

# Analysis of thermo-mechanical processes and design sensitivities evaluation using an Eulerian formulation and application in welding

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## Abstract

A systematic design approach has been developed for solving quasi-state three-dimensional thermo-mechanical material processes using finite element methods. The thermo-mechanical processes considered are governed by one-way coupled thermo-elasto-plastic response. The quasi-state thermal problem is solved first using an Eulerian formulation, where the heat flux is fixed in space and the material flows through a control volume. For constant velocity and heat flux distribution, the Eulerian formulation reduces to a steady state problem, whereas the Lagrangian formulation remains transient. Streamline Upwinding Petrov Galerkin stabilization is employed to suppress the spurious oscillations occurring due to the nature of the Eulerian formulation for the thermal problem. The quasi-state non-linear mechanical problem is then solved using an Eulerian formulation importing the results of the thermal problem. The mechanical problem can be analyzed in two ways, one way being streamline analysis, where the displacement field is the unknown field which is solved. The constitutive equations are solved by integrating along the streamline to yield the plastic strains. The problem can also be analyzed using mixed formulation, where the unknown fields are displacements, plastic strains and equivalent plastic strain. In the mixed formulation, the constitutive equations and the equilibrium equations are solved simultaneously. The two different methods of analysis are then compared. In order to solve the thermo-mechanical process in the Eulerian configuration, the constitutive equations and the initial and boundary conditions are mapped onto the Eulerian configuration and the system of equations is solved using the Newton-Raphson scheme. The design sensitivities are then computed for both the thermal and mechanical analysis, using the direct differentiation approach.