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Numerical Investigation of the Effect of Shell Material and Thickness on the Mechanics of Motorcycle Helmets Impact

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ABSTRACT: In motorcycle accidents, the acceleration caused by the collision has a huge risk to the health of the motorcyclists and passengers. In this study, the finite element method was used for dynamic analysis of impact mechanics to predict the effect of the shell material and thickness on the head injury criteria of the helmeted head (including head, shell, foam, comfortable foam and strap). The open-face helmet, including three current market materials, were selected. Head orientation, in most accidents, at the collision moment is oblique. In the simulated impact model, the head is also placed obliquely. The results of this study are validated by the experimental results and valid published data. The simulation results show that there is an optimum thickness for the helmet shell regardless of its material. In order to determine the optimum thickness, there must be compromises between the various parameters such as head injury criteria, shell failure, weight, and price. According to the results obtained for the shell thickness, if the thickness increases, the weight and range of acceleration increase while the probability of shell failure decreases. If the thickness decreases, despite decreasing the acceleration in the head, the stress in the shell increases that leads to failure.

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1- INTRODUCTION

Road accidents are one of the most important causes of death in the world. Peden [1], as well as Koornstra et al [2], showed that motorists are 30 times more likely to be injured in a traffic accident than car users because motorists are less safe than other users of vehicles. Mills and Gilchrist [3] shown that oblique impact is the most common type of collision in the world that causes linear and rotational acceleration. Motorcycle helmets protect against head-to-head collisions along with head protection during an accident and have benefits such as protection against wind and dust as well as preventing adverse weather conditions. The helmet consists of two main parts: the outer shell and the foam. The shell is the outermost layer of the helmet to protect against impacts. The shell protects against foam breakage and sharp objects during impact by spreading the impact over a large area of the helmet.

In the present study, the effect of the material and the thickness of the shell and the velocity of impact, on linear and rotational acceleration on the open-face helmet is investigated using the finite element method considering the shell in three modes, including two composites and one thermoplastic material for open-face helmets. The numerical solution results are validated with laboratory results as well as valid articles. By examining the role of shell thickness in helmets and its effect on head injury criterion as well as thickness optimization, not only does helmet play a protective role in the moment of collision, but also the possibility of material savings, weight loss due to the extra thickness and thus convenience in use is also fully available.

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2- METHODOLOGY

In this research, ABAQUS software explicit solver has been used to simulate motorcycle impact because loads on the helmet set and the head occur in a very short time and the explicit solvers also simulate instantaneous processes such as impact and shock. The important role of the contact between the layers and their friction that creates tangential force, the thickness of the layers, the complex helmet geometry, the existence of large deformations, as well as the nonlinear and independent behavior of the foam strain rate, are the reasons for using the finite element to obtain the center of mass acceleration. The helmet specimen purchased was measured using laser scanning technology and designed in the SolidWorks software. This model includes all parts of a helmet including shell, foam, comfortable foam, chin-straps, and fabric strap fittings. To simulate the behavior of the foam, we consider the elastic-plastic foam. To simulate the elastic behavior of the foam, we use Hook's law and to simulate the plastic foam behavior we use the crushable foam capability available in the ABAQUS software. The foam behavior used is shown in Fig. 1.

The helmet shell, which is usually 2.5 to 5.5 mm thick, is made of thermoplastic materials such as Acrylonitrile Butadiene Styrene (ABS) and polycarbonate or composites such as Glass Fiber Reinforced Polyester (GRP) and Kevlar. The strap keeps the head attached to the set while using the helmet. The helmet chin-strap is made of nylon or PET with a density of $700\ kg/m^3$, and $1000\ Mpa$ elastic modulus and

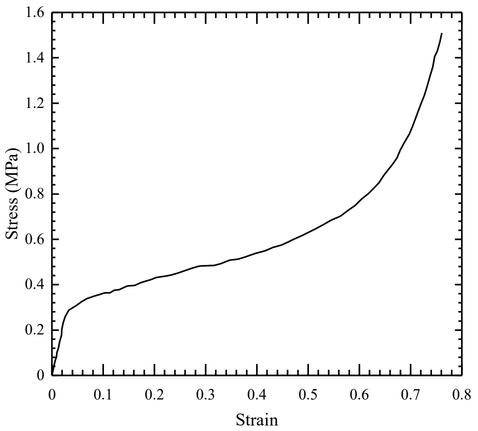

Fig. 1. EPS65 foam stress-strain curve [4]

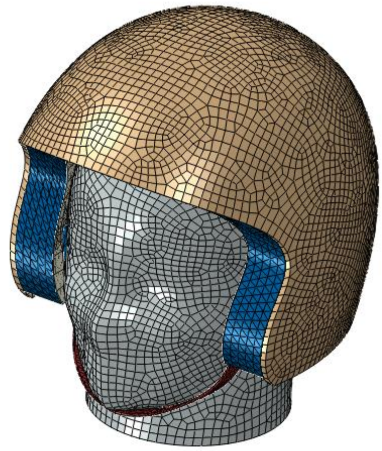

Fig. 2. Finite element helmet set model

Poisson's ratio of 0.2. The chin-strap is intended to prevent head displacement in the helmet, so to simulate the chin-strap as accurately as possible to prevent head movement, before the original model is simulated, a preliminary ABAQUS run pulled the chin-strap ends up through both sides. The shape of this deformed mesh was then imported into the main ABAQUS model.

To simulate the impact mechanics, the penalty algorithm and surface to surface contact is used. The inter-layer contact with the coefficient of friction between the shell and the ground is 0.4, the shell and foam layer is 0.5, and between the head and foam is considered 0.2. To create an integrity of the simulation, between the inner and outer layers of the foam as well as the foam and the comfortable foam, tie constraints have been used.

3- RESULTS

An ABS shell helmet was used to validate the results. This model has been tested in the laboratory under conditions very similar to the finite element model. The acceleration is measured on the head by a connected accelerometer mounted at the center of mass. The collision time in the experimental test is recorded by the accelerometer sensor. The output signal of this sensor is dominated by voltage, which is eventually converted to acceleration-time diagrams based on the transformations. Fig. 3 compares the experimental results with the numerical solution results. By examining the dynamic behavior of the helmet according to Fig. 3, the results of the numerical solution are validated with the real experiment results.

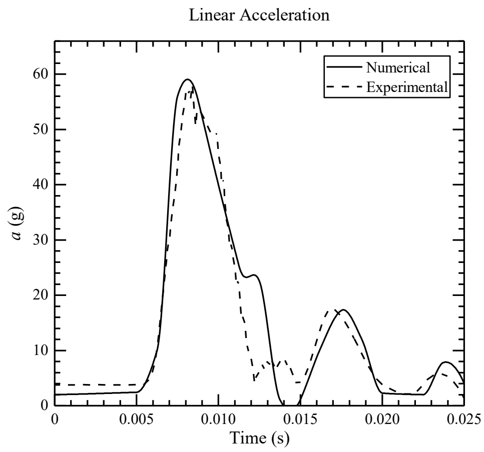

Fig. 3. Experimental and numerical acceleration comparison

The results show that with increasing shell thickness, the maximum stress on the helmet shell decreases and the linear and rotational acceleration on the head and helmet assembly increases. Also the performance of different materials according to the head injury criteria, for the same thickness (3 mm) is 95, 135 and 150 for Kevlar, ABS, and GPR, respectively.

4- CONCLUSION

In this research, the dynamic behavior of motorcycle helmets was verified using the finite element method with the experimental results to calculate the maximum linear and rotational acceleration applied to the head at the collision moment. The maximum linear acceleration was estimated at 70g, which was within the permissible range by calculating and determining the head injury criteria. Also, the maximum angular acceleration of the head was estimated $2.5\ \text{krad/s}^2$. The impact velocity is slightly above 5 m / s to have more reliable results. The results show that the peak head rotational acceleration directly depends on shell thickness at the impact site, impact velocity and the shell material while, it was shown that to be a function of foam material and thickness, the friction coefficient between the shell and road and the head collision direction. Although, in the helmet standards, there is a strong shell to prevent failure, as the research has shown, the thickness of the shell increases the acceleration of the head, leading to damage. Choosing the best thickness from the investigated thicknesses, similar to any case study of the design problem, requires a compromise between different parameters. If the thickness is high, the shell will less tense and protects the head from impact, and if the thickness is low, the acceleration on the head assembly decreases and still retains health. In addition to safety and head protection at collisions, it is important to select the kind of helmet. Therefore, it is best to design the shell thickness by considering the price of different materials, the stress applied to the shell, and the amount of linear and rotational acceleration applied to the head, with a thick shell on impact prone points more than anywhere else, in addition to reducing weight and ease of use, preventing breakage due to stress on the shell, producing the least linear and rotational acceleration and additionally saving on the cost and consumption of materials.

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