Hot Tap Heat Transfer

Joining steel with a weld is an age-old practice. Welding onto a steel pipeline pressurized with a highly combustible hydrocarbon mixture, however, is an entirely different beast. This process, known as hot tapping, can be both incredibly dangerous and necessary. Thus, assessing the safety of a given hot tap welding procedure beforehand is a valuable service.

This assessment necessitates an accurate thermal model of the welding process. As an example, suppose we consider the case in which a repair sleeve is welded onto a pressurized pipe filled with a hot process fluid. If we represent this configuration as an axisymmetric geometry with a horizontal axis of rotation, we can visualize one circumferential weld as in Figure 1. With this geometry, we can model the thermal history resulting from a weld pass using the finite element method to solve the heat equation with a time-dependent heat source representing the weld pass.

Suppose you are given the density of steel ρ, the specific heat capacity of steel c_P, the thermal conductivity of steel k, the time-dependent source term representing the heat imparted by the weld $f(x,t)$, the heat transfer coefficient and ambient reference temperature (h_{ambient} and T_{ambient}, respectively) corresponding to G-Ambient, the heat transfer coefficient and process fluid temperature (h_{process} and T_{process}, respectively) corresponding to G-Process, and the geometry in Figure 1. Assuming Neumann boundary conditions, setup and solve this heat transfer problem in Python using the FEniCS finite element package for $0 \leq t \leq 10$ seconds. For the purpose of simplifying the finite element model of the weld pass, also assume the following:

1) The weld cross section corresponds to the triangular region in Figure 1, which is assumed to be an isosceles right triangle. We denote this region as $\mathcal{W}$.
2) The heat source is sinusoidal in time, uniform within $\mathcal{W}$, and zero everywhere else. More specifically, assume that $f(x,t) = 2700 \cdot \frac{1}{2}\left(1 + \cos((t+5)(\pi/5))\right)$ BTU/s-in$^3, \forall x \in \mathcal{W}$ and $f(x,t) = 0$ BTU/s-in$^3, \forall x \notin \mathcal{W}$.
3) The process fluid has a constant temperature and a constant heat transfer coefficient. More specifically, assume that $T_{\text{process}} = 325°$F and $h_{\text{process}} = 48.0$ BTU/hr-ft^2-F.
4) The ambient atmosphere has a constant bulk temperature and a constant heat transfer coefficient. More specifically, assume that $T_{\text{ambient}} = 70°$F and $h_{\text{ambient}} = 9.0$ BTU/hr-ft^2-F.
5) Boundaries indicated by G-Insulated are insulated.
6) The geometry is characterized by the dimensions in Figure 1. Specifically, assume that t-sleeve = t-wall = 0.188 in, L-wall = 1.5 · L-sleeve, L-sleeve = 10 · t-wall, and t-gap = 0.02 in.
7) The material properties are constant. More specifically, assume that $\rho = 0.284$ lb/in^3, $c_P = 0.119$ BTU/lb-F, and $k = 31.95$ BTU/hr-ft-F

Create a GitHub repository for your solution, and share the link.

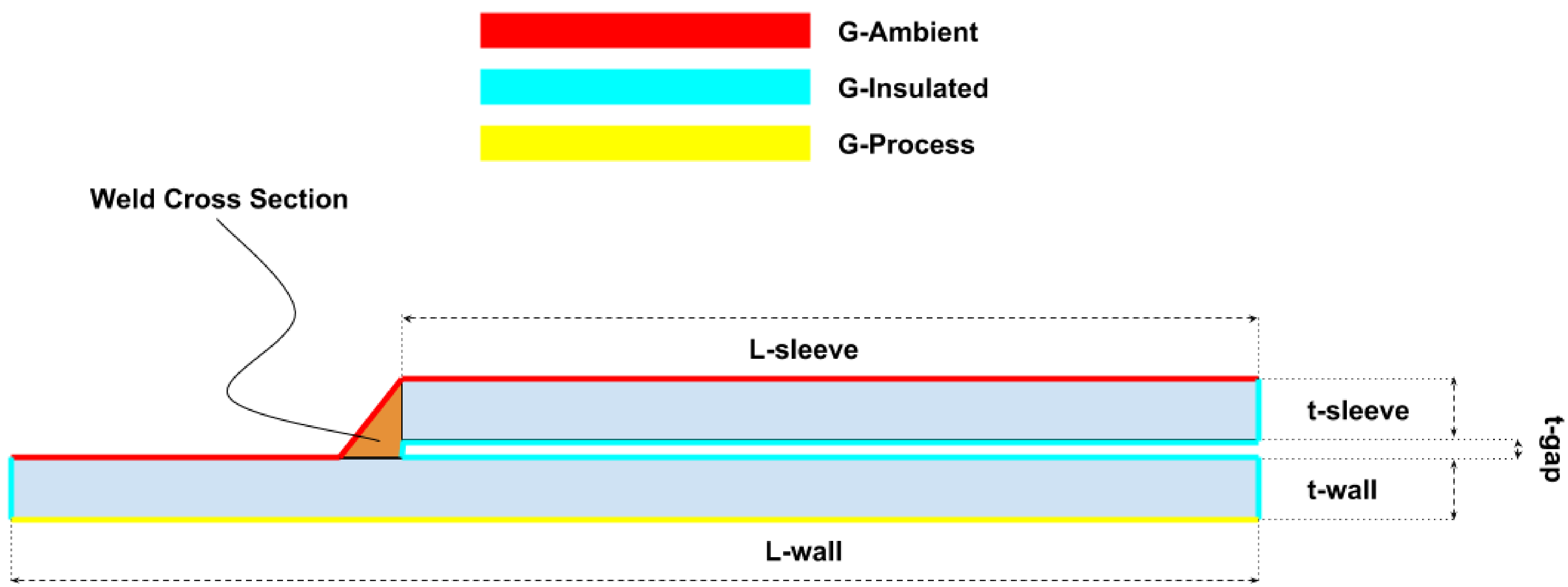

Figure 1: Illustration of the axisymmetric sleeve geometry.