Prediction of Dynamic Material Failure – Part I: Strain Rate Dependent Plastic Yielding

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The dynamic behavior of materials plays a major role in crashworthiness. During a high speed crash event, the material undergoes different strain rates that may affect its constitutive behavior. For instance, in the first milliseconds of such an event, the strain rates near the contact region between the impacting and the impacted areas are extremely high. The strain rate then tends to rapidly decrease as energy is progressively dissipated during the crash. In the case of metallic materials, this means that the material is experiencing a viscoplastic regime under non-constant strain rate. The viscoplastic deformation process causes adiabatic heating at high strain rates where this heating tends to soften the material. At the same time, as the strain rate decreases, the heat caused by plastic deformation is then transferred to the surroundings and therefore the material behaves in a different fashion than at the beginning of the crash. For an accurate description of the material deformation under such conditions, the aspects involving plastic straining and adiabatic heating have to be somehow taken into account if one aims to have relevant simulation results. In this contribution, we address this question by firstly numerically calibrating the viscoplastic behavior for two modern steel alloys using *MAT_224 in fully coupled thermo-mechanical simulations in LS-DYNA. In this manner, we are able to correctly consider the thermal effect associated with the different strain rates. However, coupled thermo-mechanical simulations are unfortunately prohibitive when simulating a full vehicle collision as it would require extremely long simulation times. Therefore, two alternative approaches are assessed in this paper. In the first one, we make use of a pseudo-thermal analysis where the material heating is estimated from the plastic work by using Taylor-Quinney's coefficient in *MAT_224. In the second approach, effective yield curves, which inherently take into account the softening effects of adiabatic heating, are calibrated for classical von Mises plasticity through *MAT_024 in LS-DYNA. A true viscoplastic formulation is also considered here. In this case, the resulting strain rate dependent yield curves may have to cross each other in order to correctly match experimental data under different strain rates. As could be expected, the crossing of yield curves poses an algorithmic challenge which has been further investigated during this work and whose results will be presented. Furthermore, the calibration of such strain rate dependent yield curves is quite difficult using classical extrapolation functions. Therefore, we propose in this contribution an extended version of Hocket-Sherby's extrapolation where strain rate dependent parameters are incorporated. The results show that the newly proposed extrapolation scheme is able to generate dynamic yield curves for *MAT_024 that match experimental data under different strain rates.