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Rapid prototyping of a lightweight splitboard clip using 3D printing of composite base filaments

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Abstract

The objective of this work is to develop a novel splitboard clip using fiber-reinforced 3D printing. Since the sport is practiced in alpine terrain under sometimes difficult conditions, particularly high demands are placed on the equipment and its development. On the other hand, splitboarding is still a niche sport, with comparatively low numbers of followers [1], which limits the budget for development costs. Therefore, the improvement of components and the development of new parts can benefit a lot from rapid prototyping. Especially the process of fiber-reinforced 3D printing using carbon fiber filament offers great potential, since the prototypes could be tested directly under real conditions. A 4-point bending test, comparing the strength of the new designed parts and of other clips, which are already available on the market, has shown that the new parts, produced in an additive manufacturing process, are not as strong as some other clips on the market. However, field tests have verified that these new splitboard clips could withstand the forces of a test ride, harsh alpine conditions and so far meet all requirements.

1 Introduction

Splitboarding is a comparatively young subspecies of snowboarding [2]. Here, the athlete can split his snowboard into two halves. Equipped with a special binding and climbing skins, it allows the athlete to climb mountains without using chairlifts, snowcats or other aids. Due to their shape, the two halves of the board function like two snow shoes and prevent the athlete from sinking into deeper snow and slipping on icy patches during the ascent. Fig. 1 shows a typical procedure of splitbaording.

Figure 1: Sequences of a splitboarding tour: climb – assembling of the board –downhill run

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Once the athlete reaches the top or his destination, he can reconnect the two halves of the board to form a snowboard again. Hence, he is able to ride down the mountain. The splitboard clips have a special role in this process, as they are a main part of the detachable connection between the board halves [3]. It should be possible to connect the two parts of the splitboard in such a way that its riding characteristics are comparable to a normal board. Therefore, the clips must prevent the board halves from bending in the longitudinal axis. Part of the stiffness is realized by the binding's plug-in system, but the influence of the clips in the "nose" and "tail" area cannot be neglected. They must connect the snowboard in a manner that the forces, acting during the descent, can be transmitted and give the board the necessary torsional stiffness. To do this, the clip must pull the board halves together as tightly as possible to generate the greatest possible form fit. In addition, there are further requirements for the equipment and especially the splitboard clips:

- **Lightest possible weight (since the equipment has to be moved up the mountain).**
  Commercially available splitboard clips are made of metallic material. By using fiber-reinforced 3D printing, it was possible to produce clips with extremely low weight. The clips, mounted on the splitboard, therefore have no noticeable disadvantage when ascending mountains.

- **Tool-free assembling of the two board halves (tools would be unnecessary weight).**
  It should be possible to put the two halves of the board together without the additional use of tools. On the one hand, the tools would increase the weight of the equipment, and on the other hand, tools can be forgotten or even get lost on a trip, making it impossible to assemble the board halves.

- **Reduce the number of moving parts to an absolute minimum**.
  Moving parts are usually susceptible to malfunction or failure. For example, levers could freeze due to weather conditions, or other mechanisms could lose their function over time. Therefore, the number of moving parts and mechanisms should be kept to an absolute minimum and possible sources of failure should be eliminated at the earliest design stages. Furthermore, moving parts can become loose and thus distract the athlete "acoustically" by rattling.

- **The overlap of the clips over the board’s edges should be kept as small as possible**.
  A bigger overlap of the clips over the edge of the board and therefore over the counterpart would lead indeed to a higher bending stiffness. But since the edges must provide support during the ascent, especially in steep passages, the entire weight of the athlete would rest on the overlapping parts of the clips. This could damage the clips or even worsen the edge hold, which could cause a risk of fall and thus injury of the athlete.

In view of this number of requirements, it becomes clear how complex the further development of splitboard clips or even the development of a new splitboard clip will be. Changes at one point of the component could negatively influence other requirements. Therefore, all design stages must be continuously validated and ideally tested in practice. Serial produced splitboard clips, that are on the market right now, are made of metallic material and require high investments for tooling. Hence sales of the clips should amortize the capital expenditures, the clips must be sold comparatively expensive or be sold for several seasons. This is where the advantages of rapid prototyping using fiber enforced 3D printing can be optimally exploited. Through the development of a 3D-printable splitboard clip for serial production, the cost for further improved generations of clips could be significantly decreased.

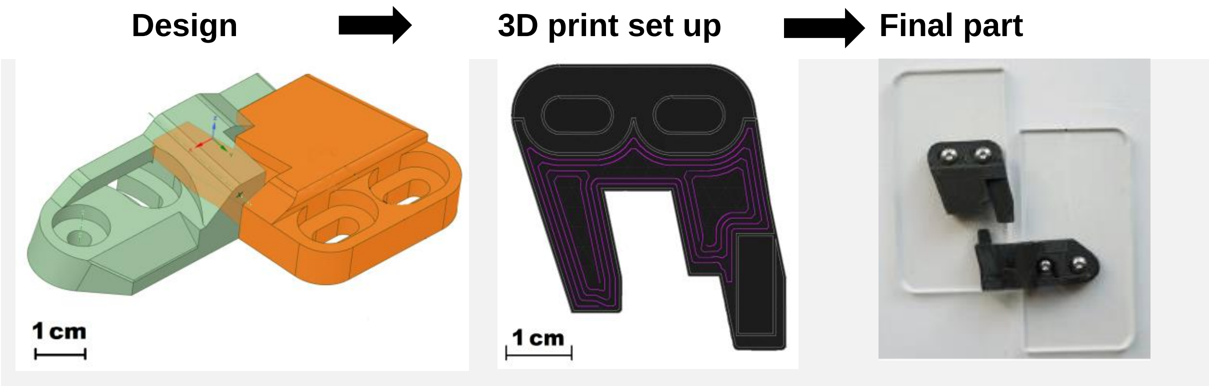
2 Development of a new splitboard clip

2.1 Advantages of fiber enforced printing

Some of the requirements explained in the previous section can be validated using 3D-printed prototypes. But for a few points on the list of requirements, however, suitability in practical use must be verified. In particular, the fault-free functioning of the connection mechanism under extreme alpine conditions, as well as under the influence of snow and ice, and the stability during the descent cannot be tested by using conventional 3D-printed parts. 3D-printers mainly use thermoplastic material, like polyamide and so the risk of breakage in cold conditions and therefore the risk of accidents would be too high. The main requirement here is to withstand the forces acting during the downhill run. Classic splitboard clips are made of metal to withstand the corresponding loads during the descent. Thermoplastic components from the 3D printer, in a comparable size, do not have the necessary strength and rigidity to ensure a safe descent. A failure of the prototype could lead to a malfunction of the sports equipment or even to an accident. The associated risk of injury of the test driver is unacceptable [4], making it difficult to carry out a test under real conditions.

Over the last few years, the range of printable materials has increased considerably. New techniques, such as fiber-reinforced printing, have become marketable. In particular, the use of carbon-fiber-reinforced filament material makes it possible to print components with a strength that is comparable to that of metal components [5]. Thus, the risk of a breaking clip during a test drive is significantly reduced. In this paper, the complete design process of a new clip will be realized using fiber-reinforced 3D printing, with a special focus on the possibilities and limitations.

The main advantage of this process is the low production costs. Since no new tool molds have to be manufactured for minor changes of the component, the additional costs for further, slightly adapted prototypes are relatively low. An overview of the individual production steps is shown in Fig. 2.



a) CAD model of the two parts of the clip

b) Position of the reinforcing fiber (pink) in the left clip

c) Final version of printed clips in functional test (on a simplified splitboard model)

Figure 2: Production steps in the prototyping process

In the first step the component is designed using CAD software. The resulting model is then adapted for 3D printing and the position of the reinforcing fibers is determined. Previous research has shown that the orientation of the reinforcement fiber has a significance impact on the performance of the final part [6]. Finally, the part is produced using a "Mark Two" printer from "Markforged", equipped with "Onyx", a micro carbon fiber filled nylon and an additional continuous carbon fiber. For printing the "Onyx" fiber is heated to 275°C and the carbon fiber is heated to 230°C to realize a good bonding with the nylon fiber. The mechanical properties of both materials are shown in table 1 [7].

Table 1: Overview - material parameters of the filaments used for printing

	Composite Base "Onyx"	**Continuous Fiber Carbon**
Density (g/cm3)	1.2	1.2
Tensile Modulus (GPa)	2.4	60
Tensile Strain at Break (%)	25	1.5
Flexural Strength (MPa)	71	540
Flexural Modulus (GPa)	3	51
Heat Deflection Temp (°C)	145	105

First functional tests can be carried out using these prototypes.

It is a major advantage of rapid prototyping that requirements can be gradually improved and in each case checked directly on the printed parts. This has an enormous benefit, especially for small companies or in relatively new industries. Since these companies rarely have the budget for high development costs or even their own “classical” prototype production. 3D printing makes it possible to implement new ideas directly.

Furthermore, it is still conceivable that due to low quantities series production using 3D printing could be cheaper than the classic production of parts in injection molding processes. The 3D-printing software, used for manufacturing of the prototypes, calculates a part price of 10€ for a pair of printed splitboard clips. Clips already on the market are sold for around 50€, 44.95€ for a pair of Spark clips [8] and 54.95€ for a pair of Karakoram “Ultra Clips” [9]. Due to the continuous improvement of the equipment, parts could already be technically “obsolete” before the tool costs for the injection molding process have been covered by a corresponding number of sold products. If splitboard clips, produced by fiber-reinforced printing, are actually suitable for regular use and not only for test drives still needs to be tested. Currently, there are no verified test methods or data to check whether a splitboard clip can withstand the stresses of continuous use. A long-term field test is planned for the next winter season. Clips will be given to different athletes, and used under normal operating conditions. The athletes keep record, under which conditions the clips failed. In this paper it will only be shown, if the clips can achieve the necessary strength to provide a safe application for the athletes. This is to be assessed with the help of 4-point bending tests based on DIN 53293 [8]. The full parameters of the test are specified in paragraph 2.3.

2.2 Design of the new clips

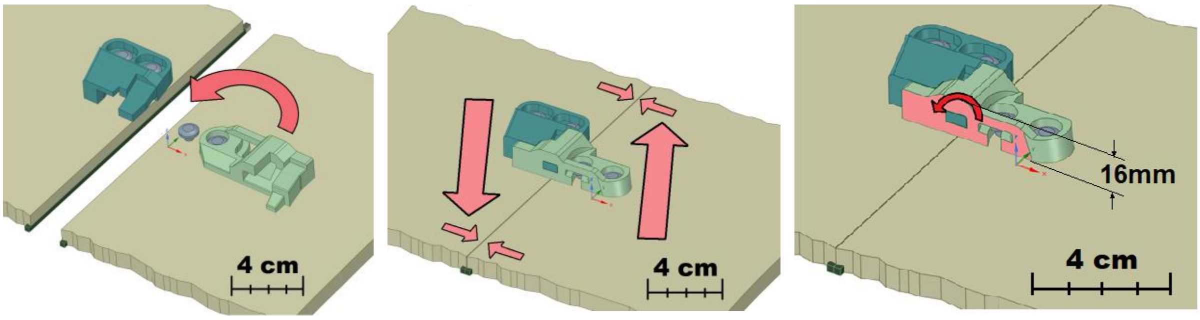
In order to meet the design requirements for printable components as closely as possible, a design was chosen in which the two clips are connected with a plug-in connection. The interlocking mechanism is designed by using a beveled construction in such a way that the board halves are drawn closer together the deeper the two parts of the clip are inserted into each other. The mechanism is shown in Fig. 3 a and 3 b. The red arrows show, how the beveled design (big arrows) pulls the board halves closer together (small arrows).

Due to the elongated design of the mounting holes on the left part of the clip, even inaccuracies and poor tolerances of up to 6 mm between the inserts of the splitboard can be compensated. The alignment of the connector was selected and adjusted so that during use no snow should penetrate into the affected areas. Respectively the design makes it easy to remove the snow again.

By choosing the plug-in connection, the entire construction consists of only two components: the two halves of the clips. Due to the small number of moving parts, potential sources of error are reduced enormously. The only moving part in this design is the rotating right part of the clip. Therefore, a possible source of error is loosening of the mounting screw. However, this failure can be prevented by checking the screws before the tour and, if necessary, by retightening them.

Another benefit of the design are the integrated neodymium magnets. These tiny magnets, put into the clips during the printing process, give an extra hold to the plug-in connection. Furthermore, the integration of another magnet in the board can prevent movement of the rotatable right-hand clip half. The rotatable design of the right clip half, in the turned away position (cf. Fig. 3 a) completely reduces the overhang. With an overhang of only 3 mm on the left clip half, the overhang here is significantly lower compared to 7 mm overhang at the Spark clips and 9 mm at the Karakoram clips. This allows a maximum edge hold and brings additional security in extreme situations.

By turning in the right half of the clip, shown by the red arrow in Fig. 3 a), for plugging together the clips, a certain overlapping of the two clip halves is additionally created. This significantly improves the bending stiffness of the entire construction. The height of the clip was selected as 16 mm, so that it additionally favors the bending stiffness, but does not build up too much visually and would thus be disruptive. The height of the clip on the relevant side is made clear in Fig. 3 c) by the reddish coloring.



3 a) Rotatable design of the right clip | **3 b) Tightening construction** | **3 c) Biggest height in the critical area**

Figure 3: Function of the plug-in connection and surface to increase the bending stiffness

2.3 Testing of the final design

Testing of the final design is done in two stages. In the first stage, the clips are tested in a 4-point bending test. For this purpose, a base plate was made from an old snowboard and equipped with a mounting device for splitboard clips. The base plate including all dimensions is shown in Fig. 4.

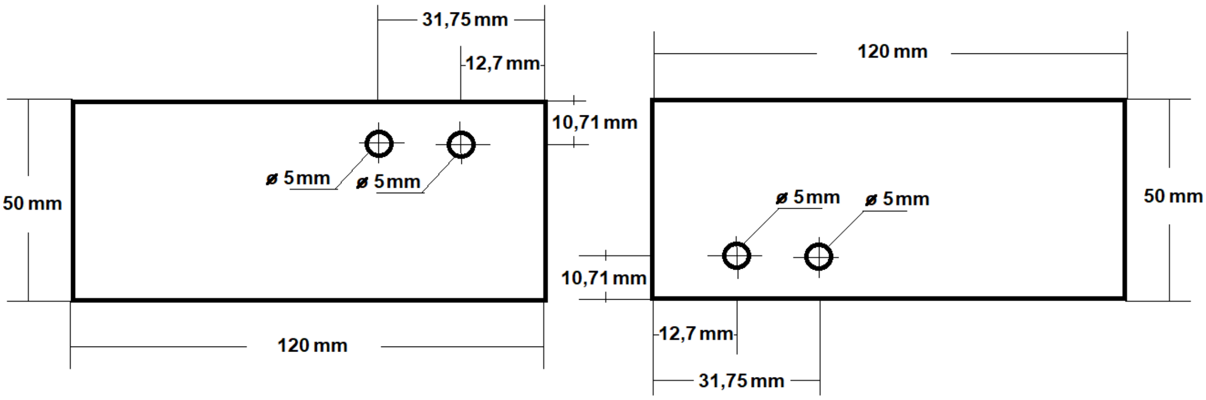


Figure 4: Measurements of the base plate for the 4-point bending test

At the moment, there are no standards or regulations, which specify what forces a splitboard clip must withstand before it is allowed to fail in the bending test. Therefore, two further clips from established manufacturers, were selected for the bending test. The data obtained was used to evaluate how the newly designed clips rank. The 4-point bending test was carried out in accordance with DIN 53293 [10]. Due to a shortage of splitboard clips on the market, only one sample of “Spark” clips and one sample of “Karakoram” clips was available for testing. Three samples of the newly developed clips were tested. The test was performed at a climate of 22,6 °C and 51 %rH with a speed of 5 mm/min. The support distance (L_A) was 200 mm and, due to the dimensions of the splitboard clips, the distance between the two loading points (L_S) was specified with 150 mm. The schematic structure of the test is shown in Fig. 5.

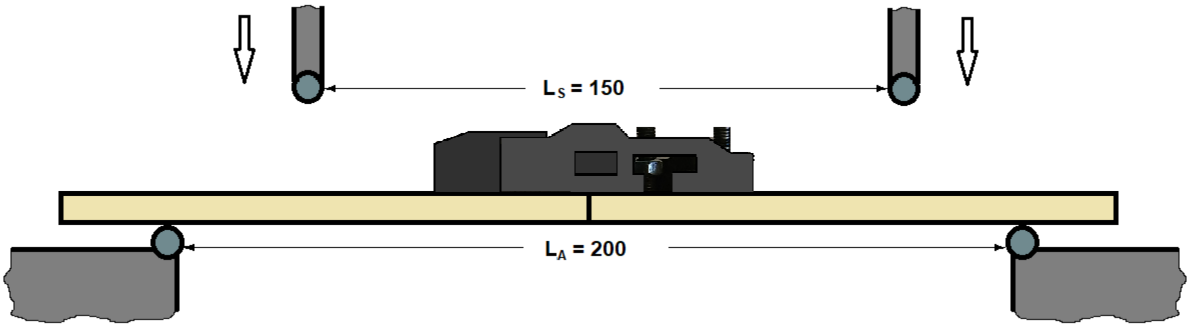


Figure 5: Setup of the 4-point bending test for testing of the clips

Reaching of the yield point was defined as the stop criterion. In the test, the maximum force and the deformation when this was reached were recorded. The results of the bending test and the weight of the respective clip variants are compared in Table 2.

Table 2: Overview of the measured values at the different clips

	Spark "Fixie"	KARAKORAM Ultra Clips	Newly Developed Clips
Weight	18.3 g	37.2 g	17.8 g
F_{max} in 4PBT	582.44 N	202.75 N	123.62 N
Bending at F_{max}	22.4 mm	30.1 mm	29.7 mm

The newly designed clips are among the lightest clips with only 17.8 g. The deflection of 29.7 mm is comparable with that of the other competitors. However, the clips withstand significantly lower forces than comparable clips in the 4-point bending test with only around 124 Nand a standard deviation of 1.5 N. This can be explained by the fact that the other competitors clips are made of metal and the new clip is made of carbon fiber reinforced nylon. Whether the value of 124 N should be regarded as critical or whether the clips of other manufacturers are currently significantly oversized cannot be assessed at the current state of research.

To better classify the results from the laboratory test, field tests were carried out in a second stage. For this purpose, the newly developed and printed clips were screwed onto a splitboard. During test runs, various points were checked by test riders. The test riders checked whether any problems were encountered on the ascent. For example, they assessed whether the rotatable clip stayed in position or whether the clip design is susceptible to icing. After reaching the top of the mountain, the test drivers checked that the clips can firmly connect the two halves of the board and whether it is possible to perform the assembling with gloves. During the following descents it was evaluated whether the necessary stiffness of the board could be achieved, or respectively whether the clips could withstand the forces acting on them during turns and jumps. After several test runs, no damage to the clips was detected. Nor did the clips fail at any point during the field tests. It can therefore be concluded that the basic requirement of sufficient strength is met by the new clips. A subsequent survey among the test drivers showed that all points are met and that no disadvantages could be identified during the test runs compared with other clips.

However, these assessments are based on the subjective feelings of the test drivers. Since snow covered slopes are necessary for the test drives and the test period is therefore seasonally limited, it has only been possible to interview two different test drivers so far. The test was performed on January 18th 2021 at an outside temperature of -4.5° and a relative air humidity of 100%. Further trials and test drives will be necessary in the future. Particularly to investigate, how the clips will perform in even colder conditions.

3 Discussion and conclusion

Using the example of “splitboard clips”, this work showed that the development effort, as well as the development costs for complex sports equipment, can be significantly reduced by using rapid prototyping. The use of carbon fiber-reinforced nylon filament made it possible to print prototypes that could be used and tested under real conditions.

It needs to be mentioned that the printed components were only able to achieve around half the maximum force of other splitboard clips in the 4-point bending test. However, since there was no failure of the printed components during the field tests, it can be assumed that some of the clips from other manufacturers are oversized. Based on the lack of standards and the poor research situation, in the area of the forces acting during splitboarding, it is not possible to validate this assumption. As the number of field tests carried out was low and only two different test drivers were available in the last winter season, further tests are planned for the future. Likewise, a long-term field test in the coming winter season should provide information on whether the design of the newly developed clips is sufficient to withstand extreme situations and their loads. For future work in this field, it is also recommended to record the acting forces during splitboarding. Based on this data, the results from 4-point bending tests can be classified much better. On the one hand, this will provide better information about the safety of newly developed components. On the other hand, by knowing the exact load cases, CAD models could be calculated. This allows to save material, where it is not needed and can lead to further weight reductions, which is a priority in the development of splitboard equipment.

Another point is a calculation for the manufacturing costs of the clips in the various production processes and a market analysis of the expected sales figures. On that basis, it can be estimated whether production by means of fiber-reinforced printing would be even more economical and can replace the current production processes.

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