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Mechanical and dynamical properties of racing snowboards and their modification by different binding plates

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Abstract

One-piece binding plates in snowboard racing have initially been introduced at the Olympics in 2006 by the later gold medalist. Today different types of such binding plates are used and play an important role to setup the equipment according to individual preferences. This study aims to quantify to what extent different binding plates modify the mechanical and dynamical properties of racing snowboards. The mechanical and dynamical properties of five racing snowboards with and without binding plates were characterized by laboratory measurements of the following parameters: Overall bending stiffness, bending stiffness distribution, torsional stiffness of rear and front body, force distribution along the running base, natural frequencies and their damping ratios. An increase in bending stiffness of 3.5% to 10.7% was measured for the different binding plates. Concerning torsional stiffening, large differences were found between the tested items of 0% to 19.7% for the front body and 2.6% to 35.1% for the rear body of the snowboard-binding plate systems. Free vibration tests showed a strong increase in damping for 4 of 5 binding plates while one plate damped distinctively less, which was also the only binding plate causing a clear change of the force distribution along the running base. While all plates cause relatively low bending stiffening, indicating a consensus about what a binding plate in snowboard racing should provide, the role of torsional stiffening and damping is probably considered controversially among manufactures and athletes as strong differences were found for these properties between the tested binding plates. It could be shown that current binding plates do partly modify the mechanical and dynamical properties of the snowboard - binding plate system to an extent that is larger than the differences between the analyzed racing snowboards itself.

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1. Introduction

One-piece binding plates in snowboard racing have initially been introduced at the Olympics in 2006 by the later parallel giant slalom (PGS) gold medalist Phillip Schoch. Since the 2010 PGS Olympic gold medalist Jasey - Jay Anderson again succeeded with a newly developed type of a one-piece binding plate an increased relevance were ascribed to binding plates and their influence on the riding performance of the whole snowboard-binding-boot system. Today just a few different types of such binding plates are used and play an important role to setup the equipment according to individual preferences of the athletes.

In racing snowboarding as well as in alpine skiing, binding plates are considered to provide several advantages such as enabling larger edging angles (prevent the so called boot-out), decreasing the orbital angular moment during carving, providing continuity of the deflection curve (avoid partial over-stiffening by the boot) or increasing damping (Howe, (2001)). Moreover, binding plates are used to optimally transmit and distribute external forces from the athletes to the snow. Due to the two-legged stance on a snowboard one-piece binding plates modify the way how moments are transmitted to the snowboard, due to opposite sided leg movements. By that, snowboard deformations are strongly influenced and in consequence the snowboard-snow interaction which determines the whole systems performance.

Although there are many publications dealing with snowboard mechanics no studies about racing snowboards are known to the authors (Buffinton et al. (2003); Subic et al. (2008)). On the one hand this is surely due to the fact that manufacturers rarely share their knowledge; on other hand the today's rather small racing snowboard industry has only limited R&D capacities. Nevertheless an ongoing development process especially driven by the athletes can be observed. In order to support these efforts a profound analysis of the current racing snowboard binding systems was initiated by the Swiss snowboard racing team to quantify to what extent different binding plates modify the mechanical and dynamical properties of racing snowboards.

2. Methods

The mechanical and dynamical properties of five racing snowboards with and without binding plates were characterized by laboratory measurements of the following parameters: Overall bending stiffness, bending stiffness distribution, torsional stiffness of rear and front body, force distribution along the running base, natural frequencies (1st and 2nd bending; 1st torsional) and their damping ratios. The measurements were carried out in 2011 at Davos, Switzerland. The snowboards as well as the binding plates have already been used before the measurements. Table 1 specifies the tested snowboards and binding plates.

The Vist binding plate model consists of two aluminum plates which are connected by two polymer beams like it is shown in Fig. 3 (b). Usually the plates are separately screwed on the polymer beams and then the whole plate is screwed on the snowboard. Nevertheless, by mounting the binding plate on the snowboard the two aluminum plates as well as the polymer beam are already sufficiently held in position. So, to mount the Vist binding plates properly not all screws have to be used. In practice, this fact gives room to setup the equipment according to the athletes' individual preferences. Therefore, we tested one of the two Vist binding plates without the extra screws.

Table 1.Tested snowboards and binding plates.

Setup No.	Snowboard manufacturer	Snowboard mass	Snowboard length	Binding plate manufacturer	Binding plate mass	Binding plate specification
1	Kessler	3905 g	1.85 m	Apex	1984 g	---
2	Kessler	4028 g	1.85 m	Vist	2039 g	Model 09 / 10 extra screwed
3	SG	4104 g	1.85 m	Vist	2621 g	Model 11 / 12
4	Black Pearl	4345 g	1.85 m	Vist	2001 g	Model 09 / 10;
5	Black Pearl	4440 g	1.85 m	Kessler	2022 g	---

2.1. Bending and torsional stiffness

A 4-point bending test was conducted which considers the snowboard specific two point loading to the designated position of the binding plates in contrast to the DIN ISO standard 5902. The snowboards were supported at their contact points like it is shown in Fig 1 (a). During loading up to a deflection of 80 mm, the deflection in the middle of the two loading positions and the applied load were continuously recorded using a miniature ring load cell (type 8438 – 6001; Burster Präzisionsmesstechnik GmbH & Co. KG, Gernsbach, D) and a laser displacement transducer (type CP35MHT80; Wenglor Sensoric GmbH; Tettnang, D). The overall bending stiffness C was then derived by the slope of a linear fit of the force – deflection data points. The deflection of the loaded and unloaded snowboard was measured in 4 mm steps along the snowboard with the automatically moving laser displacement transducer. The difference of the two curves yields the effective deflection curve which was fitted with a 6^{th} grade polynomial. The bending moment M_b and the bending stiffness distribution EI_y was then calculated according to the equation (1). A torsion test was conducted according to Fig. 1 (b) for the rear and the front body. The snowboards were rigidly fixed at the middle of the rear (front) foot binding inserts while a moment was applied at the shovel (tail). The torsion angle of the shovel (tail) and the applied moment was continuously record by a rotary potentiometer and a miniature ring load cell. The torsion stiffness of for rear and front body Tf and Tr were then derived by the slope of a linear fit of the moment – torsion angle data points.

$$EI_y(x) = -M_b(x)\,\frac{\left(1+w'^2(x)\right)^{3/2}}{w''(x)} \qquad (1)$$

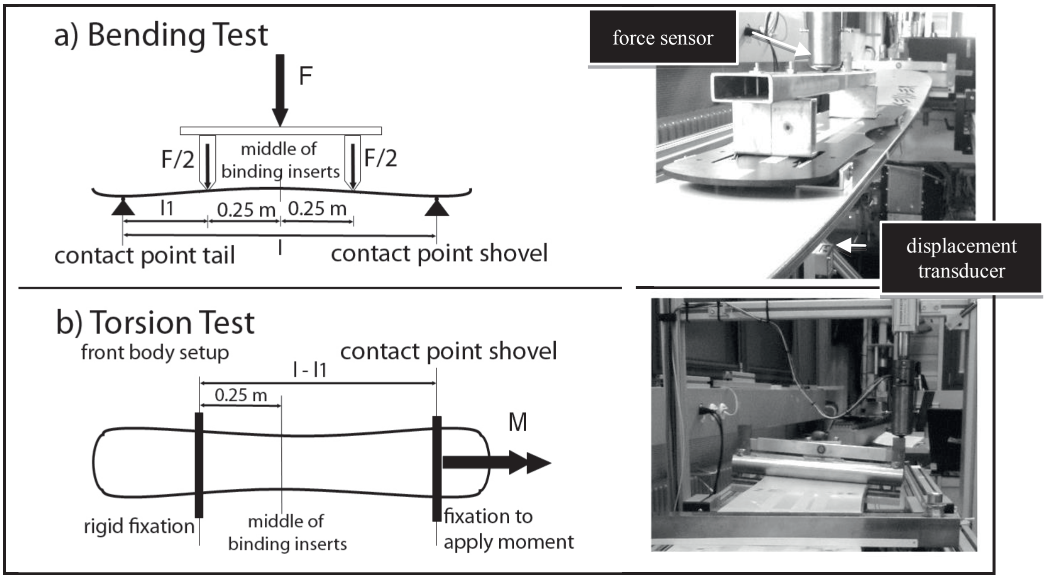

Fig. 1. (a) 4-point bending test setup; (b) Torsion test front body setup.

2.2. Vibration analysis and force distribution

A free vibration test of the snowboard's front part was conducted according to Fig. 2 (a). Torsional and bending vibrations were excited by a standardized procedure where a rubber tipped hammer hits the snowboard at the outer side of the fore body. A FFT of the signals of the two uniaxial accelerometers was used to determine the natural frequencies and damping ratios of the first and second bending mode as well as of the first torsion mode shape. The decay rate was determined with an exponential fit. The quotient of decay rate and corresponding natural frequency yield the damping ratio. The force distribution measurements were done on the device described by Lüthi (2006). A force of 800 N was applied at the same position as described for the bending test. Each row of six lateral force sensors was summed up to receive a two dimensional force distribution curve along the snowboards longitudinal axis. All mentioned measurements were repeated three times and then averaged.

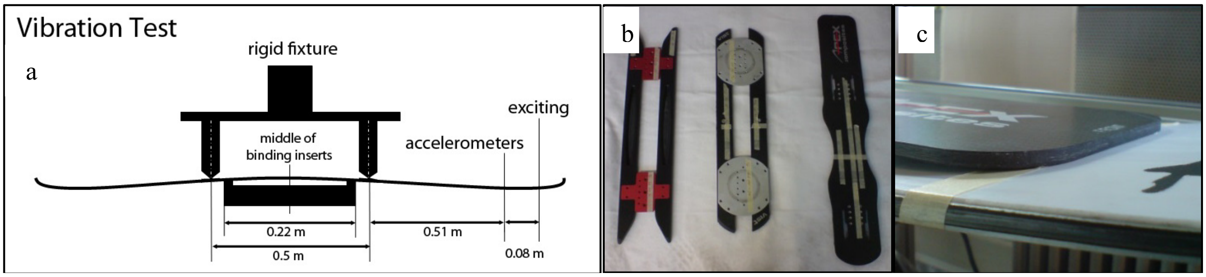

Fig. 2. (a) Vibration test setup; (b) Three tested binding plates: Kessler (le); Vist (mid): Apex (le); (c) Collision of the Apex plate during testing.

3. Results & Discussion

3.1. Bending and torsional stiffness

The comparison of the measured overall bending stiffness's with and without binding plates show that all binding plates causes a stiffening of the snowboard – binding plate system although all plates are mounted with a fixed-end free-end bearing arrangement. The largest stiffening effect of 10.7 % was measured for setup 1. However, Fig. 3 (c) shows that the fore body of the binding plate collides with the snowboard after a deflection of about 50 mm, which causes a sudden and strong increase from about 6 to 19 % in bending stiffness. Hence, the stiffening effect of the Apex binding plate is comparable to the other tested binding plates unless a certain deflection is not exceeded. Although setup 2 and 4 are equipped with same binding plate models, a difference in stiffening of around 2 % was found which is due to the extra screwing of setup 2. Differences in stiffness between the different snowboard models were found between 1 and 16 %. Differences among snowboards of the same type were found between 2 and 4 % indicating that only stiffening effects larger than this must be considered relevant.

Table 2. Means ± s (n = 3) of the overall bending stiffness with and without binding plates.

Setup No.	C_{board} [N / m]	$C_{board\text{-}plate}$ [N / m]	Δ C [%]
1 (0 – 0.08 m)	5086 ± 4	5632 ± 8	10.7
1 (0 – 0.05 m)		5368 ± 16	5.5
1 (0.05 – 0.08 m)		6037 +- 25	18.7
2	5180 ± 4	5462 ± 3	5.4
3	5592 ± 4	6015 ± 21	7.6
4	4838 ± 7	5013 ± 12	3.6
5	5043 ± 7	5275 ± 3	4.6

The bending distribution measurements showed similar bell-shaped curves for four of five tested snowboards with maxima between 690 and 740 Nm^2 located between the binding inserts (Fig. 3). For snowboard 3, a wave like curve was found with two maxima located at the binding inserts and distinctively higher stiffening for the front and the rear part of the board. Compared to Subic et al. (2008) the observed values are considerably higher but still plausible as the tested items are designed for elite racing. For all tested setups the binding plates caused an increase in stiffness primarily in the middle section of the boards. The largest effect was found for setup 1 and 3 – the lowest for setup 5, which is consistent with the measured overall bending stiffness values.

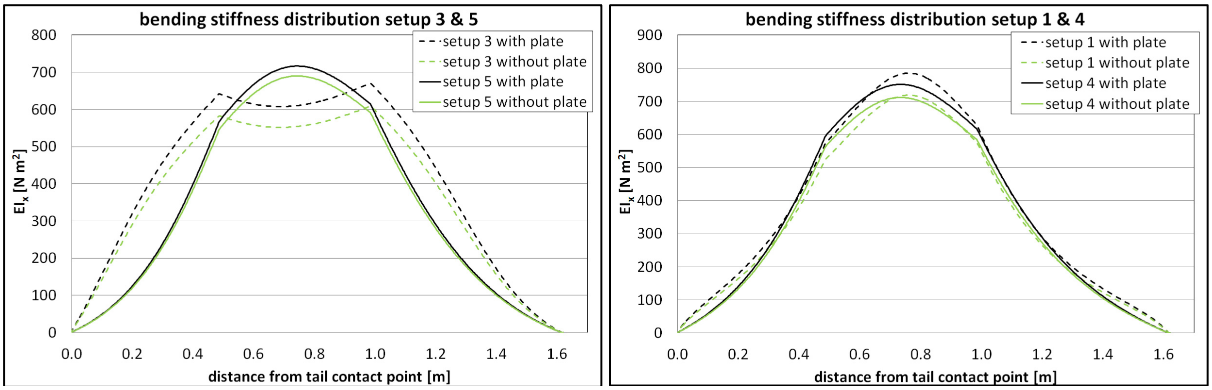

Fig. 3. Influence of the binding plates on the bending stiffness distribution.

The tested snowboards differed in their torsional stiffness up to 34 % for the front body and up to 25 % for the rear body (Tab. 3). Between same types of snowboards unexpected large differences were found up to 10 % which might be due to fact that the snowboards were already been used. Due to the observed weight differences slightly structural differences can also be assumed.

Three of the tested binding plates showed a rather small torsional stiffening effect from 0 to 6 %. A distinct stronger stiffing up to 35 % was measured for setup 1. As it was shown by Fischer et al. (2006), high torsional stiffness and rather low bending stiffness is a desired attribute to improve subjective riding performance in alpine skiing. Although it is open if those findings can be transferred to snowboard racing, the results show that binding plates can be used to alter torsional stiffness independently from bending stiffness.

Table 3. Means ± s (n = 3) of the torsional stiffness of the front and rear body with and without binding plates.

Setup No.	Tf_{board} [Nm / °]	$Tf_{board-plate}$ [Nm / °]	Δ Tf [%]	Tr_{board} [Nm / °]	$Tr_{board-plate}$ [Nm / °]	Δ Tr [%]
1	3.84 ± 0.01	4.60 ± 0.05	19.7	5.15 ± 0.02	4.96 ± 0.09	35.1
2	3.96 ± 0.01	4.04 ± 0.06	1.9	5.52 ± 0.04	5.88 ± 0.09	6.4
3	4.34 ± 0.03	4.59 ± 0.08	5.8	6.00 ± 0.04	6.72 ± 0.11	11.9
4	4.80 ± 0.09	4.91 ± 0.1	2.3	5.88 ± 0.06	6.03 ± 0.03	2.6
5	5.15 ± 0.02	5.15 ± 0.05	0	6.45 ± 0.04	6.45 ± 0.07	1.6

3.2. Vibration analysis and force distribution

The most pronounced result of the free vibration tests was the strong differences in damping by the binding plates. Four binding plates showed an increase of damping of the 1st bending frequency ranging from 205 to 332 % while for the binding plate 1 an increase of only 47 % was found (Tab. 4). The analysis of the 1st natural bending frequencies confirms the results of the bending tests by showing a positive correlation of bending stiffness and natural frequencies. As the deflection of the snowboards' front body at the vibration test was rather small, binding plate 1 has not the same pronounced effect like on the bending stiffness. Comparing the snowboards without binding plates, distinctively lower frequencies were found for snowboard 4 and 5 due to their higher weight. Contrary, the low weight of snowboard 1 leads to a higher frequency although the bending stiffness is rather low.

The 2nd bending frequencies analysis showed values between 35 and 41 Hz. The frequencies decreased for four of five binding plates. Only setup 2 showed a small increase of 2.1%. For setup 1 the frequency drops from 41 to 33 Hz by adding the binding plate to the system. This is probably an effect of adding mass between the fixation and the 2nd vibration node. The analyzed 1st torsion frequency ranged from 39 to 45 Hz and does only partly confirm the torsion stiffness measurements. The increase of setup 1 is smaller than expected. A slight increase of 1 to 4.1 % was measured for the other setups which is consistent with the likewise small increase found at the torsion tests.

The Force distribution measurements again showed the outstanding characteristics of binding plate 1 which was the only causing a considerable change of the force distribution curve like it is shown in Fig. 4 (a). Exemplarily for the other setups, where the binding plates did not modify the force distribution, the force distribution of setup 5 is shown in Fig. 4 (b). Strong differences were found between the different snowboard models emphasized by the comparison of Fig. 3 (a) and (b).

Table 4. Means ± s (n = 3) of the 1st natural bending frequency with and without binding plates and the difference of damping ratio.

Setup No.	$Fb1_{board}$ [N / m]	$Fb1_{board\text{-}plate}$ [N / m]	Δ Fb1 [%]	Δ d_{Fb1} [%]
1	10.1 ± 0.1	10.8 ± 0.0	6.6	47
2	9.8 ± 0.0	10.5 ± 0.0	7.1	332
3	10.2 ± 0.0	11.6 ± 0.1	13.4	175
4	8.7 ± 0.0	9.1 ± 0.1	4.2	205
5	8.9 ± 0.1	9.1 ± 0.1	1.9	221

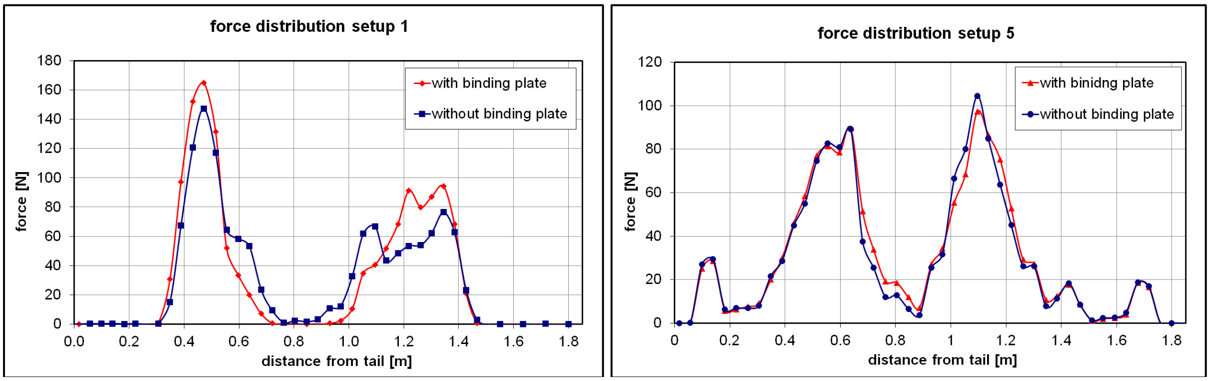

Fig. 4. (a) Modification of the force distribution by binding plate 1; (b) No modification of the force distribution was caused by binding plate 5.

4. Conclusion

The mechanical and dynamical properties of the 3 different types of racing snowboards could be shown, revealing distinct differences in the bending stiffness distribution, torsional stiffness and force distribution. The modifications of the mechanical and dynamical properties by different binding plates were quantified. All tested binding plates showed a relatively low bending stiffening effect, indicating a consensus about what a binding plate in snowboard racing should provide. The role of torsional stiffening and damping is probably considered controversially among manufactures and athletes as strong differences were found for these properties between the tested binding plates. It could be shown that current binding plates do partly modify the mechanical and dynamical properties of the snowboard - binding plate system to an extent that is larger than the differences between the analyzed racing snowboards itself.

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