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Clustered Void Growth in Ductile Metals

Sandia National Laboratories

Timothy D. Kostka

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Early Career R&D Program

Problem

Fracture in ductile metals occurs through the processes of void formation, growth and coalescence. Ultimately, voids grow large enough to join together and fracture occurs.

In order to assess the safety and reliability of components made from stainless steel, we wish to develop a predictive capability to determine material integrity after the component has undergone loading.

Initial imperfections ⟶ Void coalescence ⟶ Material fracture

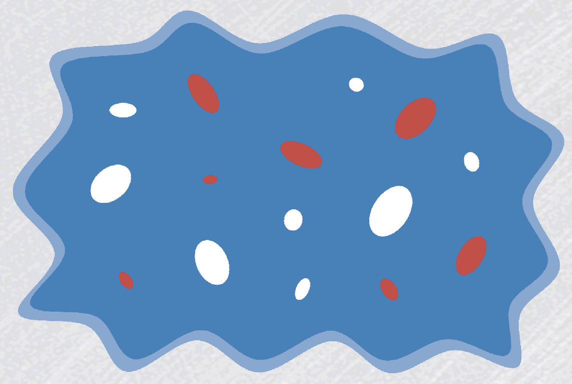

Figure 1: Typical microstructure of after a metal forming operation. Both voids (white) and inclusions (red) are present.

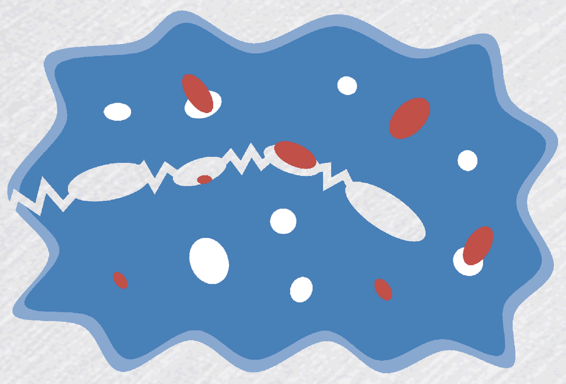

Figure 2: Under loading, nearby voids grow and link up to form the beginning of a fracture surface.

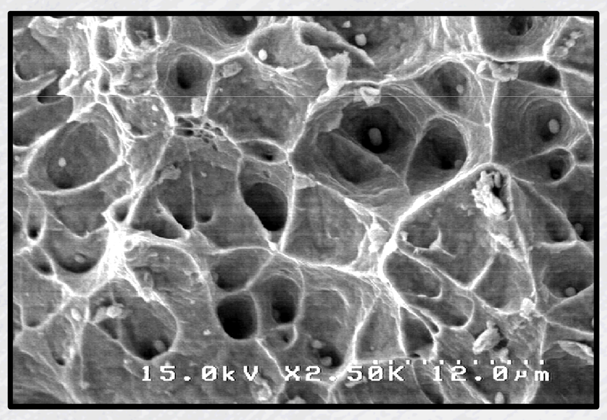

Figure 3: Fracture surface of stainless steel 304L. Inclusions can be seen at the center of the large voids which have coalesced.

Approach

Our approach to this problem is to model discrete voids in a 2D periodic microstructure and observe their behavior in a large deformation plasticity finite element framework.

Periodic microstructure generation

Based on an initial void volume fraction of 3%, a randomized periodic microstructure is generated. After choosing a unit cell, the geometry is meshed such that nodes on opposite sides exactly match each other. The software program internally ties the two sides together in a seamless fashion.

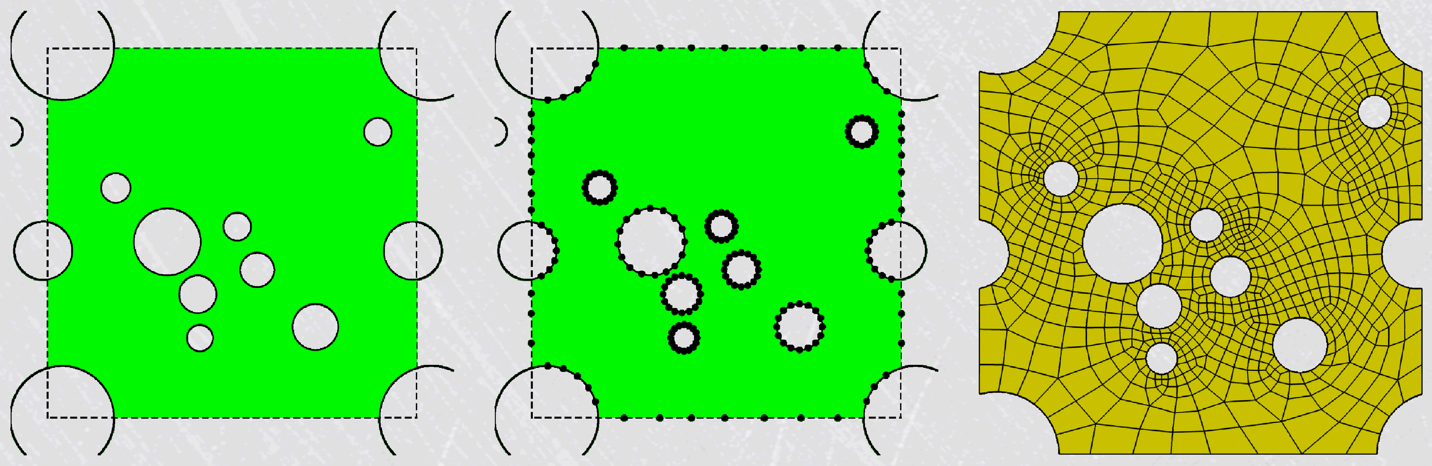

Figure 4: After an initial periodic microstructure of voids is generated (left), boundary nodes are placed (middle) and the final unit cell mesh is then created (right).

Finite element formulation

Standard linear elements do not efficiently capture the material response in this regime. Therefore, we have implemented a quadratic element formulation as shown in Figure 5. These elements have been shown to be over an order of magnitude more efficient than more common formulations.

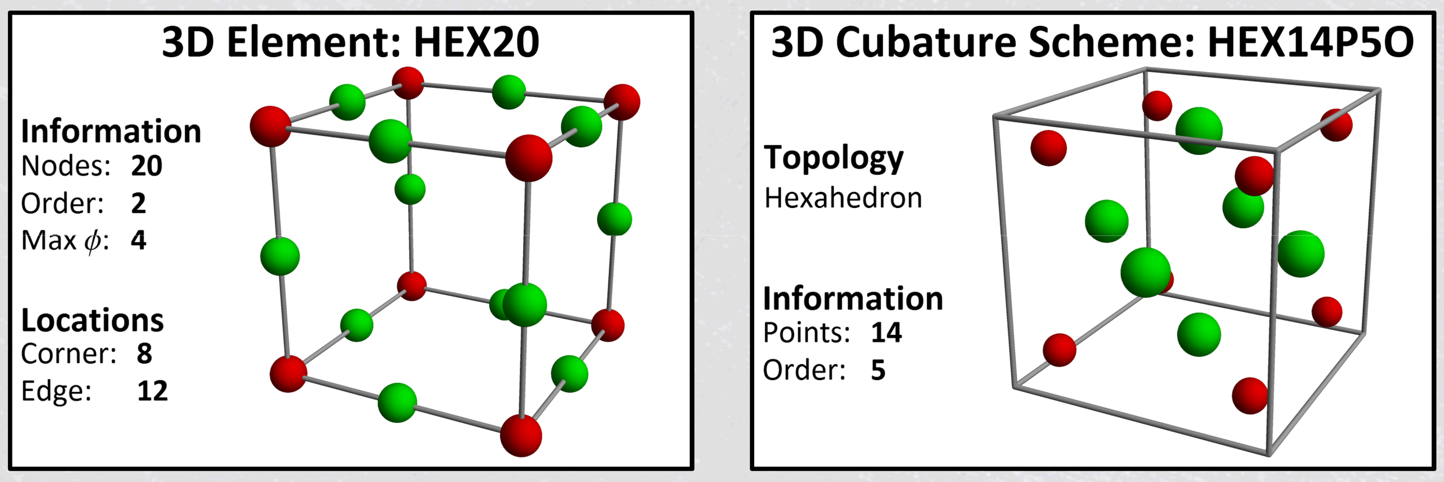

Figure 5: Nodal locations (left) and cubature points (right) of the quadratic 20 noded hexahedral element and corresponding 14 point, 5th order integration scheme used in this analysis.

Results

In a set of 32 randomly generated microstructures, we tracked the load bearing capacity of the material over a range of deformation. The general behavior is shown in Figure 6.

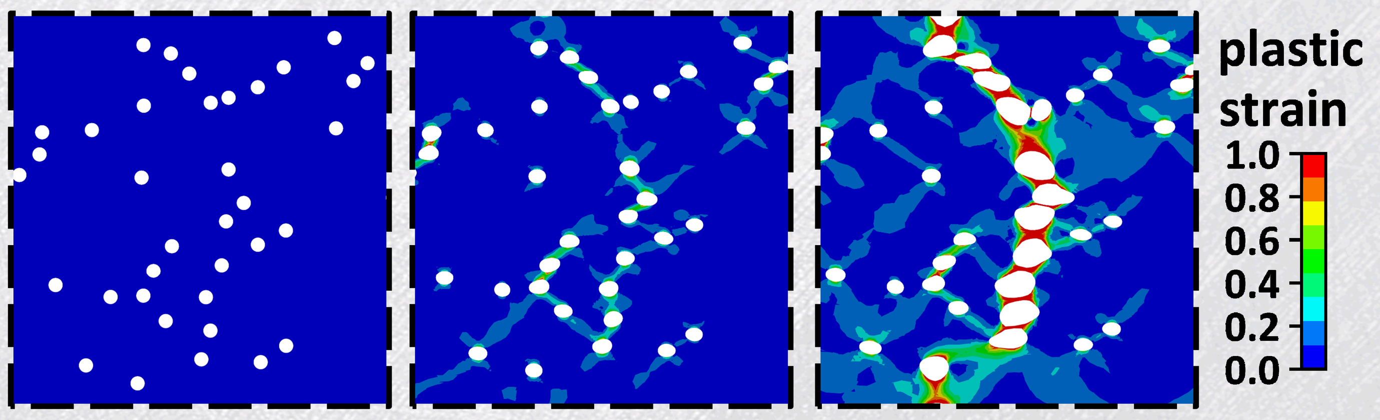

Figure 6: The evolution of void coalescence from an initial configuration (left), to an intermediate state (middle), to the formation of a fracture surface (right).

The material response was tracked to get a 95% confidence level of the onset of necking (Figure 7). This is the point at which the material can no longer safely support further loading.

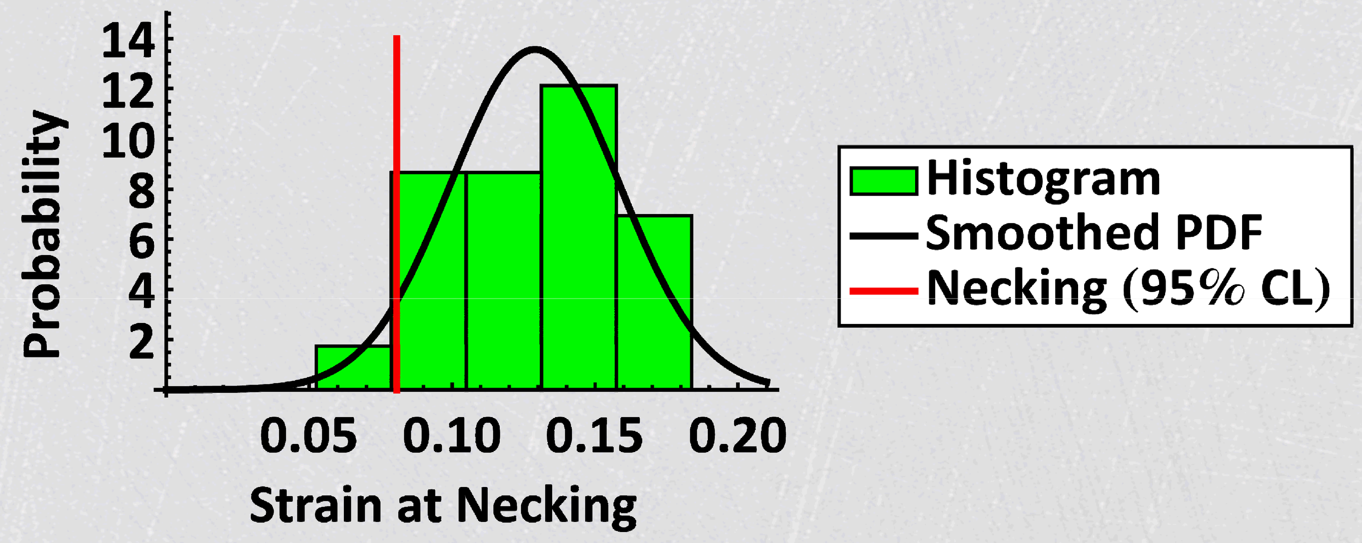

Figure 7: The distribution of necking strains from a 3% initial void volume fraction. The red line indicates the strain at which the material is 5% likely to be in necking.

Significance

The ability to model ductile fracture is of critical importance to Sandia's mission to ensure the safety and reliability of the U.S. nuclear weapon stockpile.

The results of this work will aid in the development of advanced void growth laws for use in modeling fracture in ductile metals to support Sandia's mission.

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