A novel calibration procedure of Johnson-Cook damage model parameters for simulation of scratch abrasion

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Scratch abrasion is an abrasive wear mechanism in which a sharp indenting body penetrates and slides through the counter material. The stress state in the vicinity of the indenter is multiaxial and non-proportional and determines the involved damage mechanism. This stress state evolution cannot be investigated experimentally. Hence, the authors investigate scratch abrasion by means of finite element analysis fed with a continuum damage model, which transforms the complex stress trajectory into material degradation and removal. Stress triaxiality is used in the majority of continuum damage models to include effects of the first and second stress tensor invariant (i.e., hydrostatic stress and von Mises stress) on failure strain. The Johnson-Cook (JC) damage model is one such model that has been used to simulate scratch abrasion. However, the failure strain at equal values of triaxiality may differ. Recent damage models such as Bai-Wierzbicki addressed this issue by including the third deviatoric stress tensor invariant (referred to as Lode angle), and showed significant impact on material failure in line with experimental data.

The damage model parameters must be experimentally calibrated in the range of stress state to mimic the damage during scratch abrasion. According to our earlier research, the stress state during scratch mainly involves negative values of triaxiality and Lode angle. However, in literature, damage models are typically calibrated using experiments with positive values of triaxiality and Lode angles, and no calibrations have been reported involving scratch abrasion stress state.

In this work, a novel calibration procedure is developed to calibrate the JC damage model parameter against the experimental scratch response. This method uses a small set of scratch simulations for calibration that are well-chosen based on triaxiality and Lode angle obtained from the plasticity simulations, together with the following criteria: 1. Simulations should cover ploughing, wedging and cutting 2. Simulations should spread across different indenter geometries and load profiles to induce a wide range of stress trajectories. Then, an optimization procedure is used to obtain the appropriate JC damage model parameter by minimizing the error between the experimental and numerical scratch depth responses. Finally, the abrasion results are compared using the obtained JC damage parameter from both the novel and the “typical” calibration procedure.

Keywords: Johnson-Cook damage model, Calibration, Scratch abrasion, Stress triaxiality, Lode angle parameter,

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