# TOPOLOGICAL AND SHAPE DESIGNS FOR CRASHWORTHINESS CRITERIA

**Qing Li**[a], **G.P. Steven**[b] **and** **Y.M. Xie**[c]

[a]School of Aerospace, Mechanical and Mechatronic Engineering,
The University of Sydney, Sydney, NSW 2006, Australia
qli@aeromech.usyd.edu.au

[b] School of Engineering, University of Durham, Durham DH1, 3LE, United Kingdom
grant.steven@durham.ac.uk

[c]School of Civil and Chemical Engineering, Royal Melbourne Institute of Technology,
GPO Box 2476V, Melbourne 3001, Australia
mike.xie@rmit.edu.au

Over the past decade remarkable progress has been made in the development of software used in crash simulation and analysis. A number of commercial codes have been available with accepted accuracy. However, there has been little report in its inverse problem yet, i.e. topological and shape optimization for crashworthiness. The difficulty is primarily raised from two folders on (1) the nonlinear sensitivity analysis and computational cost [1], which become particularly challenging in various topological designs; (2) dynamic multi-modals and non-convex design space, which do not lend the crash problems themselves well to classical gradient techniques. The paper aims at developing an alternative approach to the crashworthiness design problems. The Evolutionary Structural Optimization (ESO) [2] will be applied to reduce the dependence on the continuum sensitivities.

In a crash simulation, it is frequently found that plastic deformation in some locations may be much higher than others. This implies that the material of the crashing elements may have different contributions to the crashworthiness goal. Ideally, the energy absorption levels in all location are near identical. To represent the relative performance of element's material, a dimensionless factor is formulated by dividing the crash energy absorption by each element to the highest one as,

$$\alpha = U_e / U_{max} \tag{1}$$

where $U_e = \int_{t_f} \int_{\Omega_e} \frac{1}{2} \sigma\varepsilon dxdt = \int_{t_f} \int_{\Omega_e} \frac{1}{2} E_{ijkl} \frac{\partial u_i}{\partial x_j} \frac{\partial u_k}{\partial x_l} dxdt$ computes the strain energy absorbed by the candidate element (*e*th) and $t_f$ represents the final time of the crash process. It is worth pointing out that the total internal energy should contain the elastic and plastic components, i.e. $U = U^e + U^p$. Eq. (1) gives an indication to gradually shift material of the design domain from a lower energy absorption location to a higher one. As a consequence of this process, the resulting structural performance becomes more and more uniform in terms of the crashworthiness criterion.

In general, standard FE codes directly or indirectly provide the outputs for computing the internal energy of each element, which facilitates the use of any matured commercial package of crashworthiness analysis in industry. Therefore, the ESO method presented herein can readily be implemented in a variety of existing well-established analysis platforms. The examples of both topology and shape designs are also shown in this study to demonstrate the capabilities of the present method.

## References

[1] Zabaras N, Ganapathysubramanian S and Li Q, "A continuum sensitivity method for the design of multi-stage metal forming processes", *International Journal of Mechanical Sciences*, v. 45, p.325-358, 2003.
[2] Xie, Y.M. and Steven, G.P. 1997. *Evolutionary Structural Optimization*, Springer-Verlag, Berlin.