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ScienceDirect

Procedia Engineering 147 (2016) 228 – 233

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Evaluation of catcher mask impacts

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Abstract

Concussion awareness in sports-related injuries has increased over the past decade. This has resulted in improvement in protective equipment and in our understanding of head injury. While contact sports such as ice hockey or football are of interest, concussion also occurs in non-contact sports like softball and baseball. The aim of this project was to describe facemask response to ball impacts. The study involved one face mask design and two types of foam padding. A method is presented that allows foam characterization at deformation rates and magnitudes representative of impact conditions. The foam impacts were modelled numerically and shown to agree with experiment. The facemask/foam system was placed on a Hybrid III headform and impacted with softballs to measure its response experimentally. A numeric model of the facemask/foam system on a model of the Hybrid III headform showed good agreement with experiment. Facemask impacts with a stiffer foam showed superior attenuation at high speeds (above 31 m/s) while a softer foam attenuated impacts better at low speeds.

Peer-review under responsibility of the organizing committee of ISEA 2016

Keywords: impact; head injury; numeric simulation; foam characterization

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1. Introduction

In the U.S. 15% of sports related concussions happen in baseball [1] where ball impact was the leading mechanism of injury [2]. Several studies have considered baseball to facemask impacts. Laudner compared the impact characteristics for traditional and hockey style headgear [3], Beyer analyzed impacts on the field and reproduced them experimentally [4], while Shain studied the attenuation performance of masks by shooting baseballs to the headform with and without a facemask [5].

In 2010, Shain and collaborators tested baseball facemasks [5]. Recurring incidents of concussion among catchers suggest current equipment certification may be limited in its application to Traumatic Brain Injury (TBI). The aim of this study was to determine if catcher mask-ball impacts can be described using finite element analysis. To this end, foam pad materials used in facemasks were characterized at strain rates similar to play. A model of a catcher mask on a headform was impacted with a softball. The model results were compared with physical impacts between a softball and a face mask supported by a headform.

2. Materials

Two foam systems (denoted “a” and “b”) were compared in this work. System “a” was a bilayer foam (Wilson Dyna-Lite), consisting of a closed cell composite layer comprising polyvinyl chloride and nitrile butadiene rubber (Ensolite 405C, hereafter denoted as “a1”) and an open cell polyurethane layer (hereafter denoted as “a2”). System “b” was an open cell polyurethane monolayer (Zorbium 83I). Their properties are summarized in Table 1.

A commercial facemask (Wilson, WTA3017) was measured to construct a finite element model. The facemask cage was

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Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.218

made of steel tubing with a 1 mm wall thickness of 6 and 7 mm outer diameter. The tubes comprising the facemask cage were welded together and coated with a 1.4 mm thick layer of polyurethane. The properties of the steel tubes and coating are given in Table 2. Both foam systems were encapsulated in a fabric envelope, modelled as shell elements and assumed to be rigidly bonded to the foam. Fabric stiffness was found from tensile tests (10kN INSTRON 5969) as summarized in Table 2.

Table 1: Foam pad densities and cell sizes

Name	Material	Cells	Density [kg·m^3]	Cell size [µm]
a1	PVC, NBR	Closed	38.9	68.7
a2	PU	Open	34.7	207.6
b	PU	Open	54.6	240.5

Table 2: Steel and PU coating material properties

	E [GPa]	ρ [g/mm^3]	ν
Steel	210	7.8E-3	0.3
PU coating	0.87	0.95E-3	0.48 [8]
Fabric	0.1	8E-7	-
Thin bars	210	8.653E-3	0.3
Thick bars	210	8.635E-3	0.3

3. Experimental Procedure

3.1. Foam pad characterization

The facemask foam materials were characterized using a 13 mm diameter air cannon [6]. A 18.3 g projectile was fired at foam samples at speeds ranging between 10 to 33 m/s. The foam samples were supported by a 5 kN load cell, which measured the impact force. Light gates between the barrel and sample measured the incoming projectile speed. Displacement was found by dividing the impact force by the projectile mass and integrating twice. Stress-strain curves were obtained from the load-displacement results.

3.2. Headform impacting

The facemasks were experimentally evaluated by placing them on a 50th percentile male headform (Hybrid III, Humanetics). The headform and neck (Fig. 1) weighed 4.54 and 1.54 kg, respectively. The headform assembly was attached to a table that was allowed to recoil on low friction rails after impact [7]. The headform was equipped with three linear accelerometers and three angular rate sensors with a range of 500 g and 8000 °/s, respectively. The sensors were arranged so that their axis aligned with the center of gravity of the headform. Light gates between the cannon and headform measured the speed of the ball just prior to impact (between 22 and 36 m/s).

4. Foam Characterization

4.1. Impact results

Foam materials are sensitive to deformation rate and magnitude, which for computational models must be characterized independently. Constant strain rate curves were generated by taking partial results from tests at different impact speeds where the measured strain rate was within ±50 s^{-1} of the target strain rate.

Foam stiffness was observed to increase with increasing strain rate. The response of the “a1” foam was the least sensitive to strain rate, while the “b” foam was the most sensitive.

The difference in strain rate dependence was due to the foam microstructure. Since “a1” is closed cell, strain rate sensitivity is only due to polymer deformation. With the open cell foams (“a2” and “b”), air escapes from the cells to form a second method of strain rate dependence.

4.2. Finite element analysis

The facemask foam impact testing was simulated using the finite element code (LS-DYNA, version 4.2). Since the foam cell size was more than two orders of magnitude smaller than the sample size, they were assumed to be isotropic and homogeneous. A model was constructed of the foam sample impacts using quarter symmetry with a total of 5418 elements. The impactor bar was modelled as a full rigid quarter cylinder. To decrease the computation time the bar length was shortened and the density was correspondingly increased. This approximation does not reduce the fidelity of model since the elastic wave in the bar is orders of magnitude shorter than the impact duration. The supported side of the foam sample was constrained to prevent motion parallel to