Validation of an Iteration Free Material Model for Paperboard (NEO)

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The NEO model is a non-linear material model that utilizes experimentally curve fit constitutive relations with switches to mimic elastic-plastic responses. This model was developed by Lindström (2019) to be primarily used for paperboard and highly orthotropic materials. Due to the explicit nature of the constitutive relations, the stresses are obtained using total strains and hence a constitutive equilibrium loop is not required. The lack of a constitutive equilibrium loop potentially makes the NEO model a very computationally efficient material model compared to other elastic-plastic models in the literature. Furthermore, the switch-wise nature of formulation presents a unique opportunity to incorporate new mechanics with little development times and computational cost. However, due to limited representation in the literature, the accuracy and validity of this model are relatively unproven. This was the primary motivation for this thesis project.

The primary aim of this project was to: *determine the validity and relative accuracy of the NEO model for in-plane elastic-plastic responses*. This study emphasised the accuracy and validity of the model, and as such, the computational efficiency was not assessed. To evaluate the validity of the NEO model, a version of it was implemented into LS-Dyna and compared directly to models developed by Borgqvist et al. (2014) (XIA) and Borgqvist et al. (2014) (EBT). All models were calibrated to data obtained by Alzweighi et al. (2022) for a 260mN paperboard material. The primary loading regimes investigated were in-plane uniaxial cyclic loading and biaxial tensile loading and unloading. These loading regimes were selected to replicate experimental results collected by Alzweighi et al. (2022), and thus experimental comparisons were also included. Due to the orthotropic nature of paperboard, all simulations were performed for a variety of material directions to assess the directional dependence.

Overall, the performance of the NEO model was promising. For all results, the NEO model showed a strong correlation with the EBT model and the experimental results, where they were valid. Unfortunately, during the biaxial tests Alzweighi et al. (2022) experienced significant slippage, which invalidated quantitative comparisons between the biaxially loaded NEO simulations and the experimental results. The majority of errors between the NEO model and the EBT and XIA models could be attributed to calibration differences, and no significant limitations of the NEO model could be seen within the scope of this study. Therefore it is concluded that, given appropriate calibration, the NEO model and EBT models are equivalent for plane-strain in-plane loading conditions. Furthermore, when uniaxially loaded, the NEO model showed no difference between material directions that were specifically calibration to and off-axis material directions that were predictive. This suggests that the NEO model is valid for general loading cases, and the material direction has little influence on the model's performance.

Since all significant differences between the NEO model and the EBT and XIA models could be attributed to calibration, it is concluded that the NEO model is equivalent to these models for in-plane elastic-plastic loading. Correlations between the NEO model and the experimental results, where valid, also support this conclusion. Discrepancies in the calibration may mask some limitations of the models; however, the scale of the differences between the NEO and the EBT and XIA models is small enough that these limitations can be concluded as insignificant. The major limitations of the NEO model stem from limits on the scope of this study and are not a direct reflection of this model. Beyond the scope of this study, the NEO model may experience some discrepancies when modelling highly directionally coupled materials due to the yield plane definition. This limits the model to orthotropic materials. Furthermore, the direct curve fitting nature of the NEO model makes it sensitive to calibration errors; this was exemplified in this study as all significant errors were related to calibration.

To further validate the model, the calibration could be improved in future studies to focus on any fundamental issues with the NEO model. However, since the accuracy of the NEO model was shown to be reasonable relative to the EBT and XIA models, expansion into other mechanics such as out-of-plane effects, damage and moisture are recommended for future studies. Finally, as the lack of a constitutive equilibrium loop could improve the computational efficiency, it is highly recommended that the NEO model be used on high element explicit models to exploit this advantage.