On the Sensitivity of Creasing Force to Parameters in Constitutive Models of Paperboard

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ABSTRACT

Paperboard products are widely used for many years by various industries, ranging from a paper-based aseptic liquid packages to book covers. In many of its applications it has to be folded in order to form a particular shape of a package or a book. A single and a multi-ply paperboard can and should be creased before folding. Ideally, the paperboard should delaminate into a finite number of thin, unbroken layers throughout the thickness of the paperboard. The highly anisotropic behavior of paperboard, the big number of material parameters, progressive delamination between the plies and the inelastic non-uniform deformations thorough the thickness of multi-layer paperboard, make the numerical simulations of creasing and folding a difficult task. In this work the sensitivity analysis of creasing force is carried out in order to select an important set of parameters and hence the best suited constitutive model for paperboard in creasing test simulations.

Paper and paperboard has two main in-plane directions, usually called machine direction (MD) and transverse or cross direction (CD), in which the material behavior is different both in elastic and inelastic range. In typical paper the machine direction is the one with a stiffest response, it is known that the MD and CD direction differ by a factor of two or even three (especially for machine-made paper), and the MD can be 100 times 'stiffer' than the out-of-plane direction (here called the ZD). The reason for the stiffer response in the MD is due to alignment of the fibers which arranged themselves mainly in the MD during manufacturing. Paper behaves differently also when is loaded in tension and compression for all three directions. Behavior in tension is stiffer then in compression for both directions (MD and CD); here a factor of two is commonly found. The lower stiffness in compression is due to a partially structural response of the sample, which can not be neglected.

In the literature many constitutive models capable to capture the complicated behavior of paperboard and/or paper can be found (see e.g. [1, 2]). Some researchers focus their attention on proper selection of material model for both, paper and the interface in order to correctly simulate the creasing and folding (se e.g. [3, 4]). The anisotropic elasto-plastic constitutive models for paper contain many material parameters (ranging from more then ten in Hill model to almost forty in Xia model) which are not easy to be identified from the standard tests (see e.g. [2, 5, 6]), also the interface behavior between the plies has to be characterized by a non-standard testing (see [3, 4]). If one consider to use a constitutive model which distinguishes the difference in compressive and tensile behavior of paper (e.g. Hoffman, Tsai-Wu or Xia models), what implies to use more tests to characterize additional parameters (as proposed e.g. in [6]), the sensitivity analysis comes as a great tool for a proper material model selection in order to reduce the experimentation costs. By computing the sensitivities of creasing force to the constitutive parameters embed in various material models we can find out which parameters are less important (i.e. measurements are not sensitive to its perturbation) in order to eliminate those parameters from the identification process (by choosing an 'a priori' approximate value) and therefore reduce the number of necessary experiments.

For comparison reasons the experimental data and material parameter values are taken from works [2, 3, 4, 6]; The sensitivities are computed by forward differences based on FE results obtained from Abaqus with user material model subroutines. Totally four models (namely Hill, Hoffman, Tsai-Wu, and Xia models) were implemented, tested and compared based on the sensitivity analysis. In Figure 1a typical test setup is shown; Figure 1b shows the typical curves of creasing force vs displacement for two creasing depths.

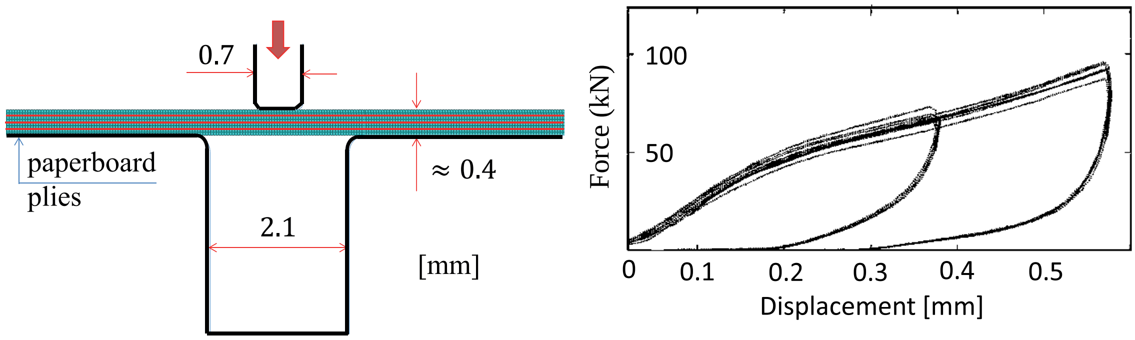

Figure 1: (a) typical test setup; (b) force-displacement diagram in CD (reproduced from Huang and Nygards [3]).

References

[1] P. Makela, S. Ostlund, Orthotropic elasticplastic material model for paper materials. *Int. J. Solids Struct.* 40:5599-5620, 2003.

[2] Q.S. Xia, M.C. Boyce, D.M. Parks, A constitutive model for the anisotropic elastic-plastic deformation of paper and paperboard. *Int. J. Solids Struct.* 46:4192-4207, 2009.

[3] H. Huang and M. Nygards, A simplified material model for finite element analysis of paperboard creasing. *Nord. Pulp Paper Res. J.* 25:505-512, 2010.

[4] L.A.A. Beex, R.H.J. Peerlings, An experimental and computational study of laminated paperboard creasing and folding. *Int. J. Solids Struct.* 61:1-48, 2000.

[5] M. Nygards, Experimental techniques for characterization of elastic-plastic material properties in paperboard. *Nord. Pulp Paper Res. J.* 23:432-437, 2008.

[6] T. Garbowski, G. Maier, G. Novati, On calibration of orthotropic elastic-plastic constitutive models for paper foils by biaxial tests and inverse analyses. *Struct. Multidisc. Optim.* DOI: 10.1007/s00158-011-0747-3, 2011.