A 3D-continuum model for paperboard possessing a high degree of anisotropy.

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ABSTRACT

Paperboard is a fiberous material made from cellulose wood fibers. The paperboard possess a high degree of anisotropy, which stems from the manufacture procedure where the majority of fibers becomes aligned in the MD-direction (Machine Direction). Classically, paperboard is characterized as an orthotropic material where the normals to the symmetry planes are denoted as MD, CD (Cross Direction) and ZD (out-of-plane). The magnitude of the material properties in MD are typically 2-3 times higher compared to CD properties and about one magnitude higher compared to ZD properties, cf. [1]. Due to the large difference in the mechanical properties between the in-plane and out-of-plane directions, a combination of continuum and cohesive elements, cf. [2] has traditionally been employed to model the large anisotropy. In this work, a model, which is able to handle the large degree of anisotropy using a purely continuum based model, is presented.

To handle the anisotropy, three vectors are introduced, which phenomenologically represent the MD, CD and ZD directions of the material, denoted as $\boldsymbol{v}_0^{(MD)}$, $\boldsymbol{v}_0^{(CD)}$ and $\boldsymbol{n}_0^{(ZD)}$ in the reference configuration. It is assumed that the in-plane vectors deform as line segments and the out-of-plane direction deforms as a normal vector. The mapping to the deformed configuration is then given by

$$\begin{aligned} \boldsymbol{v}^{(MD)} &= \boldsymbol{F}^e \boldsymbol{v}_0^{(MD)} \\ \boldsymbol{v}^{(CD)} &= \boldsymbol{F}^e \boldsymbol{v}_0^{(CD)} \\ \boldsymbol{n}^{(ZD)} &= J^e \boldsymbol{F}^{e-T} \boldsymbol{n}_0^{(ZD)}, \end{aligned} \tag{1}$$

where $\boldsymbol{F}^e$ is the elastic deformation gradient, defined from a multiplicative split of the deformation gradient and J^e is the determinant of $\boldsymbol{F}^e$.

The model is developed using a hyper-elasto plastic format in the spatial setting. An elastic free energy is proposed and the yield surface proposed in [2] and enhanced in [3] is used to model the in-plane properties. In this work, the yield surface has been modified to account for the out-of-plane plastic behavior as well. An expression for the plastic spin is determined and it is shown to be important to specify, due to the large anisotropic plastic strains that are present. The choice of plastic spin allows for a control of the direction in which permanent deformations will occur.

The developed continuum model is used to model the creasing and folding processes. In creasing, a male tool is pressed on the paperboard into the groove of a female tool, inducing permanent deformations on the paperboard. A well defined fold line emerges on the paperboard after

creasing, which acts as a hinge in the subsequent folding. The model has been implemented in a finite element framework. The simulated deformation pattern of a line fold is shown in Fig. 1, together with experimental measurements.

a)

b)

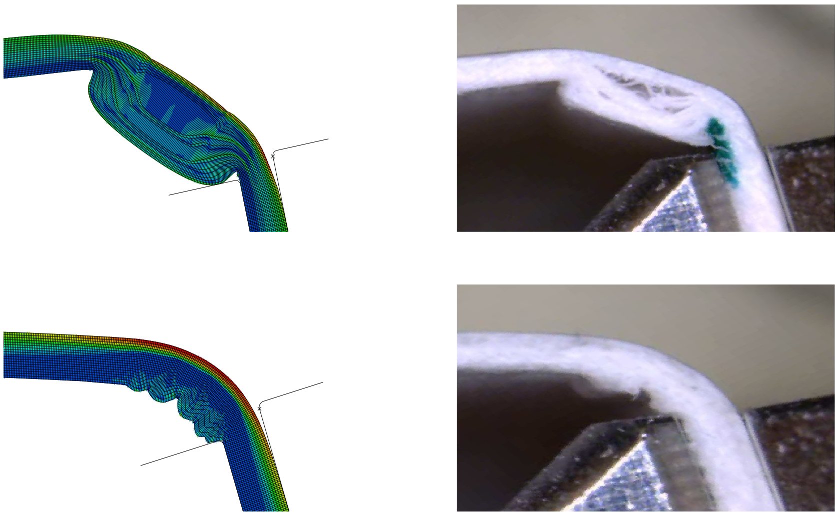

Figure 1: Simulated and measured deformation pattern of folding a paperboard. a) Paperboard creased prior to folding, b) Paperboard not creased prior to folding.

On the basis of Fig. 1, it can be concluded that the overall experimental deformation pattern is captured in the simulation. In the simulated folding of the creased paperboard, some elements are stretched several hundreds of percent, indicating a deformation similar to that of delamination. The results in Fig. 1 indicate the potential applications for the model, where local deformation phenomenons such as wrinkling can be predicted.

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References

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