Explicit simulation of blade cutting and through-the-thickness fracture in multi-layer, thin-walled structures

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This work is devoted to a finite element computational tool for the simulation of fracture propagation and blade cutting in multi-layer shell structures.

The thin-walled structure is discretized with eight-nodes solid-shell elements of the type developed by Schwarze and Reese [1] and based on reduced integration with hourglass stabilization. On the one hand, this choice allows for a simple implementation of fully three-dimensional constitutive behaviours and for the cohesive description of fracture phenomena, since solid-shell elements are formulated using displacement degrees of freedom only. On the other hand, the presence of different layers can be accounted for by stacking up one or more solid-shell elements per layer along the thickness.

Through-the-thickness crack propagation is described by means of a cohesive approach. Blade cutting is simulated using directional cohesive elements, as proposed in [4] and in [5], where the transmission of cohesive forces between the two flanks of the crack accounts for the interaction between the blade and the process zone. While the approach in [4] and in [5] was restricted to one-layer thin shells, in the present work crack propagation through the thickness of different layers is explicitly considered.

A conditionally stable explicit time integration is used to deal with the several nonlinearities involved in the problem, such as large deformations, contact, crack propagation and delamination. When a solid-shell discretization is adopted, the stable time step becomes very small, since it is governed by the element thickness, typically small if compared to its in-plane dimensions. This problem is overcome by implementing the selective mass scaling technique proposed in [2-3] for inertia dominated problems and extended to the case of multi-layer structures. According to this approach, the element mass matrix is locally modified to scale down the highest eigenfrequencies with small or negligible changes to the lowest ones. As a result, the stable time step is determined by the minimum in-plane size of the elements only, as for classical shell elements, without accuracy losses.

Benchmarks drawn from the literature on the dynamics fracture of shells are used to test the proposed numerical tool. Moreover, the procedure is applied to the simulation of the cutting of a thin-walled laminate used in the carton packaging industry.

References

[1] M. Schwarze and S. Reese. A reduced integration solid-shell finite element based on the EAS and the ANS concept. Large deformation problems. International Journal for Numerical Methods in Engineering, 85, 289-329, 2011.

[2] G. Cocchetti, M. Pagani and U. Perego. Selective mass scaling and critical time-step estimate for explicit dynamics analyses with solid-shell elements. Computers & Structures, 127:39-52, 2013.

[3] G. Cocchetti, M. Pagani and U. Perego. Selective mass scaling for distorted solid-shell elements in explicit dynamics: optimal scaling factor and stable time step estimate. International Journal for Numerical Methods in Engineering, 101, 700-731, 2015.

[4] A. Frangi, M. Pagani, U. Perego and R. Borsari. Directional Cohesive Elements for the Simulation of Blade Cutting of Thin Shells. CMES-Computer Modeling in Engineering & Sciences, 7:205-224, 2010.

[5] M. Pagani and U. Perego. Explicit dynamics simulation of blade cutting of thin elastoplastic shells using “directional” cohesive elements in solid-shell finite element models, Computer Methods in Applied Mechanics and Engineering, 85, 515–541, 2015.