A multi-scale framework towards prediction of the martensite/ferrite interface damage initiation

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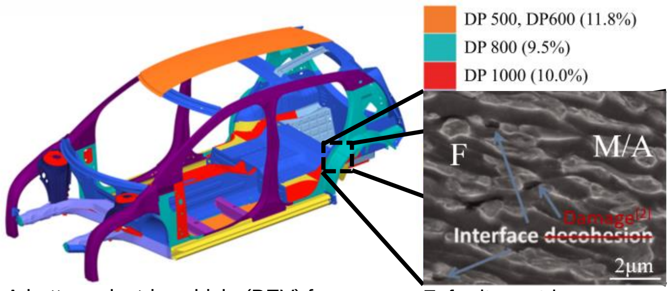
I. Introduction

Background: Martensite/ferrite (M/F) interface damage largely governs the failure of dual-phase (DP) steels, which are among the most attractive advanced multi-phase steels for automotive applications.



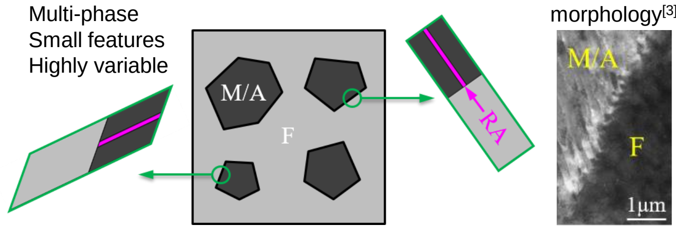
A battery electric vehicle (BEV) frame with >30 wt% made of DP steels[1]

F: ferrite matrix
M/A: martensite island

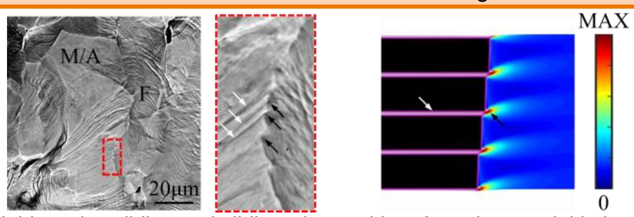
Motivation-1: Direct numerical simulations of DP steel microstructures are **computationally prohibitive**.

M/F interface in general:
- Multi-phase
- Small features
- Highly variable

Interfacial morphology[3]



Motivation-2: Martensite **substructure boundary sliding** mechanism dominates the M/F interface damage initiation.



Highly active sliding and sliding-triggered interface damage initiation, revealed by experiments[4] and simulations[3], respectively

Goal: A multi-scale modelling framework for predicting the M/F interface damage initiation, which takes the **relevant microphysics** into account.

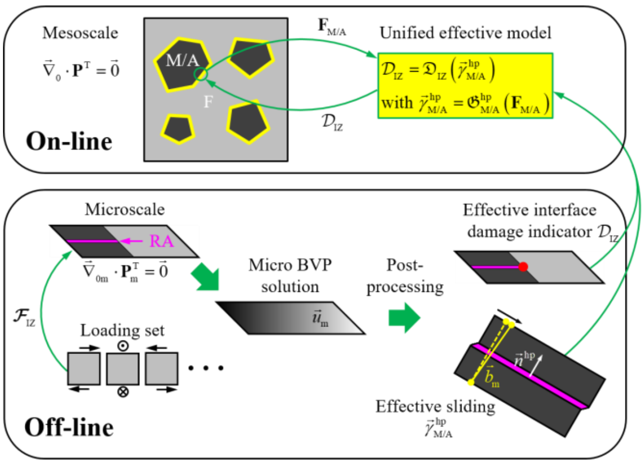
II. Multi-scale framework

Hypothesis-1: **Sliding-triggered** M/F interface damage initiation mode is dominating[3].
Hypothesis-2: Specific M/F interfacial morphology is **secondary** compared to the sliding mechanism[3].

Overview

Off-line:
- Perform interfacial zone unit cell simulations
- Post-process BVP solutions
- Construct **a unified effective interface damage indicator model** by model reduction

On-line:
- Perform simulation on a DP steel mesostructure
- Predict interface damage hot spots

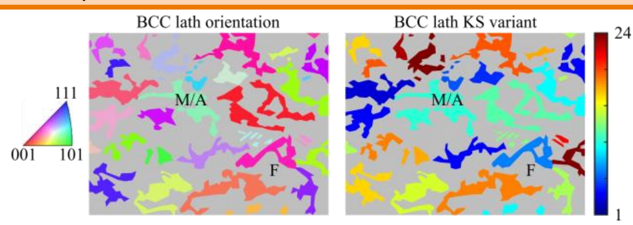


Features
- One reference master damage indicator + two unified geometrical correction functions
- Calibration only **once for a given material**
- Prediction of damage hot spots in one step

$$\mathcal{D}_{IZ} = \mathfrak{D}_{IZ}\left(\bar{\gamma}^{hp}_{M/A}\right) = \int \mathfrak{M}\left(c^{d}_{IZ}\left(\bar{\gamma}^{hp}_{M/A}\right)\right)\mathfrak{M}^{i}\left(f^{d}_{0IZ}\left(\theta^{hp}_{0}\right)\right)\dot{\mathcal{D}}^{i}_{IZ}\left(\theta^{hp}_{0,r}, \bar{\gamma}^{hp}_{M/A}\right)dt$$

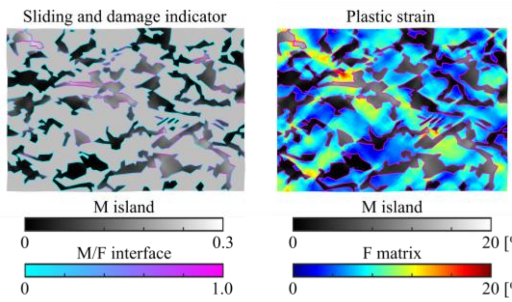
III. Application

Geometry: A DP steel mesostructure with multiple martensite islands embedded in a ferrite matrix.
Materials: Reduced lath martensite model[5] and isotropic elasto-plastic ferrite model.



Interface damage initiation analysis

Hot spots:
- Around martensite islands with high **sliding activity**
- Exact locations also depend on **interface orientation**



An **efficient microphysics-based** approach!

References

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