Many metals and alloys, e.g. cast aluminum alloys contain microstructural heterogeneities in form of silicon particulates, intermetallics, precipitates and voids. Experimental studies on ductile failure in have shown that these morphological variations strongly affect microstructural damage nucleation due to particulate cracking and interfacial decohesion, as well as ductile damage growth by matrix rupture due to void growth and coalescence. Modeling these materials requires consideration of large domains with special attention on the microstructural morphology. The concept of multi-scale modeling provides the necessary framework for selective micro-analysis in a very limited region of a macroscopic computational domain. The multiscale models undergo domain partitioning based on the evolution of stresses, strains and/or damage in the microstructure. This presentation will discuss four important ingredients of multi-scale modeling of ductile failure in heterogeneous cast aluminum alloys. These include: (i) a multi-scale characterization based preprocessor for multi-scale models; (ii) microstructural analysis module for ductile fracture; (iii) a homogenization based continuum damage model for ductile materials that can be used in macroscopic analysis modules and (iv) a multi-scale framework for ductile crack propagation.

In a concurrent multi-scale model, it is prudent to partition the initial computational domain based on information of the underlying microstructure, prior to mechanical analysis. The morphology-based domain partitioning (MDP), as a preprocessor to multiscale modeling, is intended for two reasons: (1) to determine microstructural RVE's that can be used in the "bottom-up" homogenization for different regions in the computational domain; and (2) to identify those regions, where the morphology alone can cause a breakdown in the homogenization assumption. For effective micro-mechanical modeling, the Voronoi Cell FEM model will be discussed. The model will account for particle fragmentation in the microstructure and ductile failure through matrix cracking in the form of void growth and coalescence. An adaptive, locally enriched VCFEM or LE-VCFEM framework is developed for simulating ductile fracture in narrow bands of localized plastic flow and void growth. An anisotropic continuum damage model for pressure dependent plastic materials is developed for macroscopic analysis in a multi-scale material modeling framework. The model is based on homogenization of microstructural variables obtained by LE-VCFEM analysis of microstructural representative volume element (RVE) containing particles, matrix and voids. Finally, all of the above modules will be integrated in an adaptive concurrent multi-scale framework to model the entire evolution of a ductile crack.