Mechanical Simulation of Modern Racing Skis

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Abstract

Modern racing skis are complex composite products featuring a lightweight design, emerging from decades of engineering experience. High requirements on the performance as well as on the outer appearance necessitate a thorough exploration of the design space. In this paper, the mechanical behaviour of a modern carving ski is studied for characteristic loading conditions using the finite element (FE) method. Parameter studies are carried out to identify the influence of major design parameters in preparation for further investigations employing structural optimisation methods.

1 Introduction

In order to satisfy conflicting customer requirements such as high speed even in narrow curves, agility and simultaneous controllability as well as the avoidance of undesired dynamical effects, current ski designs utilise a variety of materials in a complex integrated structural design. Besides wood being the traditional material, steel, aluminium, polymers, glass-fibre reinforced plastics (GFRP) as well as carbon fibre reinforced plastics (CFRP) are used. From a design viewpoint, the mechanical behaviour of a ski is its main feature to be modified in order to satisfy functionality requirements. Currently, the design process for modern carving skis is carried out in a time-consuming iterative way, with simulation tools being applied rather sparsely. It is therefore desirable to understand the influence of the main design features as well as to predict the influence of changes on an early stage of the design process by means of mechanical simulation. In this paper, the finite element method is used to model the mechanical behaviour of a modern carving ski in characteristic loading conditions.

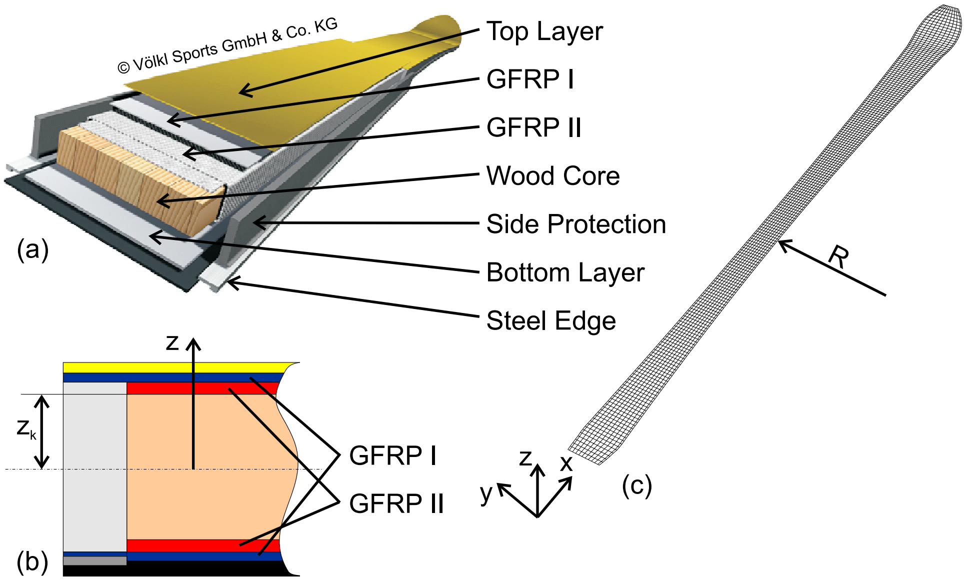

Fig. 1: Lay-Up of investigated ski (a), idealised cross-section (b), FE-Model (c).

2 Model Description

2.1 Investigated Racing Ski Design

The investigated ski model is shown in Fig. 1 (a, b) with he Lay-Up featuring the main materials used in current ski designs. A laminated wood core having a characteristic shape is embedded in several layers of GFRP. The steel edges protect the Polyethylene (PE) bottom layer. On the sides, sheets made of Acrylonitrile-Butadiene-Styrene (ABS) are attached and the ski is protected with a top layer made of Thermoplastic Polyurethane (TPU), featuring the unique design. Main geometric feature of the ski is the shape of the wood core. Its curved shape with a varying thickness and width has a major influence on the mechanical behaviour of the component. For a carving ski, the radius R of the edge of the central section is a well-known parameter (see Fig. 1 c), even to the customer.

2.2 Finite Element Model

From a mechanical viewpoint, the structure can be idealised as a curved laminate [1]. Due to the complexity of the resulting boundary value problems, the finite element method [2] is employed for numerical analysis. For the discretisation of the structure, shell elements with four nodes and six degrees of freedom (displacements u, v, w and rotations ϕ_1, ϕ_2 and ϕ_3) accounting for finite membrane strains and arbitrarily large rotations at each node are used (see Fig. 1 c). Within the framework of a higher-order laminate theory, anisotropy effects induced by the materials and the curved structure are taken into account. In order to effi-

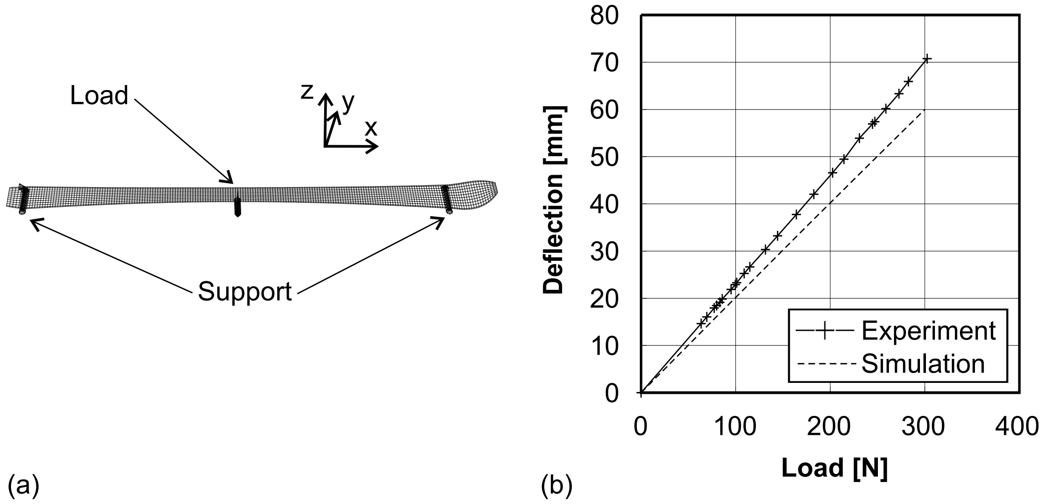

Fig. 2: Three-Point-Bending: model (a), results (b).

ciently carry out parameter studies and optimisations, the mesh is generated automatically by means of a FORTRAN program. Nodes and elements are created and the shell sections are allocated depending on their position. This approach also allows to efficiently change lay-up, geometry and mesh density.

The relevant anisotropic elastic constants for the wood core as well as for the GFRP layers are determined experimentally on test specimens in bending and torsion experiments. Having obtained an independent set of material data, all the necessary data for geometric parameter studies are readily available.

3 Analysis of the Bending Characteristics

During straightforward drive, the ski is mainly loaded in bending. Therefore, the bending characteristics, being of particular interest to the designer, are studied in experiment and theory.

In a three-point-bending test the specimen is clamped at the edges whilst still being free to expand in axial direction. The load is applied at the centre of the mid-section and the displacement of the location where the load is applied is measured as well as the deflection of the entire centreline.

For the FE-simulations, the boundary conditions discussed above are applied to the model (see Fig. 2 a). In Fig. 2 b, the load-displacement-curves are shown. As expected, the structure exhibits a linear-elastic behaviour. Experiment and simulation show moderate agreement. The higher stiffness of the model might be due to the kinematic assumptions imposed by the shell model.

In a next step, several design parameters are varied in the simulation. Fig. 3 a shows the

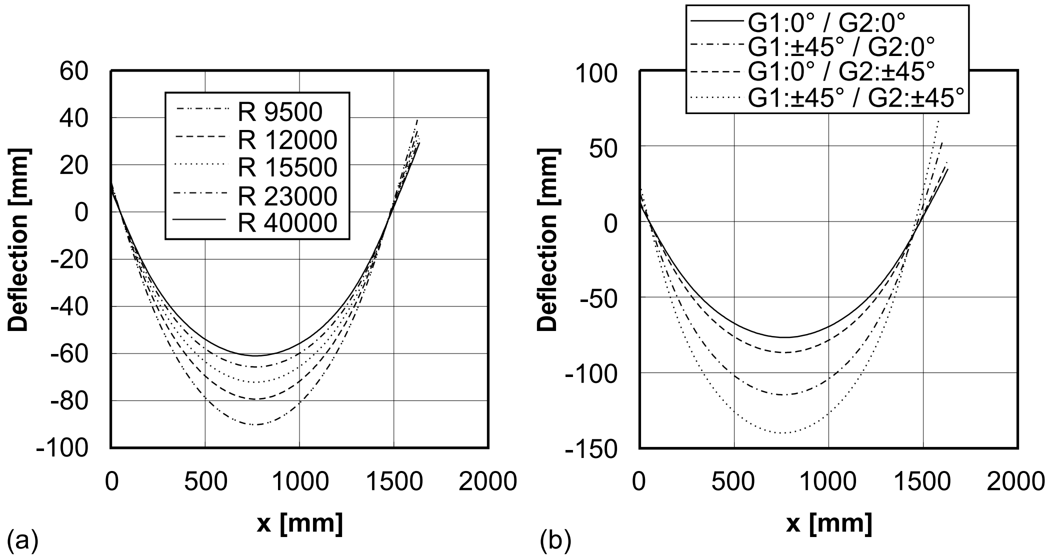

Fig. 3: Parameter variation for three-point-bending: edge radius (a), angles of GFRP layers (b).

deflection of the centreline for different edge radii for constant width of front and back ends. Starting from a very soft structure for $R = 9500$ mm, the stiffness increases with increasing radii. For the big radius of 400000 mm, the side edges are nearly parallel. A change in the lay-up of the GFRP layers indicated in Fig. 1 b is studied in Fig. 3 b. With both layers being oriented in $0°$-direction, the structure exhibits a high flexural stiffness. Changing the lay-ups from $[0°/0°]$ to $[\pm 45°]$ leads to a decrease in flexural stiffness, with a simultaneous increase in torsional stiffness.

4 Analysis of contact pressure loading

While driving through curves, the ski is, depending on the attack angle, loaded in a combination of torsion and bending. The ski-ground-contact is, for a flat ski, established by the entire bottom layer, and, for an inclined ski, established by the steel edge. For the designer, the contact pressure characterising the grip available and the reaction forces and moments applied by the driver are of particular interest.

In a laboratory experiment, the ski is clamped in the mid-section with free rotation allowed around its y-axis. With a characteristic force, the ski is pressed on a comparably stiff bed until full contact is achieved. After that, the pressure distribution under the bottom surface or the steel edge respectively, is measured. The experimental set-up can be carried out with different angles of inclination.

For the finite element analysis, the model is fixed in a manner corresponding to the experimental set-up. A rigid plane with the desired inclination angle is translated relatively to

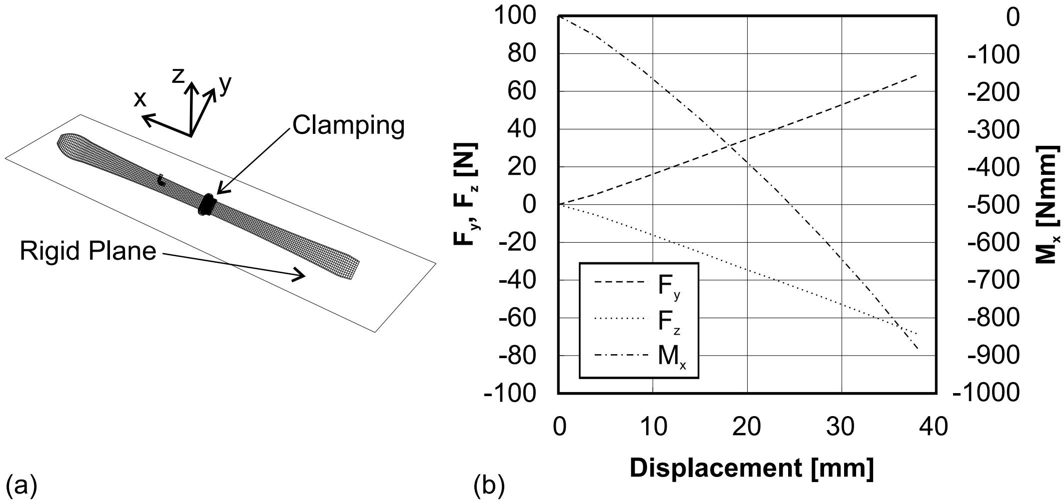

Fig. 4: Contact pressure loading: model (a), reaction forces and moment (b) for $45°$ inclination angle.

the ski (see Fig. 4 a). The ski-ground-contact is taken into account by the numerical formulation, resulting in a highly nonlinear boundary value problem being solved incrementally. In Fig. 4 b, the reaction forces and moments to be applied by the driver are plotted as a function of the displacement of the rigid plane for an inclination angle of $45°$.

Simulation results for the same experimental set-up are shown in Fig. 5 for different edge radii (a) and GFRP layer angles (b). Due to the geometrical restrictions, the maximum possible displacement decreases for increasing edge radii. From these simulations, the stiffness increase for increasing edge radii can be observed.

From the results for changing GFRP lay-ups it can be seen, that the $[0°/0°]$-design is much stiffer than the $[\pm 45°]$-design. Although this type of loading is a combination of bending and torsion, it is dominated by bending, which explains the higher stiffness of the $[0°/0°]$-design.

5 Conclusion and Outlook

A structural analysis of a modern carving ski was carried out using the finite element method. The material parameters were determined experimentally on different test specimens. Three-point-bending experiments have been simulated and compared to experimental results showing good agreement. Additionally, the characteristic situation of contact pressure loading has been simulated with a contact formulation for the ski-ground contact. Various numerical parameter studies on the influence of the edge radius and the lay-up of the GFRP layers have been carried out in order to characterise their effect.

It has been demonstrated, that the finite element method can be used as a powerful tool

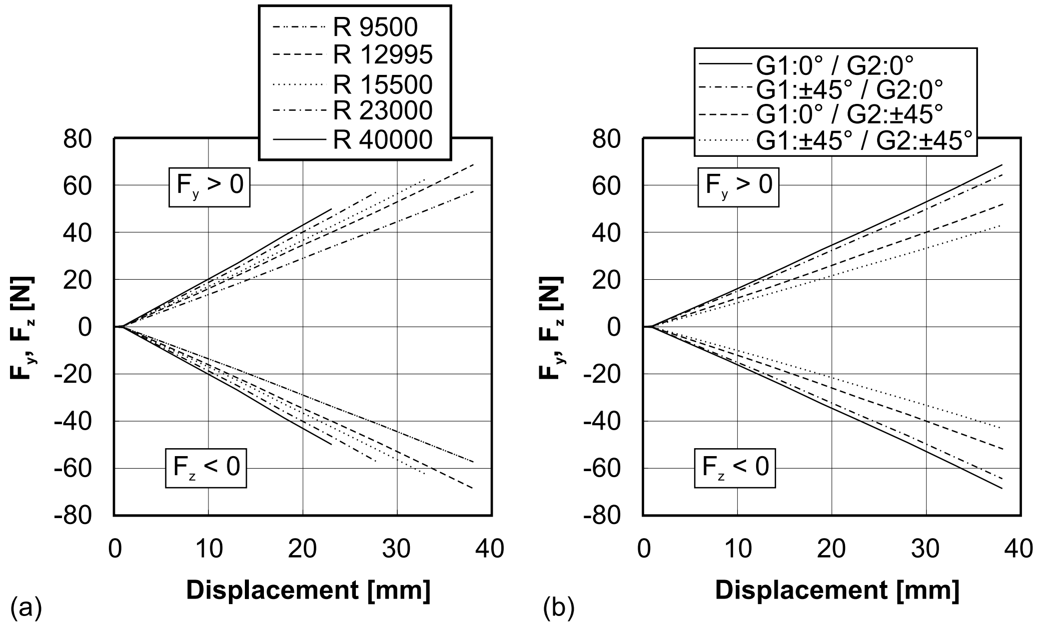

Fig. 5: Parameter variation for contact pressure loading: edge radius (a), angles of GFRP layers (b).

within the ski design process. Time-consuming and costly iterative empirical efforts can be reduced by means of numerical simulations. Besides a refinement of the model, the use of structural optimisation methods [3] in the design process appears to be a promising field for future work.

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