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A NUMERICAL STUDY OF THE BICYCLE HELMET DROP TEST

O. Krupička, M. Šudrich, J. Vyčichl *

Abstract: *The study focused on helmet drop tests conducted in numerical software LS–DYNA. For this purpose new virtual models of the test–head according to ČSN EN 960 (2007) and impact pad were created. A modified model of a bicycle helmet, utilized in earlier studies and obtained from 3D scan of a real bicycle helmet, was also used. The models had similar properties as a real drop test has. The aim was to find out the output value of the model head acceleration during impact and determination of Head Injury Criterion.*

Keywords: ***Bicycle, Helmet, HIC, Impact, LS–DYNA***

1. Introduction

The aim of the study was the creation of virtual drop test of bicycle helmets which would be a close approximation to an actual helmet drop test. The main target of this study was to obtain acceleration and Head Injury Criterion (HIC) values on the test–head during impact. The influence of the impact angle of the helmet at pad, for two types of bicycle helmet, was also observed. This was ensured by the appropriate choice of materials for used models and defining of the virtual test in FEM software. Numerical analysis was conducted in LS–DYNA Solver and modification of models in LS–PrePost.

2. Virtual models

The creation of the test–head and impact pad, for simplicity, was conducted directly in Design Modeler in Workbench. The helmet was created by scanning real bicycle helmet, which had been purchased by Department of Mechanics and Materials on Faculty of Transportation Sciences.

2.1. Test–head model

The test–head model for study was modeled according to ČSN EN 960 (2007). The base of the virtual model consisted of parallel planes. The base plane was perpendicular to the vertical axis. A reference plane was derived from the base plane as well as other planes. The distances of the base and the reference plane were different for each head model as well as the distance between the other planes. According to the table values, in ČSN EN 960 (2007), there was part of head above and below the reference plane modeled.

For analysed model, there was chosen a head of size M that corresponds to the inner helmet circumference 600mm, total height of 247mm and volume 4.86dm^3. For the numerical analysis, structural steel was used for test–head as material. The density of material was adjusted to 1153.10kg/m^3, so the height of test–head was 5,60kg.

2.2. Bicycle helmet model

A Virtual model of a bicycle helmet was created earlier by Micka and Vyčichl (2007) using a 3D hand–scanner. After the scanning process, some improvements were needed in Blender and Netgen software. The purpose of these improvements was to simplify the whole surface of the helmet.

*Bc. Ondřej Krupička, Bc. Martin Šudrich, Ing. Jan Vyčichl, Ph.D.: Czech Technical University in Prague, Faculty of Transportation Sciences, Konviktská 20; 110 00, Prague 1; CZ, e-mail: ondra.krupicka@gmail.com, msudrich@gmail.com, vycichl@fd.cvut.cz,

Tab. 1: Material properties

	Structural steel	EPS	ABS
Material type	Elastic	Crushable foam	Modified piecewise linear plasticity
Young's modulus	200.00GPa	62.73MPa	3.00GPa
Density	7850.00kg/m^3	100.00kg/m^3	1040.00kg/m^3
Poisson's ratio	0.30	0.01	0.40
Maximum tensile stress	x	1.30MPa	x
Dumping coefficient	x	0.20	x
Yield stress	x	x	60.00MPa
Tangent modulus	x	x	1.02MPa

Expanded Polystyrene (EPS) material is, by Mills and Gilchrist (2008), one of the most common materials for bicycle helmet today and Acrylonitrile Butadiene Styrene (ABS) polymer is a common material for the helmet shell. It was necessary to use a crushable foam type material. For the purpose of the study the material library of Micka (Jíra and Jírová) was utilised. It contained both EPS, including working curve for 100kg/m^3, and ABS polymer for the shell. For the properties of both materials, see in Tab. 1. The weight of the helmet was 0.21kg.

For the purposes of the study, there were two types of helmet created without any mounting system. The first represented an In–Mold bicycle helmet with a shell of ABS on the top surface, while the second helmet represented a Double–In–Mold with the ABS shell on all surfaces. These shells, both with the same material properties, were created at the end in LS–PrePost after final assembly and meshing.

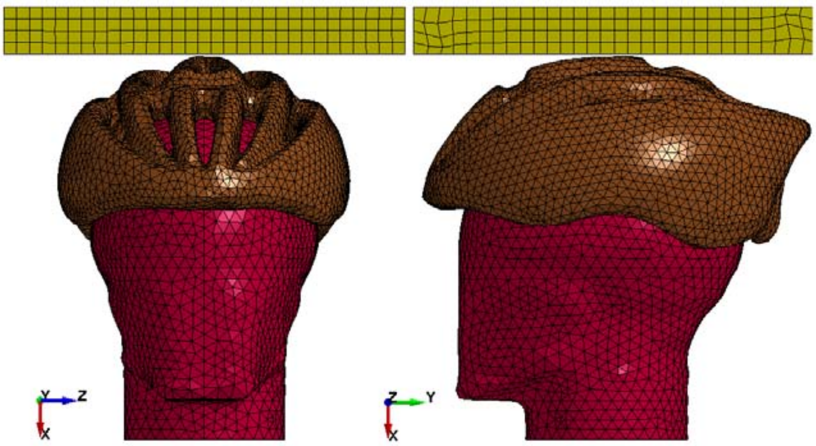

Fig. 1: Visualization of virtual models after mesh applied

2.3. Impact pad

An impact pad was created with a simple block shape. It is formed with the width of 300mm, length 300mm and a height of 35mm. As a pad material, structural steel (density 7850kg/m^3) was selected in the LS–PrePost.

2.4. Completation and boundary conditions in LS–Prepost

When the helmet was ready, the test–head and impact pad were added. Because of academic license problems in ANSYS Workbench, all models were exported in STEP format and final preparation was conducted in LS–PrePost.

The mesh was created in LS–PrePost. Due to the helmet shape the mesh was unstable in some areas so manual repair was needed. Models with the mesh applied are shown on Fig. 1. The test–head was formed by 56 457 elements (Tetrahedron) and 10 420 nodes. The helmet was formed by 52 127 elements (Tetrahedron) and 11 350 nodes. The ABS shell of the helmet was in both cases (In–Mold and Double–In–Mold) defined from the nodes forming the foam. For this reason, the definition of contact between the two parts of the helmet was not needed. The contact between the pad, the helmet and the test–head were defined as automatic surface to surface.

The helmet and test–head were evaluated at the beginning of the simulation at an initial velocity of 6.26m/s, always in the direction of vertical axis of the test–head. The chosen value corresponded to a free fall from a height of 2m just before impact. The height of 2m is a standard height for real bicycle helmet tests according to ČSN EN 1078 (1998). The tests were always calculated assuming a gravity acceleration of 9.81m/s^2. The pad is supported at all nodal points of its bottom surface. The termination time was set to 0.02s to verify convergence.

2.5. Impact angles of helmet and test–head

For study influence of impact angle, 7 model situations were created for both types of helmets. The helmet and test–head were fixed and only the location of the pad was changed. For base fall of system, the vertical axis for model head is perpendicular to the impact surface. In other situations, the pad is rotated by 30°, 60° and 90° to the front and by the same angles to the side.

3. Head Injury Criterion

The Head Injury Criterion (HIC) is usually formulated as a function of the instantaneous acceleration, see Payne and Patel (2001). The acceleration in the center of the gravity of the test–head and its maximum value were investigated on the falling system.

The human brain is very susceptible to accelerate, especially under action of a high value exceeding hundred times acceleration of the gravity. The time period, over which the acceleration takes effect, is very important. The brain is able to survive, without permanent damage, extreme acceleration values of about 200g but only up to 2ms. In values around 80g, the period during which there is irreversible damage, is much longer. In this case, it may be up to 200ms. The acceleration of 300g is critical for the human brain. Exceeding this limit leads to irreversible damage. HIC score was determined using the equitation 1.

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)\,\mathrm{d}t \right]^{2,5} \right\} max \tag{1}$$

4. Conclusions

In LS–DYNA Solver all situations were solved and then it was important to determine the acceleration of the test–head during impacts. In situations where the impact pad was rotated by 90° to the side and to the front, contact was made between the test–head and pad. It was caused by the absence of the mounting system of the helmet. Only in these 4 situations, the maximum acceleration value exceeded 300g, in other situations it did not. In most cases the g–value was around 180g for a very short time.

Then HIC for 15ms was determined; because the values were less favorable. The resulting HIC values are given in Tab. 2. The difference between both helmets was not so evident in the resulting values. However, in most cases, the maximum value of acceleration was higher for Double–In–Mold

Tab. 2: HIC score

Impact pad rotated to the side				
	Base impact	30°	60°	90°
In-Mold helmet	287,85	270,80	183,99	562,75
Double-In-Mold helmet	292,98	288,17	172,52	548,83
Impact pad rotated to the front				
	Base impact	30°	60°	90°
In-Mold helmet	287,85	281,35	230,92	371,86
Double-In-Mold helmet	292,98	278,35	202,08	371,85

helmet than In–Mold helmet, while HIC values were not. The results show that the size of the area under the curve of acceleration for Double–In–Mold helmet is smaller. The HIC score is almost the same or smaller then for In–Mold helmet. It is also evident from a sample graph on Fig. 2.

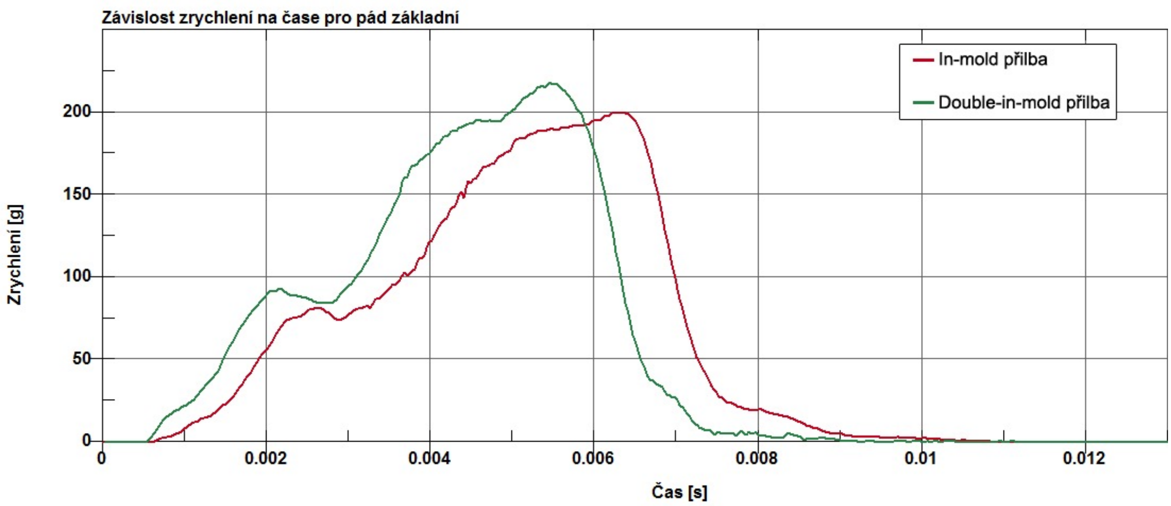

Fig. 2: Sample of acceleration-time diagram - base impact

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