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PARAMETRIC STUDY OF MATERIAL PROPERTIES OF PROTECTIVE LINER OF SKI HELMET

J. Kunecký, O. Jiroušek, J. Jírová*

Summary: *Ski and snowboard helmets are designed to undergo mechanical testing according to the standard CSN EN 1077. The requirements of the standard are based on the assumption, that the helmet is supposed to be a device which protects mainly against the injury of skull or mechanical injury, mostly at low speeds. However, during impacts at higher speeds a second issue can occur – brain injury caused by enormous deceleration. The capabilities of the helmet to absorb the energy is limited. To investigate the possibility of improvement of the protective properties at higher speeds a parametric study of numerical model of ski helmet was made. Numerical model of the helmet was created using CAE methods, the FE analysis was performed in LS-DYNA environment. Comparison of results was made using HIC value (probability of head/brain injury). As parameter the material properties of the liner were considered.*

1. Introduction

Ski helmets have become a standard part of ski equipment. Skiers are able to spend more money in their safety. Thus the minority of helmet users has grown into the majority, especially among children.

The quality and construction of helmets is strongly dependent on available standards. The manufacturers design their goods to undergo the benchmarks of the standard. In this light the importance of a good standard is undoubtable. Today's norm, CSN EN 1077 “Downhill helmets” [1] is a good compromise for design of the helmets intended to protect the head at low velocities. The experiments incorporated to the norm usually consist of a drop test performed from the hight of 1500 mm (v=5,34 m/s) and of a test of resistance against perforation (rigid anvil in several shapes, v=3.84 m/s). However, the speeds of skiers are many times higher. At large speeds the second danger can appear –

* Ing. Jiří Kunecký, Ing. Ondřej Jiroušek, PhD., Doc. Ing. Jitka Jírová, CSc., Institute of Theoretical and Applied Mechanics AS CR, v.v.i, Prosecká 76, 190 00 Prague 9, email: {kunecky,jirousek,jirova}@itam.cas.cz

the harm of brain caused by huge deceleration during the head impact. Although the standard cares about peaks of acceleration history (250g), the speed at which the helmets are proved is too small to be a good predictor of how the helmet will behave during an accident at higher speeds. To discover the behaviour of the helmet a numerical model of existing helmet was created and investigated. The goal of this article is not to fight against the actual standard. The challenge of the paper is to numerically investigate the protective capabilities of helmet at higher speeds using parametric study of material of the liner inside the helmet which strongly influences the acceleration history of head during an accident.

Willinger et al. [2] showed that the Finite Element Method is a suitable method for helmet–head modelling. Based on these conclusions the numerical model of a real helmet was created and numerically tested. The construction of nowadays ski helmet usually consists of three layers: 1) outer shell made of a hard and stiff material (protects against perforation), 2) polystyrene or impact polystyrene liner absorbing the impact energy, 3) comfort foam. The liner made of impact polystyrene [3] was considered to be the main absorber of energy and thus its material properties were taken in this study as parameter. The Young's modulus of the polystyrene was modified far away from the range of values presented in the literature [3] (6-32MPa=>20-2000MPa), while ensuring that there exist some special types of high impact polystyrene able to have such a parameters.

The comparison of results of different material models of the liner was based on HIC (Head Injury Criteria) comparison. HIC are defined as

$$HIC=\left\{(t_2-t_1).\left(\left(\int_{t_1}^{t_2} a(t)\,dt\right)/(t_2-t_1)\right)^{2.5}\right\}_{max}$$

and can be interpreted as value highly correlated with probability of brain damage. The formulation was reached after tens years of research in the field of impact biomechanics. The value of 1000 can be considered to be dangerous for brain (the probability of brain damage is very high).

2. Methods

<u>Numerical model</u>

The model was created according to geometry of a commercially sold helmet. The model was designed using NURBS surfaces (Figure 1). The extents of the helmet were measured using optical method. The model of the dummy head was also created using NURBS according to the standard CSN EN 960 [4].

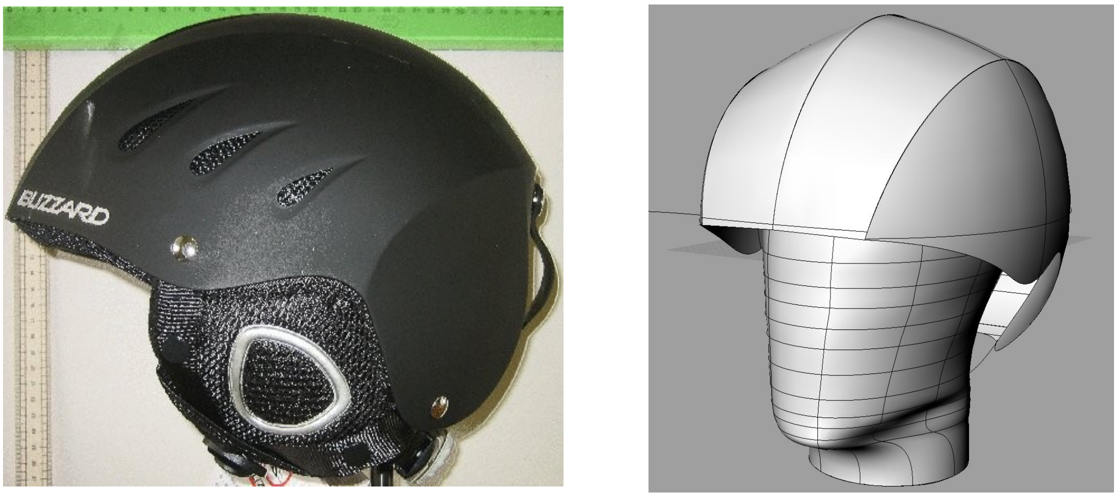

Figure 1. The helmet (left), the model of geometry with dummy head (right)

The model was meshed and prepared for the solution in ANSYS/LSDYNA environment [5]. The rigid anvil was created. The material properties were set (Table 1.)

Part	***Material model***	***Mechanical properties***
Shell	Elastic isotropic	E=50GPa, ν=0.3, ρ=3000kg/m^3
Liner	Bilinear elastic isotropic	E, $E_{tangent}$ Varied (E 20-2000MPa, $E_{tangent}$=10-1000) σ_yield=0.35 MPa, ν=0.05, ρ=50kg/m^3
Comfort foam	LS-DYNA Foam model	E=10MPa,ν=0.35, ρ=20kg/m^3
Dummy Head	Elastic isotropic	E=210GPa,ν=0.3, ρ=7800kg/m^3
Anvil	Rigid	-

Table 1.

The initial velocity was set to be 10 m/s (36 km/h). The whole numerical model is shown in Figure 2.

Figure 2. The numerical model (left), the impact simulated in ANSYS, plate anvil (right)

As the parameters the Young's modulus and tangent Young's modulus (post-yield) were taken. Two types of materials were investigated: ideally elastoplastic ($E_{tangent}$=0) and bilinear elastic ($E_{tangent}$=E/2). For each impact of given liner material properties the solution was performed and acceleration history of nodes on the dummy head was recorded (Figure 3.). The HIC value was determined using hand-written Python script. The relationships between material properties of the liner and HIC values were saved and graphed.

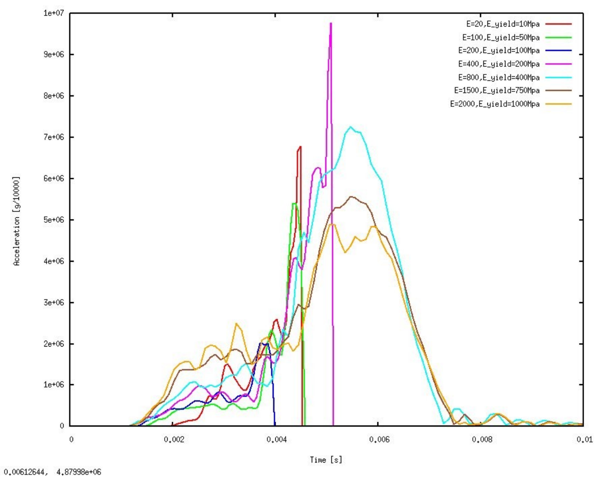

Figure 3. Recorded acceleration history of nodes on the dummy head

3. Results

For each of the material models a graph was plotted. The results are shown in Figure 4.

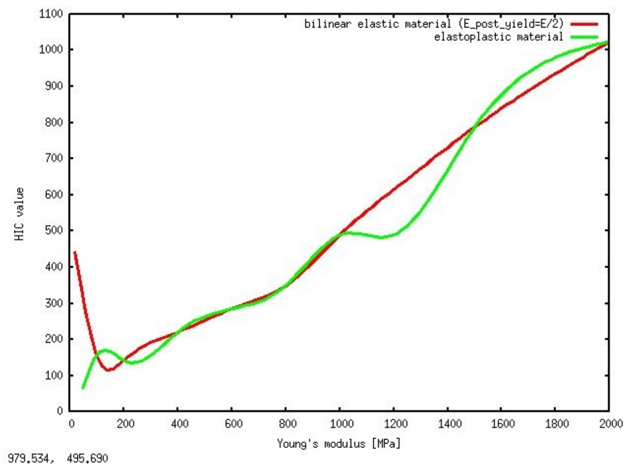

Figure 4. HIC value dependency on material properties of the liner

4. Conclusion and discussion

From the results it can be concluded that the results of both material models (bilinear,elastoplastic) are very similar. The reason could be, that the yield point can be reached only in small number of elements, thus the difference in energy absorption is not so big. It can be concluded, that safe values of HIC (=brain not damaged) can be obtained if the material has smaller Young's modulus than 1400 MPa. But, if the Young's modulus is small, there is a danger that the helmet is not able to undergo the test of rigid anvils of different shapes, described in the standard [4]. After this conclusion, another model was made in this study; the rigid plate anvil was replaced by sphere-shaped anvil (Figure 5.). All the types of material were tested again and the conclusion from these numerical solutions can be made: for smaller values of E=800MPa, the requirements of the standard cannot be reached (the head will be harmed by the anvil). Optimal values of Young's modulus are near 1000 MPa.

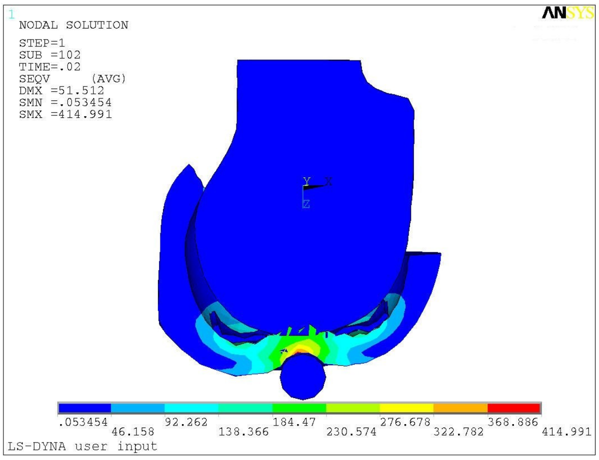

Figure 5. Von Mises stresses, rigid anvil used.

There should be pointed out the lack of experimental verification of such a model which is of very high importance. The verification is planned as soon as possible.

5. Acknowledgement

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6. References

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