FINITE ELEMENTS MODELLING OF BONE MATERIAL DISCONTINUTY IN CASE OF SKULL FRACTURE

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1. ABSTRACT

The aim of this work is to set up a numerical model in order to simulate skull fracture, and to analyse the effects of the material discontinuity induced by this non-linearity on intracranial stress field. Mechanical parameters of cranial bone were found in the bibliography for the finite element modelling of skull fracture. A failure criterion was validated with cranial bone samples and is applied to a new 3D anatomic skull model. The results comply well with the experimental bone response found in the bibliography. Finally, a simple spherical human head model was used to analyse the effects of skull fracture on head response in case of shock.

2. INTRODUCTION

In the past, many studies have been done in the field of head injury modelling, but the non-linearity induced by skull fracture wasn't considered in the human head modelling.

The skull was always modelled with a linear elastic material law with a layer of shell elements or brick elements. It's sure that this elastic modelling doesn't permit the model to predict a realistic head response in case of shock involving skull fracture.

Based on the Tsaï-Wu criterion, skull fracture modelling with three layered composite shell elements was carried out and presented in this paper.

3. METHODS AND DISCUSSION

Mechanical parameters of cranial bone were found in the bibliography for the Tsaï-wu criterion (1), which is formulated as follows for plane stresses:

$$F_i\sigma_i + F_{ij}\sigma_i\sigma_j = 1 \qquad i,j=1,2$$

We choose this criterion because it is an interactive one, meaning that the different phenomena occurring in the material such tension, compression and shearing are not supposed to happen independently. The coefficients F_i and F_{ij} include the ultimate parameters of bone and the correlation between experimental and numerical data is increased.

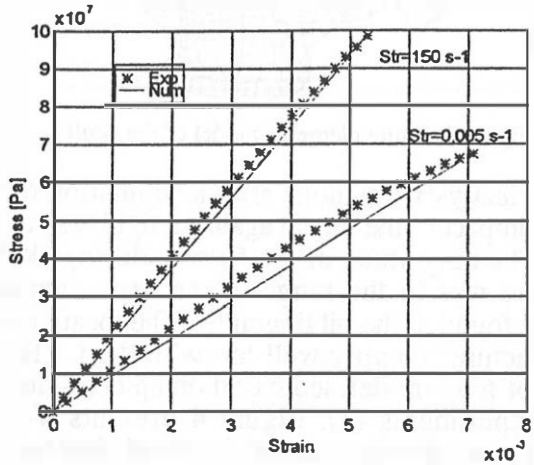

Figure 1: Numerical tensile stress-strain curves against experimental results at different strain rates(Str).

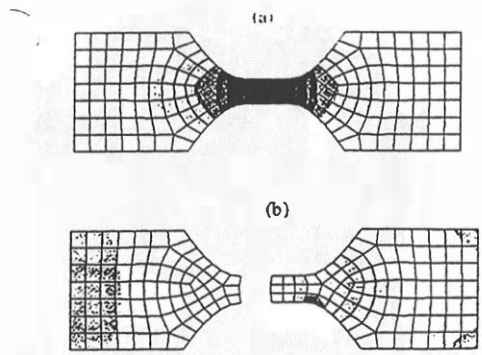

Figure 2: Finite element modelling of the dynamic tensile tests(before fracture(a), and after fracture (b)).

An elastic brittle material law was performed with Radioss finite element code (2). In a first step, this material law was validated against experimental results of dynamic traction (Figures 1 and 2) for compact bone (3). In a second step,

bone samples were modelled with three layered composite shell, in order to reproduce the inner table, the outer table and the diplöe. The compliance of the structure were validated with experimental data of the bibliography (4).

In order to consider the real geometry of the skull, a 3D anatomic finite element model of the human skull was developed (figure 3). The model consists in 3496 composite shell elements and 3536 nodes and its mass is of 0.8 kg.

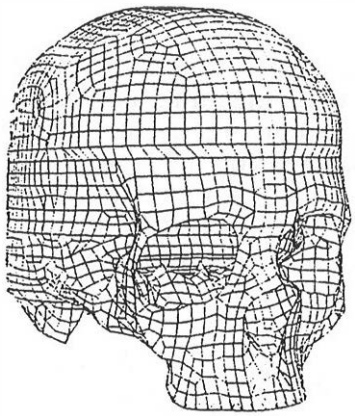

Figure 3: Finite elements model of the skull.

An analysis was done after a simulation of a facial impact of the model against a rigid wall at 5 m/s. The magnitude of the force inducing skull fracture was in the range of the experimental results found in the bibliography. The location of the fractures comply well too with the Le Fort lines of fracture defined based on epidemiology and experiments (5). Figure 4 presents Von-Mises stress distribution and fractured elements.

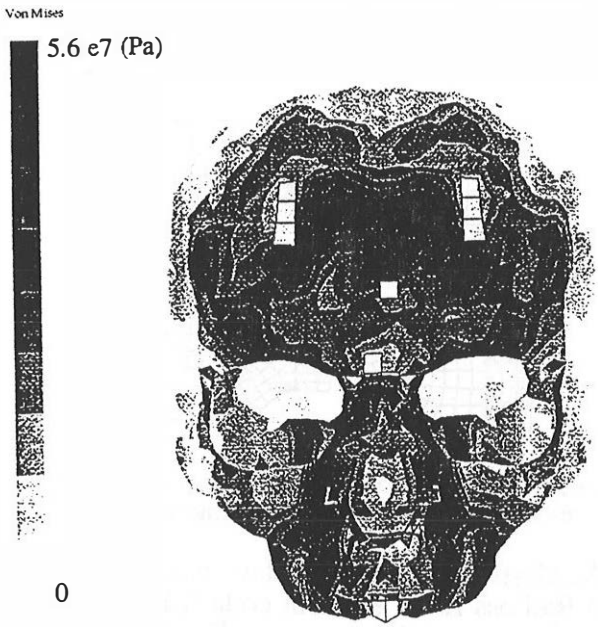

Figure 4: Von Mises stress at 2 ms after a facial impact simulation of the model at 5 m/s against a rigid wall.

These results were applied to a spherical model of the head filled with elastic solid elements representing the brain for the analysis of intracranial stress field in case of head injury involving skull fracture. The model response was compared to the purely elastic version of the spherical model. A significant difference was found in terms of contact force (figure 5) and intracranial stress.

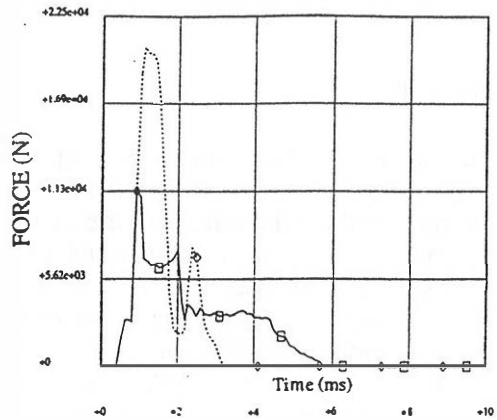

Figure 5: Contact force between the sphere and a rigid wall at 5 m/s (Elastic model (dashed lines), elastic brittle model (full lines)).

4. CONCLUSION

A new approach of numerical skull fracture modelling has been proposed in this paper. Material bone non-linearity induced by fracture has been simulated by using an interactive criterion involving the energetic aspect of bone failure. This criterion was validated against experimental results obtained with samples of cranial bone and then applied to a new 3D anatomic model of the human skull.

A good agreement was found between numerical and experimental responses both with cranial bone samples and the present 3D skull model. Numerical simulation of head impact involving skull fracture showed the importance of the skull fracture modelling, because the impact force, head acceleration, and intracranial stress distribution were changed significantly compared to the purely elastic model response.

To apply the results of this study to head injury modelling, we're now developing a new anatomic human head model which will be able to predict the skull fracture and to reproduce dynamic head response in case of shock involving skull fracture.

REFERENCES

1. Berthelot J.M., Matériaux composites, Masson, Paris (1992).
2. Radioss User's Manuel, V. 3.1, Mecalog.
3. Wood J.L., Dynamical Response of Human Cranial Bone, J. of Biomechanics **4**, pp. 1-12 (1971).
4. Hubbard R.P., Flexure of layered cranial bones, J. of Biomechanics **4**, pp. 251-263 (1971).
5. Nahum A.M., Melvin J.W., Accidental injury, pp. 254, Springer-Verlag (1993).