Damage modelling of scratch abrasion resistance

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MOTIVATION

In many engineering applications such as dredge equipment, farming tools, mining equipment etc., mechanical components suffer from severe abrasive wear due to the harmful interaction with either hard particles (e.g. dredge pumps) or rough counter surfaces (e.g. gears, mechanical seals). As a consequence, the Total-Cost-of-Ownership (TCO) of such equipment is substantial due to performance decrease over lifetime, maintenance and repair, downtime, outage and failure.

Two-body abrasion refers to the wear encountered by rubbing of softer rough surface over a harder rough surface, while three-body abrasion refers to wear caused by hard particles entrapped between two sliding surfaces.

Scratch abrasion testing is primarily used to rank materials in terms of relative resistance to abrasion, as it serves to experimentally characterize the fundamental damage mechanisms involved. Moreover, it serves as a well-defined and well-controlled setup for exploring modelling techniques for two-body and closed-three body abrasion.

Different damage mechanisms are known to contribute to scratch abrasion. The three major mechanisms for ductile materials are: cutting, wedging and ploughing. Today, (accurate) prediction of the severity and mode of abrasion wear remains a relevant research topic, because the occurrence of, and interaction between, governing mechanisms is highly sensitive to specific operating conditions, materials properties and material failure mechanisms (cutting, wedging, and ploughing). The lack of fundamental understanding of the underlying physics related to material damage hampers a systematic improvement of engineering applications faced with abrasion, at the level of material and/or component design.

OBJECTIVES

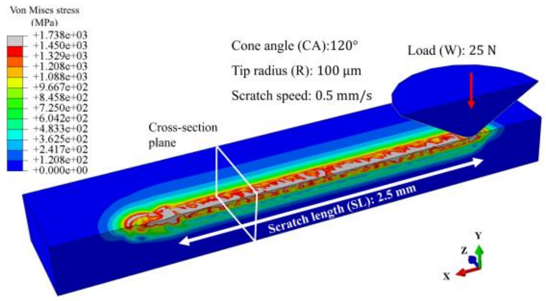

Figure 1: Contour plot of von Mises stress from the numerical simulation.

The project aims to increase the fundamental understanding of scratch abrasion processes by means of Finite Element Simulation in combination with experimental validation, eventually leading to an identification and prioritization of parameters of influence. This aim is subdivided into three concrete objectives:

1. **The first objective** is to develop a comprehensive 3D Finite Element Model of the fundamental scratch abrasion process, taking into account material degradation and potential material removal (Figure 1). Thereto a two-way coupled continuum damage model will be selected which includes Lode angle effects in addition to stress triaxiality effects on material damage (and removal). Model stability and numerical accuracy deserve particular attention.

2. **The second objective** focusses on validation of the developed FE model. This objective comprises two aspects: (a) design and testing of tailored specimen geometries and test procedures to characterize the failure strain for different stress states (shown in Figure 2) which prevail during scratch abrasion.

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Particular attention is given to highly compressive stress states, for which no conventional calibration test routines are available. The resulting failure strain locus will allow for a calibration of the adopted damage model; (b) performing scratch abrasion experiments which can be compared against numerical predictions for validation.

3. **The final objective** is to obtain an enhanced understanding of material parameter(s) governing scratch abrasion resistance to forecast abrasive wear problems. The model should allow to identify the occurrence of different damage mechanisms (cutting, wedging, ploughing, cracking), the parameters involved (related to geometry, load and material), and the corresponding wear rate.

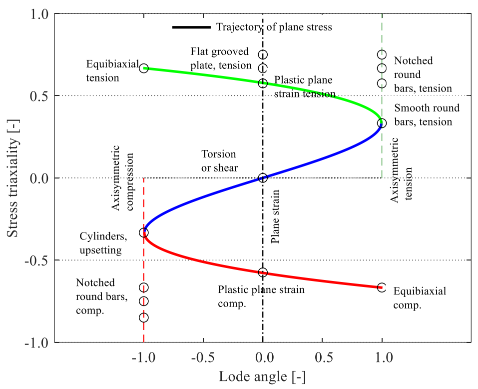

Figure 2: Representation of all experimental configuration in the space of stress triaxiality and Lode angle.

APPROACH

A suitable numerical damage model, including both stress triaxiality and Lode angle, will be used in combination with an explicit integration scheme in ABAQUS/Explicit. This damage model is embedded into a finite element model of a scratch abrasion process, which will be used to explore the involved physics and influences. The developed model is applied to study the effect of stress triaxiality and Lode angle within the damage modelling. Execution of scratch abrasion simulations using the Johnson-Cook model without Lode angle effects (as a reference) and the suitable damage model with Lode angle influence will enable us to understand the importance of Lode angle during scratch abrasion simulations. It has been identified that the stress states during scratch abrasion involve high degrees of compression (associated with stress triaxiality values lower than -0.33). A novel specimen configuration is designed to calibrate the damage model at such compressive stress states. The developed procedure will be used to calibrate of the fracture surface of steels that were selected for this project.

The next step is to finetune and evaluate the ability of the implemented damage model to reproduce different scratch abrasion failure mechanisms (cutting, ploughing, wedging). Based on existing experimental wear maps of Kato et al. which categorize the prevailing micro-mechanism as function of the penetration depth and the interfacial shear strength, at least three cases will be defined which should result in cutting, ploughing and wedging micro-mechanisms. For a given material pair, these distinct cases will be determined by choosing a particular indenter geometry in combination with specific operating conditions. The results obtained for each different mode will be validated against the experimental data obtained from scratch tests at Soete Laboratory.

Finally, a novel analytical scratch abrasion model will be developed, by computational pre-screening the abrasion resistance of different "virtual" materials with distinct mechanical properties. In this task, we attempt to reveal the material parameters which influence scratch abrasion resistance, other than hardness. This is done by creating a "virtual laboratory" in which tensile and toughness tests are simulated. Finite element models representing these tests are already available, yet should be coupled with the material damage model. To accomplish this, we aim to correlate the calibrated damage model parameters to physical properties of the material, with particular attention to stress-strain behaviour and fracture toughness.

Having obtained materials of equal hardness and different other properties, simulating their scratch resistance will reveal which material parameters other than hardness influence scratch abrasion resistance and rank their importance, thus contributing to the final objective.

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