

MATERIALS AND SCIENCE IN SPORTS

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Materials in Ski Design & Development

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MATERIALS IN SKI DESIGN & DEVELOPMENT

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ABSTRACT

This presentation proposes that the materials used in today's skis can be linked to specific performance criteria and trends in design, which have paralleled the transition from traditional to contemporary skiing technique. Performance is now the single most important issue determining the materials used, whether the intent is to produce a competitive ski for the racer or advanced recreational skier, or an 'easy to use' ski for the novice or intermediate level skier. Advanced materials including lightweight metal alloys, carbon fiber composites, Kevlar, and even piezo-ceramics have been identified as performance enhancement factors. The author combines a science & engineering professional background with many years of ski instructing experience to review the contributions of materials in ski design and development.

Materials in Ski Design & Manufacture

Background / Growth of the Ski Industry

The use of sophisticated materials in the design and manufacture of ski boots, bindings and skis has been a major factor in the advancement of recreational and performance skiing, and 'high tech' materials are frequently emphasized in the advertising campaigns promoting new equipment and clothing. Skiing, like tennis, cycling, and golf, has benefited from technological advances that have produced more 'user friendly' equipment. In fact, materials development in skis, tennis racquets, golf clubs, and bike frames is remarkably similar. This is due in part to the similarities in desired performance characteristics; e.g. lightweight, high strength, durable, responsive, shock absorbing, etc., and the need to tailor these properties to the skill level of the user. From a historical standpoint, Howard Head, an entrepreneur and avid skier, had much to do with transforming both ski and tennis racquet design and the associated materials innovations. Head pioneered the use of metal (aluminum) in ski construction, and much later, he introduced the first large body tennis racquet. In each case, the result was a revolutionary change in the performance over a wide range of individual skill levels. Head realized the significance of using modern structural materials, and the related design innovations that could be introduced as a result of moving beyond simple wood structures and traditional fabrication techniques.

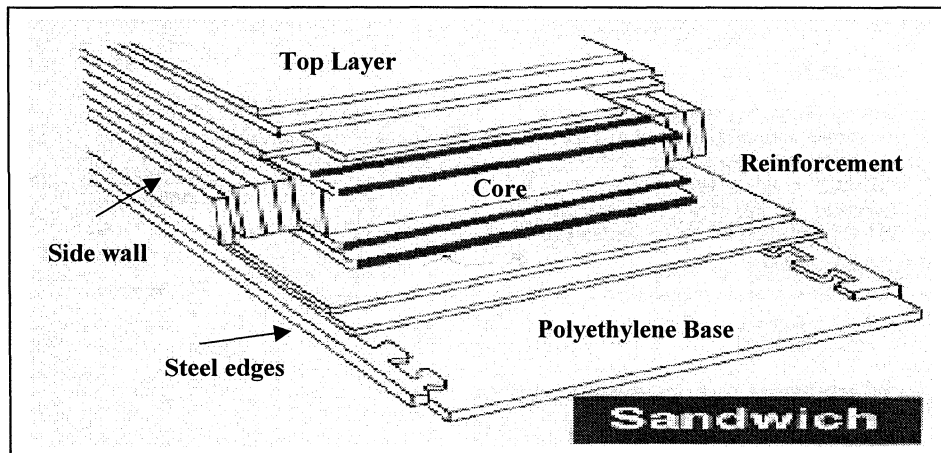
The development of the Head ski was one of the more significant factors resulting in the rapid growth of skiing as a recreational sport in the United States and elsewhere. Release bindings and double shell (plastic) boots brought about the necessary improvements in safety as well as performance. Metals, plastics, polymers, rubber and various substrate / coating combinations were employed to address the issue of coupling the skier to the skis while ensuring reliable release and detachment when the situation demanded. The improvement in equipment was a major factor in the development of the ski industry. Terrain that was formerly considered skiable only by experts, was now accessible to a large section of the skiing public, and the limits are continuing to expand as a result of innovations in materials and design.

Material Innovations / Progress in Design & Manufacturing

From the early days of wood skis, which Head and others considered excessively heavy and difficult to maneuver, the ski industry has graduated to equipment manufactured with more complex, performance oriented material combinations. Wood is highly anisotropic; it exhibits good strength and flexibility in uniaxial tension, but has poor torsion strength due to its fibrous nature. It is also sensitive to humidity and absorbs moisture, increasing the weight, reducing strength, and causing distortion. Note however, that wood continues to be an important material because of its specific modulus, i.e. modulus/density, which is comparable with steel, aluminum and titanium. Like most natural structural materials, wood has a cellular structure providing (in the absence of moisture) low density, high strength properties.

Head's original skis emerged as aluminum/wood bonded structures, and were further developed with plastic base material and steel edges. In subsequent years, the once monolithic structure continued to evolve into a more complex design involving a base, core, side-walls, top layer, reinforcement and damping layers. Wood laminates, metal, fiberglass and plastics were incorporated into ski structures as the materials became available and commercial interest in skiing grew during the fifties and sixties. The design goal was to combine good strength and flexibility along the length of the ski with adequate torsion strength to sustain a platform for the skier. In addition, as skis were designed for ever-increasing speed and more demanding terrain,

it became necessary to dampen the structures to suppress vibration over a wide range of frequency. Ski structures thus evolved as multi-component systems incorporating a wide range of materials. A typical 'sandwich' design from the 1970s is shown in the following schematic.



The sandwich design continued to evolve with torsion boxes and tubes, and using glass and carbon fibers, wood and metal laminates. High strength polymers became the materials of choice for the sidewalls, and foamed polymers were used for the core. Foamed polyurethane is still used in many skis, although lightweight slalom ski designs favored acrylic foams or metal honeycomb as core material.

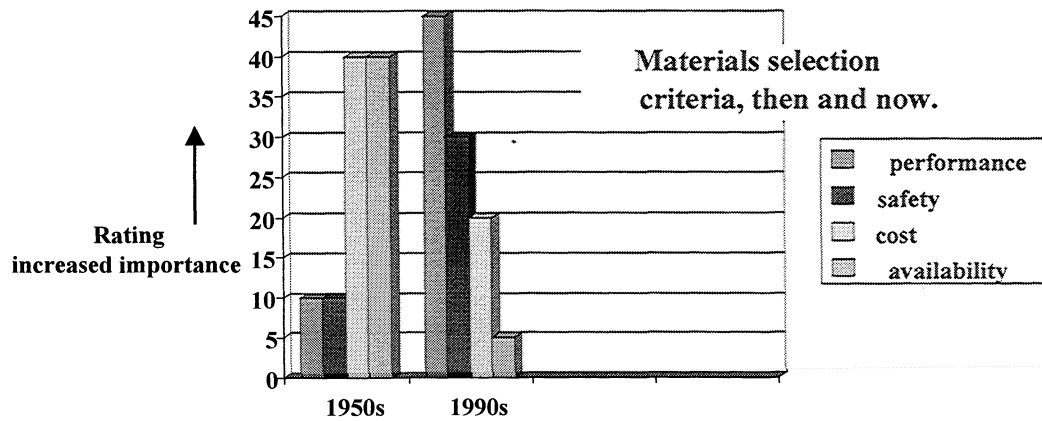
The major problem in moving from wood structures to designs incorporating metals and other materials, was the integrity of the joints between these dissimilar materials, e.g. wood / steel / fiberglass etc. In the 1950s few adhesives were available; the technology and equipment for assembling and curing complex material combinations was very limited. Development was strictly empirical, and ski testing took place on the slopes; many sets of Head's revolutionary metal skis were subject to premature failure before a successful manufacturing process was developed. Delamination was a common failure mode for skis during the 60s and 70s. In later years significant advances were made in the manufacturing technology, particularly the bonding and curing processes, and the durability of the product improved.

Materials / The Key to Performance

In what has now become an intense market, performance has become the key issue, and the materials are selected to match the ski to the customer requirements. Whether the aim is to produce a competitive product for the racer or advanced recreational skier, or an 'easy to use' ski for the beginner and intermediate recreational skier, the performance aspects are usually attributed to materials which are frequently referenced in the marketing literature. An almost unlimited variety of materials are available and there are markets for even the most expensive products (graphite and specialty composites).

Safety and durability are additional factors which influence design decisions, and which are directly linked to the materials selection criteria, specifically in relation to bindings and attachment components, as well as to the structural integrity of the ski. Some of the criteria determining ski construction today versus the 1950's are compared in the following graph. Availability and cost of material, although important, are no longer the limiting factors. Performance and safety are the key issues. Intense competition within the ski industry also

promotes the use of 'high tech' materials as marketing ploys, thus complicating the picture to some degree. Overall, today's ski provides a much improved performance, is more user friendly, and is significantly more durable than its predecessor from the 1950s.

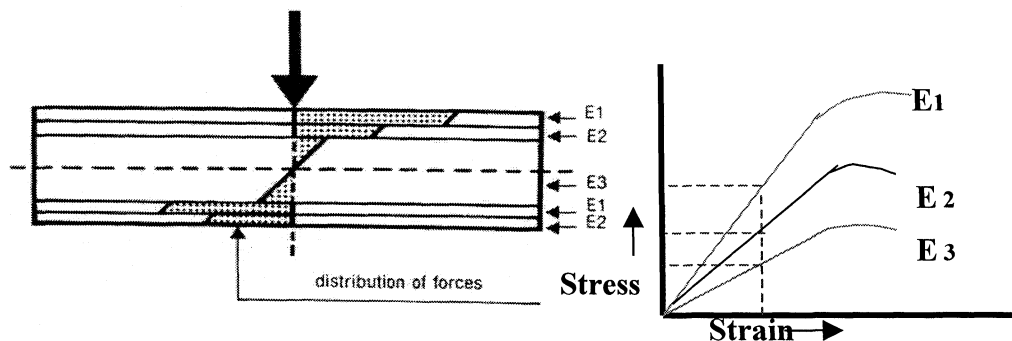


Material Functionality

As indicated previously, the same materials innovations have tended to show up in skis, tennis racquets, mountain bikes and golf clubs. The common thread in performance is a requirement for the athlete to remain in balance and control in a situation involving dynamic motion and impact. The novice needs equipment designed to absorb and insulate her/him from external impact forces, whereas the experienced athlete can profit from equipment that is more responsive. 'Sensitivity' and 'feel' are juxtaposed to shock and vibration, and skis are therefore rated according to the skill and performance level of the individual athlete; quick and responsive for the expert, slower and damp for the novice.

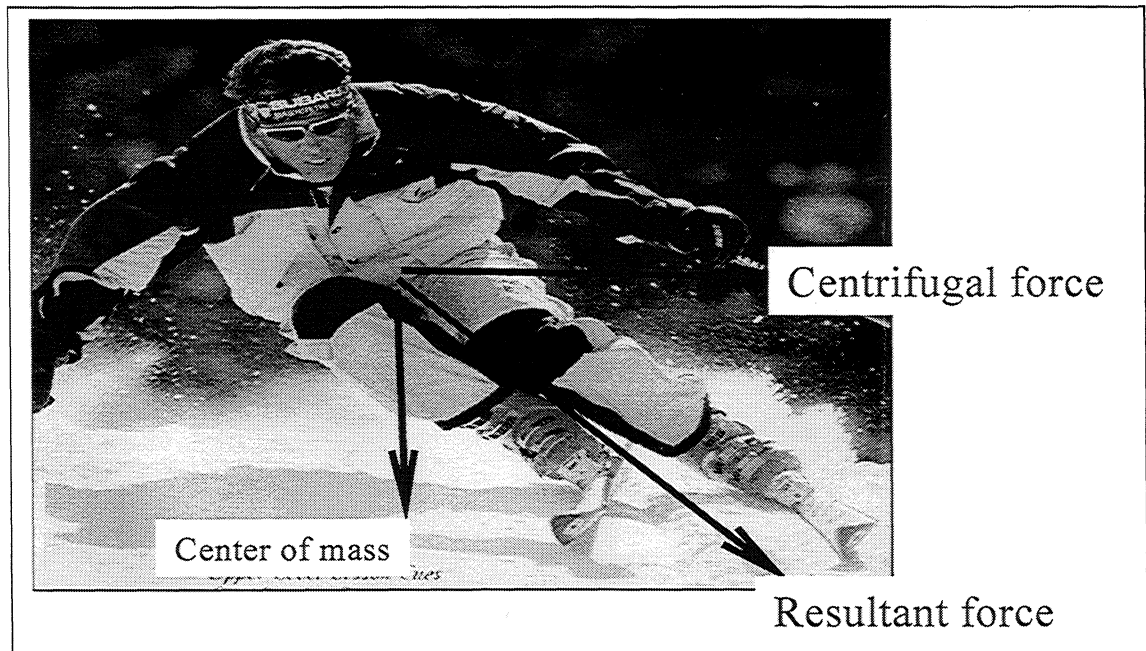
Beginning in the 1960s, and continuing through the 1980s, layered structures became quite complex as designers aimed at providing the desired characteristics in the ski, based on the specific use. Specialty alloys, polymer composites, graphite, Kevlar, and ceramic fibers were used to distribute stress, dampen vibration, and determine the manner in which the ski would flex and respond to external forces during use. The most important material property contributing to performance was specific stiffness (modulus/density), and fiberglass and carbon fiber composites had some advantage in this respect over steel and aluminum. Vibration damping, fatigue life and durability were also improved with the composite materials.

The stress distribution across the surface and the core of the ski is a function of the individual material properties, particularly the yield strength and modulus.



In a monolith, the stress field is symmetrical with the peak compressive and tension stresses located at the opposing surfaces. The location and distribution of the stress in the layered composite (above) is a function of the material modulus and the position of the layer within the lay-up. For any given amount of (elastic) strain, the higher modulus material will carry a greater portion of the total stress. The peak stress can therefore be concentrated in high strength, high modulus material layers within the structure.

In operation the ski is subjected to variable dynamic loads at multiple impact points, and is required to flex elastically to conform to extreme terrain variations. The ski must also represent a stable platform on which the skier can balance at speeds which can exceed 50kph for recreational skiers, and significantly higher for racers and advanced athletes. In the photograph below, the primary forces operating on this platform (the skis) are indicated (for one plane only). As long as the resultant force vector is inside the ski(s) / snow contact points, the skier remains in balance. Any deviation in direction or lateral slippage of the skis requires readjustment by the skier to retain dynamic balance. The strength and rigidity of the ski are therefore key factors determining the performance limits as a function of speed, terrain, weight and skill level of the skier.



The conflicting requirements (flexibility versus stability) are addressed by combining dissimilar materials with different functions within the structure, and in some instances employing multifunctional materials to enhance both the efficiency and the performance. The resistance to flexure becomes progressively higher (with amplitude) as the load is transferred to the higher modulus materials in the composite structure. Vibration damping is accomplished with rubber-like absorbing materials in the sandwich layers or in the core. Recent innovations have favored external damping devices, including mechanical and electro-mechanical devices such as piezo-ceramic materials. Piezo-ceramics can convert high frequency mechanical energy to electrical energy, and are employed to dissipate vibration motion through electrical shunts. Active damping with piezo-electric devices is under development for aircraft and automotive structures, but their use in non-critical structure, e.g. skis, is an interesting benchmark on the 'progress' in ski design and manufacture.

Design & Technique

There is a growing awareness of the underlying physics that applies to skiing and the resultant performance characteristics that govern the design and construction details of today's skis. The move in skis to wide body/narrow waist 'shaped skis', and 'fat' powder skis, mirrors the similar design trends in tennis racquets, and the enabling technology in both instances has been the materials and related manufacturing development. Shaped skis ('parabolic' or 'carving' skis, as they are designated in some areas), allow skiers to 'carve' turns at lower speeds. The skis are shorter in length, wider at the tip and tail, and narrow at the waist. A small lateral displacement is sufficient to ensure adequate edging of the ski throughout the turn. An earlier attempt to introduce short skis (in the 1980s) was unsuccessful, since the skis were designed for skidded turns and were stable only at low speed. Today's shaped skis are equal or better than their predecessors in all aspects including high-speed stability. The improvements in materials and the manufacturing technology are major contributing factors.

Most ski schools have now endorsed the use of shaped skis, and turn shape and fluidity is emphasized over edge set and rebound. The vertical motion and strong rotary twisting movements (traditional technique) during which the skis were skidded to change direction, are replaced with more subtle lateral repositioning of the upper body to allow precise tracking (carving) resulting in improved stability and control.

Conclusions / Materials & Marketing

The trends in ski design have paralleled the transition from traditional to contemporary ski technique. In a characteristic 'chicken and egg' scenario, the material and fabrication advances led to changes in technique, and the desire for continuing progress has stimulated more innovations and advanced design concepts. The resulting product is extremely efficient, durable and versatile. A vast range of ski equipment caters to all levels of ability and all types of ski terrain and snow conditions.

There is no 'universal ski' for all abilities and conditions, although most current recreational models will provide adequate performance for the average skier under most conditions. As with many commercial products, the public is overwhelmed with the myriad of choices even from individual manufacturers. The 'technical' descriptions are frequently misleading, and often use material designators to advertise the latest 'innovations'. 'Superglass', 'Elasteel', 'Zircal', 'Ceramic', 'Titanol', are just a few of the many 'materials' used over the years to introduce 'revolutionary' characteristics. In fact, the revolutionary material change was the Head aluminum ski in the fifties, and the subsequent evolutionary trend was fairly predictable. Metals (steel, titanium) are again becoming prominent in recent designs. The related design innovations resulting in shaped skis, short 'blades', fat skis, cross country skis, and the associated growth in snowboarding continues to improve public awareness and participation in the winter sports industry.

Materials and manufacturing technology will continue to influence the rate and direction of growth in the ski industry. Developments in functional materials will result in equipment improvements as well as introducing new training tools. Skiing is likely to be one of several sports experienced through new simulation technology.