Integrating Casting Porosity Predictions in Crash Tests

The Concept

Alcan, BMW and ESI Group have successfully validated the potential benefits of a coupled product/process engineering approach based on crash and cast coupling with correlation of simulation and experimental results (see Figure 1).

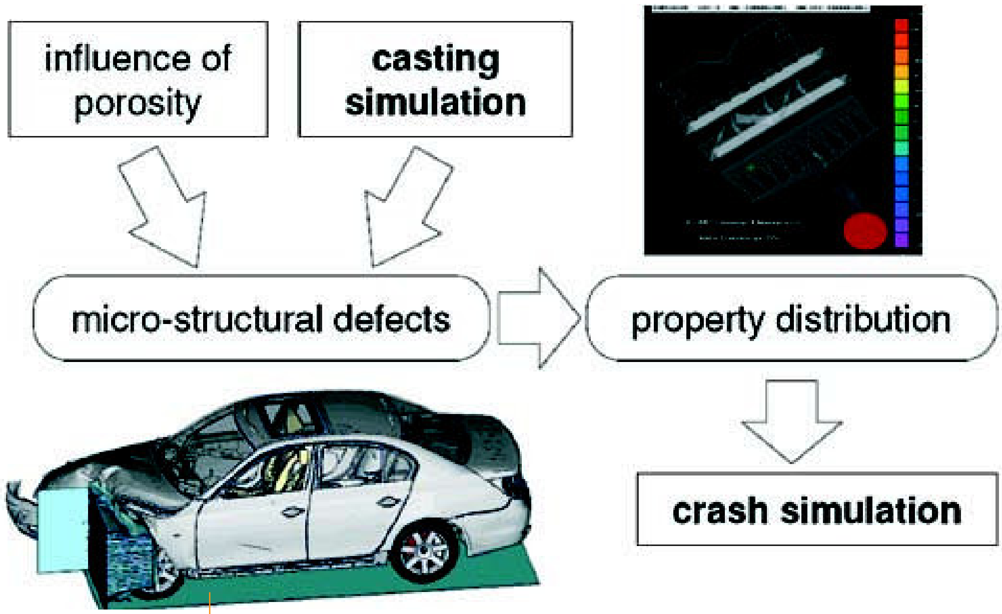

Figure 1: As shown in the flow of information outlined above, the goal of the project initiated by Alcan and BMW was to take into account various micro-structural defects resulting from the casting process (mainly micro-porosity) in crash simulation.

Aluminum Pressure Die Casting

Due to their economical benefits, aluminum pressure die cast components have become a new trend in automotive lightweight structural design. By using this casting method, a component with a complex geometry usually made up of several smaller connected parts can now be produced in one process, as a single component.

However, in comparison, pressure die castings are generally at higher risk of failure due to:

- porosity and other micro-structural defects resulting from the casting and solidification process, which in turn reduce the fracture strain of the material;
- stress and strain concentrations as a result of complex component geometry. Furthermore, due to the nature of the casting process, properties are generally homogeneous between different sections of a component.

All these effects must be considered in crash simulations in order to obtain accurate results.

Casting Process Simulation

To account for the effects of the production process, the first step in the current approach is a casting process simulation in order to predict the uneven distribution of mechanical properties, and particularly the porosity distribution within a given aluminum die cast part. Comparison of numerical porosity predictions (obtained with ProCAST) with CT-scans and micrographs show a good match, see Figure 2.

Fracture Model

Similar to other metallic materials, aluminum pressure die cast components generally fail due to one, or a combination, of the following mechanisms:

- ductile fracture (based on initiation, growth and coalescence of voids)
- shear fracture (based on shear band localization)

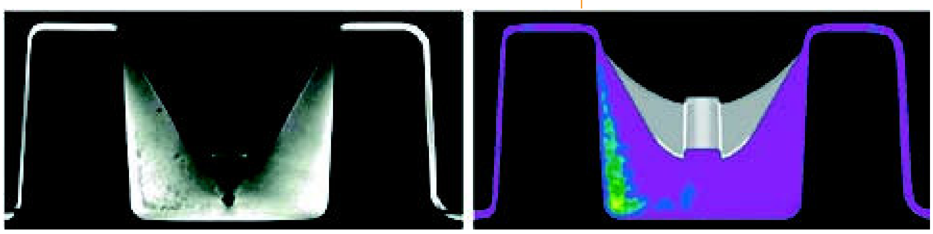

Figure 2: Shrinkage porosity – comparison between CT-scan (left) and numerical prediction obtained with ProCAST (right).

Specific ductile and shear fracture models were considered with an ad-hoc fracture criterion.

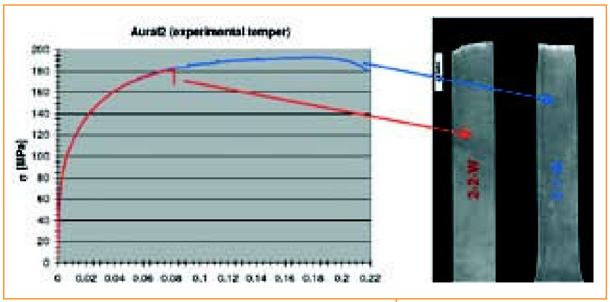

Figure 3:
Tension behavior and fracture level of a specimen with reduced amount of porosity (blue curve) and with increased porosity (red curve).

The functional relation between fracture curves and different levels of porosity was identified via extensive testing (see Figure 3). Hereby, specimens were taken from locations with representative porosity levels identified through the casting simulation. Two levels of porosity were differentiated: low porosity < 1 % and high porosity ≥ 1 %.
Using this phenomenological approach, all porosity values computed in the casting simulation were translated into the parameters of the fracture criteria to be applied in the crash simulation. This data was then mapped from the casting simulation results onto the discretization for the crash simulation.

Validation

To validate the model, numerical crash simulations are compared with experimental results of dynamic axial crush tests and three-point bending tests. Numerical simulations are performed with the explicit finite element code PAM-CRASH.

The numerical predictions match up with the actual experimental results (see Figure 4) and demonstrate the effectiveness of the presented approach for crash assessment of pressure die cast aluminum components.

Figure 4:
Dynamic axial crush test – comparison between experiment and numerical simulation.

Next Steps

Future versions of ESI Group casting solutions will allow the transfer in STL format of porosity predictions in any FEA code. This information can then be used to better predict admissible designs.

Remark

This article is an adaptation of a paper published by C. Leppin[1], H. Hooputra[2], H. Werner[2], S. Weyer[2] and R.V. Büchi[1] at the VIII International Conference on Computational Plasticity held in Barcelona in 2005 (Eds E. Oñate and D.R.J. Owen)

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Figure 5:
Porosity prediction calculated in ProCAST (left) and resulting export in STL format (right).