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Shell Interface Finite Elements for the Simulation of Folding and Cutting of Composite Laminates

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Carton packaging is one of the key ingredients for the distribution of goods from production to the final destination and it is a fast growing industry. Depending on the particular type of packaging required, the production of carton packages can be a rather complex process. The need for waste reduction and increasing competition are encouraging the development of computational tools for the simulation of the production and opening processes and for its optimization.

Two different aspects concerning the finite element simulation of the forming and opening processes of carton packages are considered in the present work: the folding of the paperboard around pre-scored crease lines for its conversion from the initial flat configuration to the final box shape; the cutting of the package laminate by means of a screw driven cap, connected to high density polyethylene teeth.

To facilitate the folding of the paperboard around the prescribed lines, before being converted into its final shape, the paperboard blank is "creased", i.e. the folding lines are scored onto the paperboard by pressing it by a male die with a rule onto a grooved female die (see Figure 1). The creasing produces a local, shear induced delamination into the paperboard structure which reduces its bending stiffness and promotes the folding around the design lines. In the present work an interface finite element for the simulation of the crease presence in a curved laminate, is presented. The element is designed to be placed between adjacent 4 node shell finite elements of the Mindlin-Reissner type. The element is formulated in terms of generalized internal forces (moments and tractions) and relative displacements (displacement jumps at the shell midsurface and relative rotations). The material model accounts for the permanent elastoplastic deformation of paper and both for the initial and progressive delamination damage due to the creasing and subsequent folding of the paperboard. Particular attention has been devoted to the definition of the dependency of material parameters on the crease penetration depth (parameter γ in Figure 1). The model has been calibrated on the experimental results provided in [1] showing good agreement, as can be appreciated in Figure 1.

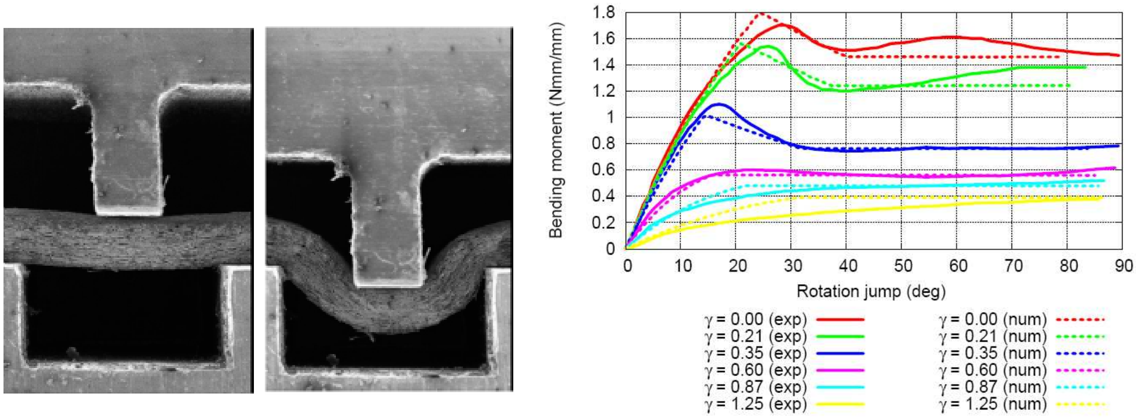

Figure 1: Creasing process and bending moment-rotation crease response for varying penetration depth.

The second problem considered in this paper is the blade cutting of the thin membrane used to seal a package containing liquid food. The membrane is typically a layered composite, with a total thickness ranging from 70 to 85 μm, made of a thin aluminium layer (6-9 μm) and various low-density polyethylene (LDPE) coating layers. In these type of materials, the failure of the aluminium layer is followed in a uniaxial tension test by a long plateau, usually corresponding to the occurrence of localized necking deformation, where the molecules of the LDPE realign along the direction of loading. The failure nominal strain of the LDPE layers can be of the order of 700-900%.

The numerical simulation of fracture and fragmentation of shells and plates is a timely topic in computational structural engineering which is receiving increasing attention (see e.g. [2, 3, 4]). However, the finite element simulation of the cutting of a thin membrane by a sharp blade can still be considered to be a challenging task. In particular, when the membrane material is very ductile, classical interface cohesive elements, where the cohesive forces are transmitted in the direction of the crack opening displacement, cannot correctly reproduce situations where the blade crosses the process zone. A simplified approach, based on the new concept of "directional" cohesive elements, is here proposed for a computationally effective simulation of this type of problems (Figure 2a). When the selected fracture criterion is met at a given node, the node is duplicated and it is assumed that cohesive forces are transmitted between the newly created pair of nodes by a massles "cable", i.e. a truss element introduced ad hoc in the model in correspondence of each couple of separating nodes. Unlike in standard cohesive approaches, the cable element is a well defined geometric entity, and its contact against the cutting blade can be checked throughout the analysis duration. When a point of a cable element is detected to be in contact with the blade, the cable element is subdivided in two truss elements and the length of the cable is now defined as the sum of the lengths of the two constituent trusses. Two forces of the same magnitude are transmitted by the two branches of the cable to the crack flanks, but the direction of these forces is different at the two nodes on the opposite sides of the crack. Application of this technique to a specific opening problem has produced encouraging results in terms of the obtained torque-rotation diagram of the cap if compared to experimental tests (Figure 2b).

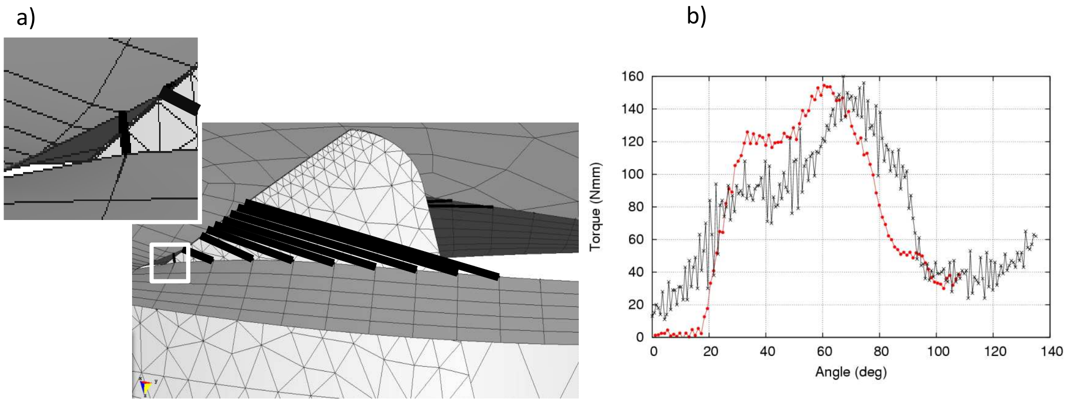

Figure 2: a)"Directional" cohesive forces. b) Torque-rotation diagram.

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