Image courtesy Stöckli Swiss Sports AG.

Giving Ski Racers an Edge

ANSYS Mechanical software is used to analyze the dynamic properties of skis.

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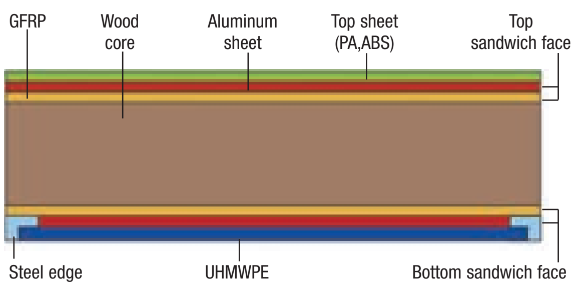
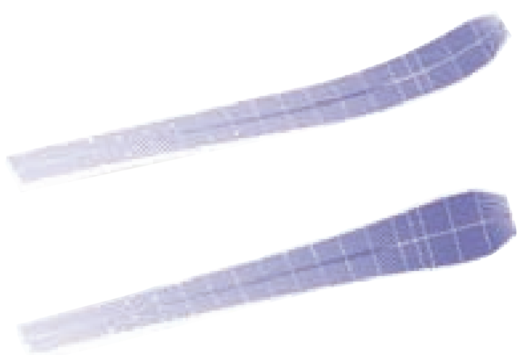


Cross-section schematic of a ski's sandwich structure. Image courtesy Stöckli Swiss Sports AG.



Images generated by FEA for (top) the second flexural mode of the front part of a ski and (bottom) the first torsional mode

As in most sports, successful performance in top-level skiing requires a combination of highly developed motor and perceptual skills from the athletes in addition to outstanding equipment. A principal aim of ski manufacturers in recent years has been to control vibration in various ways. By observing downhill racers on icy slopes in slow-motion, one concludes that low-frequency high-amplitude deformation has a detrimental effect on the ski-snow contact, decreasing control and speed. Skis completely devoid of vibration nevertheless do not provide adequate sensitivity for the athlete, making it crucial to discriminate between those frequencies that should be damped to increase performance and those that are important for the skier's "feel." Though numerical simulations have shown promise for the investigation of ski properties [1,2], little attention has been paid to the influence of the constituent materials on the dynamic response of skis.

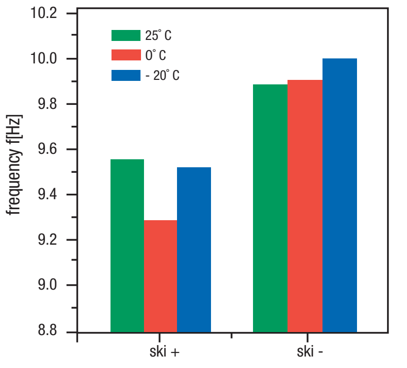
Each constituent material of the ski has a particular purpose. The top sheet, usually polyamide (PA) or acrylonitrile butadiene styrene (ABS), is mainly a protective layer. The wood core, which has a non-uniform thickness that provides a smooth bending profile, plays an important role in damping, whereas aluminum and glass fiber reinforced polymers (GFRPs), which constitute the upper and lower faces, provide stiffness in bending and torsion. The running base is commonly made of ultra-high molecular weight polyethylene (UHMWPE) to give optimum sliding behavior. Finally, hardened steel edges are positioned on both sides of the ski to provide good control during a turn. In the present work, the influence of the topsheet on the ski's dynamic properties has been investigated using a combination of numerical simulations and experimental measurements on skis with (referred to as ski+) and without (referred to as ski-) a topsheet.

In initial tests, the skis were clamped at their center locations lengthwise, placed in a cold room and their vibrational response characterized at temperatures between -20 and 25°C. Ski+ exhibited lower first resonant frequencies than ski- over the entire range of temperatures. This was attributed to the increased damping of the ski in the presence of the polyamide topsheet, which generally tends to reduce the resonant frequency [3]. A minimum in resonant frequency, equivalent to a maximum in damping capacity, was found to occur at 0°C for ski+, whereas the resonant frequency of ski-increased monotonically with temperature.

Dynamic mechanical analysis (DMA) was used to measure the damping capacity (loss factor) of the topsheet as a function of temperature at various frequencies. Each damping curve displayed a clear maximum value, or peak, at a temperature that increased as the frequency increased. At a frequency of 10-15 Hz, a damping peak was observed at approximately 0°C, which was consistent with the results of the vibrational response testing. To gain an idea of the dynamic properties of viscoelastic materials at frequencies beyond those that are directly accessible to DMA, time–temperature superposition is often used [4]. In the time–temperature superposition methodology, the damping capacity is plotted as a function of the logarithm of the frequency at different temperatures. These curves may then be superposed for any chosen reference temperature by shifting them along the frequency axis to give a single "master curve" that covers an extended range of frequencies. Using the time–temperature superposition methodology and a reference temperature of 0°C, a clear damping peak was seen to occur for the topsheet material at approximately 13 Hz, again consistent with the results of the vibrational response testing on the skis.

Elasticity-based FEA was used to model the room temperature response of the skis in a configuration identical to that used in the vibration response testing, i.e. clamped at their center locations lengthwise. The skis were represented by multi-layer meshes that incorporated elastic material parameters that were inferred from DMA measurements taken at room temperature and a frequency of 1.5 Hz. The agreement between the calculated and observed resonant frequencies for the first two vibration modes was good. For higher modes, however, the agreement was poorer. This was attributed to the viscoelastic nature of the polymer-based materials in the sandwich structure (glues, composite laminates and wood), which has not yet been included in the calculations but becomes increasingly important as the frequency increases.

The strong influence of the topsheet on the overall dynamic properties of the ski not only shows that thin layers of viscoelastic materials can have an important influence on the damping behavior of the structure, but also implies that certain specific resonance frequencies can be selectively damped by using polymers with damping peaks in the vicinity of the target frequency. In future work, it will be necessary to introduce more complex models that take into account the viscoelastic nature of the polymeric components. With knowledge of the dynamic response of skis to their constituent materials in hand, designers will have the opportunity to move one step closer to selectively improving ski performance for specific race conditions. In addition to purely mechanical aspects, special attention increasingly is being paid to the athlete–equipment interaction, i.e. the influence of the skis' mechanical properties on the "feel" and the perceived performance of the skier [5].



Comparison of the first resonant frequency of *ski+* (left) and *ski-* (right) at different temperatures. These measurements were carried out using accelerometers placed on the ski. The added weight of the accelerometers reduced the resonance frequencies somewhat but had no effect on the relative influence of the topsheet.

References

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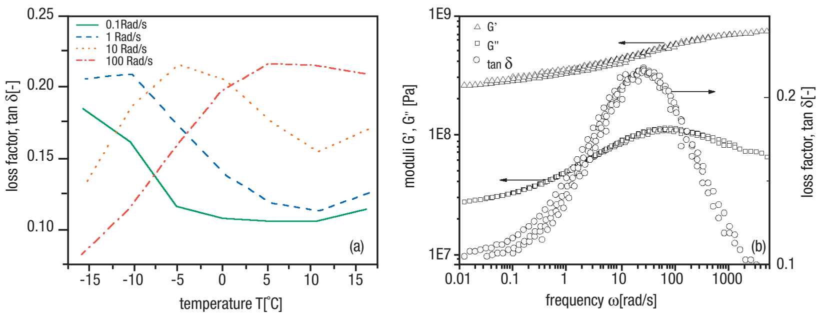

The evolution of the main damping peak of the polyamide topsheet as a function of applied frequency (left) and the time-temperature superposition for a reference temperature of 0°C (right)