in torsion.

The figure 20 shows the evolution of the bending stress according to the different paths. The first striking thing is that, in flexion, the stresses of the reference board and the triaxial board are rigorously the same, whatever the path considered. It is therefore natural to assume that the orientation of the fibres and the number of layers used (in this study) do not influence the bending behaviour of the board. However, it should be noted that for these 2 boards, neither of the fibres are oriented in the direction of bending. The conclusions drawn from this study are therefore only valid for the cases studied here, without any possible extrapolation.

Path 1 shows that the evolution of the bending stresses follow a bell-shaped curve, regardless of the board considered. This evolution is due to the board's own design, which has a traditional camber. This camber induces maximum bending stresses in the centre of the board. This is not the only phenomenon responsible for the increased stress in the centre. The fish coefficient also plays a role. The bending test elastically deforms the material by slightly lengthening it in the longitudinal direction. If a positive fish coefficient is present for all materials, the boards will then shrink in the other two dimensions, thus inducing new bending stresses. Finally, these induced stresses increase as they sink towards the centre of the object due to their addition and accumulation.

To get to the figures, the bending stresses for the reference and triaxial boards are $2.35 \times 10^8 MPa$ at both ends of the board, whereas the Flax/Epoxy board shows much better results with only $1.39 \times 10^8 MPa$, a decrease of 40.85%. For the maximum stress, the difference is even more marked. At the centre of the board at $13.85cm$, the maximum bending stresses for the reference board are $2.48 \times 10^8 MPa$ against only $1.43 \times 10^8 MPa$, a decrease of 42.33%.

Path 2 shows that the bending stress decreases in the longitudinal direction for all types of boards. However, it decreases much faster for fibreglass boards than for flax fibre boards. This perfectly logical difference comes from the fact that the maximum bending stress at point 0 according to path 2 is much lower for the flax board ($1.38 \times 10^8 MPa$) than for the fibreglass board ($2.48 \times 10^8 MPa$). It is therefore normal that the decrease to $0 MPa$ is much higher for fibreglass boards than for flax boards.

Finally, path 3 shows broadly the same development as path 2, with a decrease in bending stress in the longitudinal direction. However, it should be noted that for fibreglass boards,,the bending stress first increases slightly,,from $2.35 \times 10^8 MPa$ at $2.43 \times 10^8 MPa$ before decreasing from $6.22 cm$. The linen board starts with a small step up to $3.18 cm$ with a bending stress of $1.39 \times 10^8 MPa$, before it too starts to decrements to 0. These 2 small peculiarities must be the consequence of the way the boards were designed on the software, as they should theoretically not exist. Finally, as for path 2 and for the same reasons, the decrease in bending stress for fibreglass boards is much greater than for flax fibre boards.

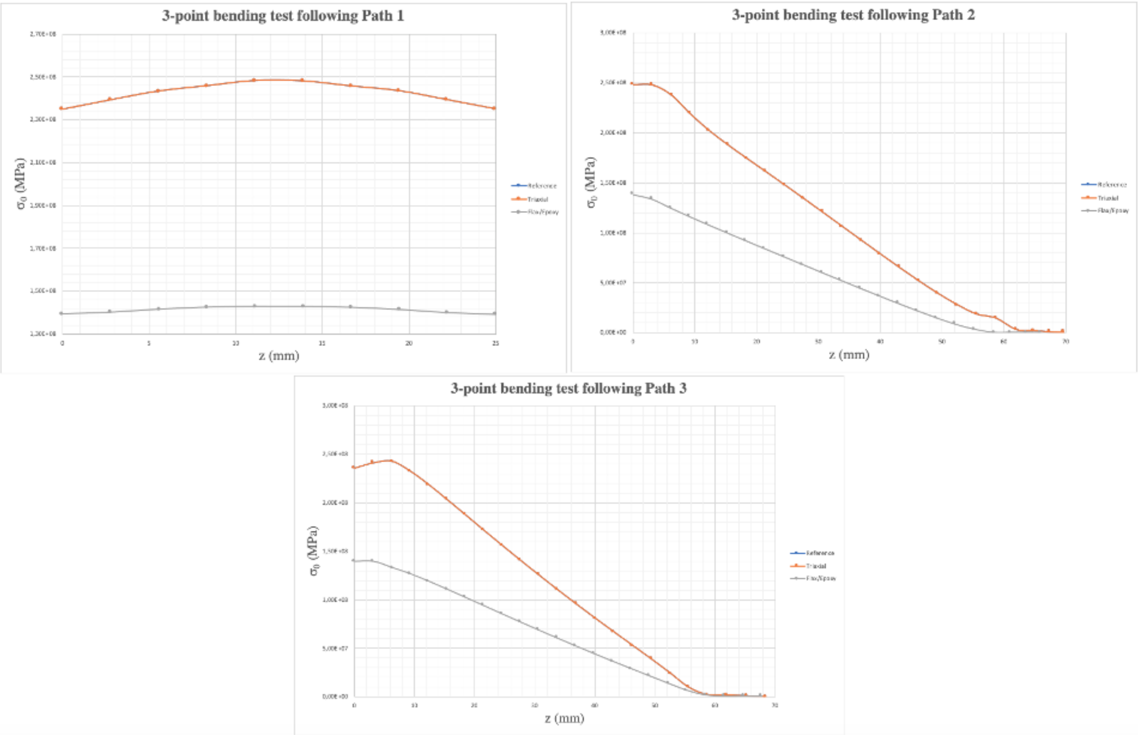

Figure 20: Graph showing the evolution of the bending constraints according to path 1, 2 and 3 for all types of board. From left to right and from top to bottom: path 1, path 2 and path 3.

4.3 Snowboard choice

Several things can be concluded from the previous results. The first thing is that the triaxial snowboard [0°,45°,-45°], compared to the reference board or the Flax/Epoxy board, offers a much better mechanical torsional behaviour. As the torsional stresses are much lower in this board, this reflects the increased stiffness of the board when loaded in torsion. Is this an advantage for freeride snowboards? As freeride snowboarding is mostly done in powder snow, too high torsional stiffness can be an advantage. As powder snow is very soft, the torsional stress in this type of snow is not the same as in perfectly packed snow or on ice. Increased torsional stiffness in powder snow may result in the rider not being able to twist his snowboard optimally because the ground response is too weak. However, this increased torsional stiffness would be perfect for alpine board making. As alpine snowboarding is practised on hard snow or even ice, a high torsional stiffness generates a very high energy within the board which can be used by the sportsman when this energy is released, called the deflection. However, for freeride snowboards, this high torsional stiffness is not necessary.

Furthermore, the presence of a third fibreglass layer in the triaxial board and the change in fibre orientation has no influence on the bending behaviour. The bending results for the reference board and the triaxial board are exactly the same. This can be an advantage because, as with torsional behaviour, the freeride snowboard has to maintain a certain flexural flexibility due to the environment in which it is used.

Finally, the addition of this third layer of fibre adds a little weight to the snowboard. Although this weight addition is small, it is still important to keep in mind that it is better to have light boards. This provides more maneuverability and the lift in powder snow will only increase.

The Flax/Epoxy snowboard has several advantages: firstly, compared to the reference board, the flax board is a little less torsional stiff in the transverse direction, but is still stiff in the longitudinal direction. This means that the snowboarder will find it easier to twist the board during a turn in powder snow, but the board will still retain a good structure in the longitudinal direction. In addition, the torsional behaviour is still relatively similar to the results found for the reference board. Thus the linen snowboard will be a little better in torsion than the reference board, without drastically changing the mechanical properties compared to current snowboards.

In addition, the linen snowboard also has a better bending behaviour. With lower stresses, the mechanical behaviour of the Flax/Epoxy board will be softer than that of the reference board, which is an advantage for freeride snowboarding. In addition, the distribution of bending stresses is also better distributed within the board without generating large disparities, which also makes the board softer with a more pleasant ride in fresh snow. Finally, although the snowboard has a lower mechanical behaviour in flexion, as in torsion, this mechanical behaviour does not differ drastically from that of the reference snowboard, it remains within the same orders of magnitude. Thus the Flax/Epoxy snowboard remains relatively comparable to current boards in bending, and does not risk breaking when snowboarding. These slightly different characteristics give the board a softer and more manageable feel in powder snow, which is the main advantage of freeride snowboarding.

The Flax/Epoxy board also allows for other improvements: on the one hand flax is an excellent vibration damper. This means that the vibrations generated during snowboarding are absorbed by the material and not by the rider's muscles, making the board easier to ride. Riding is also easier because linen is a lighter material than glass. In contrast to the triaxial board, the Flax/Epoxy board gains a little weight, which allows for easier handling and increased flotation in powder snow, which is yet another advantage. As linen is a natural material, it is also more respectful of the environment, which is becoming a criterion of choice in today's society that is striving towards more eco-responsible consumption.

However, linen is not the miracle material. It also has several disadvantages. The first is the heterogeneity of the fibres. Depending on the time of the year, the weather or the geographical position, flax fibres can have a slightly different mechanical behaviour. It is therefore necessary to be very careful in the selection of flax fibres in order to have the same mechanical properties throughout the board. In terms of budget, flax remains a cheap material, but its shaping in taffeta weaving remains more expensive than that of glass, which is another disadvantage. Finally, linen is a biodegradable material. This is a good argument when recycling materials, but it is a big disadvantage if the flax degrades during the use of the snowboard. On the other hand here the flax is trapped in a non-biodegradable epoxy matrix, so it is protected from all external aggression and there is no risk of bio-degradation during its use.

5 Conclusion

To conclude, snowboarding has undergone many evolutions since the beginning of the 20th century until today. To begin with, it was a simple wooden board, and today snowboarding has become the composite sandwich material par excellence with several types of boards depending on the discipline. As far as the mechanical structure of the freeride snowboard is concerned, the most commonly used boards today are boards with a glued laminated ash wood core and bi-axial fibreglass skins [0°,90°] in an epoxy matrix woven according to the taffeta weave. This plank is the reference plank throughout this study. The edges, the sole and the upper surface are also added to the board to facilitate the gliding and the handling of the object on the snow. All these materials, cleverly organised in an asymmetrical board, with a camber and a curve radius, make it possible to practice snowboarding as it is known today with its lot of adrenaline and strong sensations.

Using the Finite Element (FE) model, this study attempted to find improvements to the current freeride snowboarding boards in order to continue towards a perpetual improvement of this type of object. These improvements were based on the calculation of the bending and torsional stresses present in the reference board along 4 different paths, and then compared to new snowboard shapes. The first of these, a triaxial [0°,45°,-45°] fibreglass and epoxy matrix board, offers maximum torsional stresses of $469MPa$ compared to more than double the $1099MPa$ of the reference snowboard. Conversely, the bending stresses in the triaxial board are no different from the reference board. This is not the case with the Flax/Epoxy board, which has bending stresses almost 40% lower than those of glass fibres. However, the maximum torsional stresses of the flax board are slightly higher than the reference board, $1328MPa$ compared to $1099MPa$.

This study shows that the triaxial snowboard is too rigid for freeride use, but is rather intended for use in alpine snowboarding. The linen board is optimal for freeride use, provided that the fibres have the same mechanical properties as possible.

The snowboard market still has a bright future ahead of it, with more and more people using it. In the future, snowboard skins could be composed of a mixture of several materials, for example a part of glass fibres and another part of linen. The compatibility of these 2 types of fibre being optimal in an Epoxy matrix, it is possible to imagine a board with a mix of these 2 materials to cumulate both the advantages of glass and linen, without the disadvantages.

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