

Improvement and Validation of Hybrid III Dummy Knee Finite Element Model

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ABSTRACT

The public Hybrid III family finite element models have been used in simulation of automotive safety research widely. The validity of an ATD finite element model is largely dependent on the accuracy of model structure and accurate material property parameters especially for the soft material. For Hybrid III 50th percentile male dummy model, the femur load is a vital parameter for evaluating the injury risks of lower limbs, so the importance of accuracy of knee subcomponent model is obvious. The objective of this work was to evaluate the accuracy of knee subcomponent model and improve the validity of it.

Comparisons between knee physical model and knee finite element model were conducted for both structure and property of material. The inaccuracy of structure and the material model of the published model were observed. Concentrating on the published dummy knee finite element model, mesh refinement was performed, and the foam material in the front of the knee which does not really exist in knee subcomponent product was replaced by dummy skin material. What's more, a series of uniaxial quasi-static compression tests for Hybrid III 50th percentile male dummy knee skin material and rubber were performed. Material parameters of those materials were fitted using uniaxial quasi-static compression test data. By utilizing Hybrid genetic algorithm, two-order Ogden parameters for skin material and Mooney-Rivlin parameters for rubber insert were obtained respectively.

After mesh refinement and material model parameters reassignment, the hourglass of the model in the simulation of knee impact calibration test has been well controlled. The modified knee model was validated by knee impact tests under different velocities, and the relative error between the response of simulation and experiment is less than 5%. A more valid knee finite model of Hybrid III 50th percentile male dummy has been established by using a more accurate model structure and more proper material parameters.

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INTRODUCTION

The Hybrid III anthropomorphic testing device (ATD or dummy) has been widely used in frontal crash tests as a robust human surrogate for assessing the potential for human injury [1]. With the rapid development of computer technology, the finite element simulation technology has been widely applied in the field of automotive safety research. Some corporations have accumulated some experience on the establishment and validation of the dummy finite element models, such as Livermore Software Technology Corporation (LSTC) and DYNAmore GmbH. So far, the latest public finite element model of Hybrid III 50th percentile male dummy based on LS-dyna code is distributed by LSTC in May 2013 (hereafter called the LSTC model). However, the user's manual doesn't include the certification test of the knee subcomponent [2]. During the application of the model in simulation, the hourglass of the knee subcomponent is relatively high and computational instability often occurs due to the negative volume of solid elements in front of the knee.

A. Nouredine *et al.* [3] and Pradeep Mohan *et al.* [4] proposed and published FE models of Hybrid III dummy in 2002 and 2009 respectively, they used a relatively simple material model

(*MAT_VISCOELASTIC) to simulate the mechanical behavior of dummy knee skin and *MAT_BLATZ-KO_RUBBER to simulate the mechanical behavior of knee insert rubber. Moreover, model validation under the simulation of knee impact calibration test did not be addressed in their research. Wood *et al.* [5] did some research about the viscoelastic behavior of head skin material of the Hybrid III test dummy. A viscoelastic constitutive model with separable temporal and elastic responses was used to characterize the nonlinear and viscoelastic material behavior. Model parameters were determined using data from a series of uniaxial quasi-static compression tests, and the model was validated using constant strain rate tests. However, validations of these parameters in finite element simulations were not conducted, and the hardness of head skin material is different from that of knee skin material, so these parameters cannot be utilized for modeling the knee skin material directly. Cao *et al.* [6] proposed a finite element model for Hybrid III 50th percentile male dummy head, and studied influence of the elements size and type of contact on the response of dummy head calibration simulation. The study of the characteristic of biomimetic materials used in dummies and the improvement of the public dummy finite element model is very scarce through literature study.

The structure of knee subcomponent in the LSTC model is shown in Figure 1A, only the knee molded skin, kneecap and kneecap insert are shown here. In this model, a layer of shell elements are covered the entire knee skin, and Material Type 7 (*MAT_BLATZ-KO_RUBBER) are assigned to them. Beneath the shell elements, solid elements assigned with material type 57 (*MAT_LOW_DENSITY_FOAM) to model highly compressible low density foams. Comparing with the knee product shown in the figure 1B, the structure of the LSTC model isn't coincident with that since there are no polyurethane foams in the front of the knee flesh and skin assembly, only exists in the rear part.

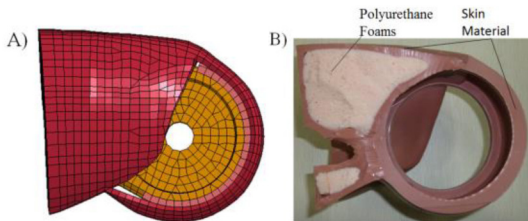


Figure 1. The structure of knee subcomponent in the LSTC model and the structure of knee flesh and skin assembly.

The peak dummy femur load in crash test as an important indicator is widely used in automotive safety regulations and New Car Assessment Programmer to assess the potential for human lower limbs injury. To obtain an accurate femur impact force in the simulation, the real structure of knee must be modeled and appropriate material models and parameters must be assigned. Through previous studies, the properties of knee skin material and kneecap insert rubber material play a crucial role in the lower limbs response during a frontal impact scenario. The goal of this study was to propose a more valid Hybrid III knee finite model on the basis of the public dummy knee model from LSTC. Mesh refinement was performed and more accurate material models and parameters were selected for modeling the skin and rubber of knee. Parameters for material model were obtained using a material test combined with optimization algorithm method.

METHODS

Mesh Refinement

The simulation of knee calibration test using the LSTC knee model was developed based on SAE J 2856-2009 [7] under LS-dyna software, shown in Figure 2. The speed of the test pendulum was set to 2.1m/s, and the mass of it was 5 kg. The bottom of the femur load simulator was fully constrained; an accelerometer unit was attached to the rear end of the test probe pendulum to measure the acceleration of it during the impact. SAE J211 CFC600 was used to filter the acceleration curve from the simulation. The curve of impact force (defined as the product of the test probe mass and the deceleration) versus time was shown in Figure 3, and the curve of model energy versus time was shown in Figure 4.

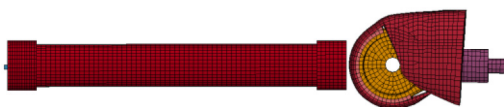


Figure 2. Simulation setup of the knee impact test using the LSTC model.

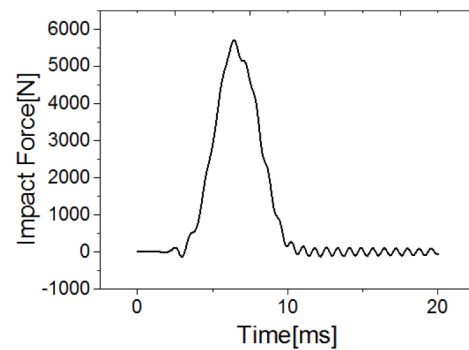


Figure 3. The curve of impact force (defined as the product of the pendulum mass and the acceleration) versus time obtained from the simulation of the knee impact test based on the LSTC model.

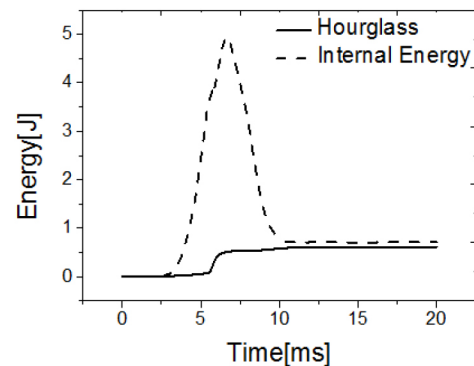


Figure 4. The curve of model energy versus time obtained from the simulation of the knee impact test based on the LSTC model.

In the LSTC model, only one layer of elements was used to model the knee skin and kneecap rubber insert. In Figure 4, the hourglass phenomenon of the LSTC model in simulation is obvious, and the hourglass energy peak value accounts for 11% of the internal energy. The relatively large hourglass energy may lead to a non-conservation of the simulation and affect the calculation accuracy, even result in an incredible simulation result. Considering that the deformable regions during the knee impact test are mainly occurred in the skin and the rubber insert in the front part of knee subcomponent, so mesh refinement was mainly focus on these parts or areas. Meanwhile, too much small size elements would lead to a huge increase of calculation cost. So two-layer skin meshes and three-layer kneecap rubber insert meshes were used in this study finally, shown in Figure 5.

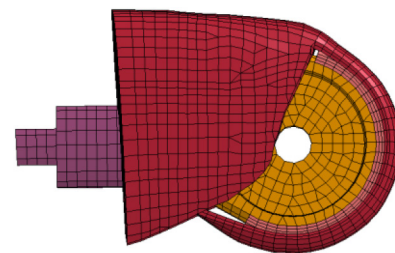


Figure 5. The knee model after refinement.

The curves of impact force versus time and energy versus time after refining the element are shown in Figure 6 and Figure 7. It is obvious that the pendulum impact force curve is becoming smoother and the