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THERMO-MECHANICAL MODELING OF MULTI-PASS WELDING AND METAL DEPOSITION PROCESSES

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ABSTRACT

The aim of this work is to describe the formulation adopted for the numerical simulation of the Metal Deposition process (MD). MD process consists of a manufacturing technology similar to the multi-pass welding used for building features such as bosses and flanges on fabricated components. Temperature evolution as well as residual stresses and distortions due to the successive welding layers are accurately studied coupling the heat transfer analysis together with the mechanical field. A fully coupled thermo-mechanical solution is considered including phase-change phenomena defined in terms of latent heat release and shrinkage effects. The material behaviour is characterized by a thermo-elasto-viscoplastic constitutive model (at macro-level) coupled with a metallurgical model (at micro-level). Nickel alloy (INCONEL-718) is the target material of this work. Both heat convection and heat radiation models are introduced to dissipate heat through the boundaries.

An in-house developed coupled FE software was the starting point to deal with the simulation and an ad-hoc activation methodology has been implemented to simulate the deposition of the different layers of melted material. Thermo-mechanical results are presented in terms of temperature evolution, residual stresses generated and prediction of the final shape. Difficulties and simplifying hypotheses are discussed.

The numerical simulation of the MD process is based on an *ad-hoc FE activation technology* able to switch on the elements placed along the welding path according to the welding process defined by the user. A control volume is defined by the cross section specified by the user and the movement in the welding direction according to the welding speed and the current time-step. A searching technique looks for all the elements included in such volume ready to be activated. These elements are added to the model and a new matrix profile is computed.

The mechanical model for the welding material is formulated taking into account features such as the thermal shrinkage occurring during the phase-change, a smooth transition from the liquid-like to a solid-like behavior and the incompressibility constraint behavior when the material is still liquid, among others. To deal with these complex phenomena the mechanical model uses a mixed variational formulation proposed with linear displacements and pressure interpolations, leading to robust simplex elements suitable for large-scale industrial computations. An orthogonal sub-grid scale approach is assumed as an attractive alternative to circumvent the Babuska-Brezzi stability condition.

The constitutive equations of the mechanical model are consistently derived from a thermo-elasto-viscoplastic potential where both isotropic and kinematic hardening have been taken into account. Material properties are assumed to be temperature dependent. It must be pointed out that the yield-surface radio, as well as the hardening effect, gradually reduce as the temperature increases, vanishing when liquidus temperature is reached. As a result, a purely viscous Norton model is assumed when liquid-like behavior must be simulated.

A benchmark simulation of a MD-joint between two tubes with a diameter of 114.5 [mm] and a thickness of 6[mm] has been carried out comparing 2D-axisymmetric, 2D-plane-strain, 3D and finally MD process simulations. The MD simulation is defined considering 3 different welding speeds of 80, 800and 8000 [mm/min], showing the importance of a MD simulation when the welding speed is low.

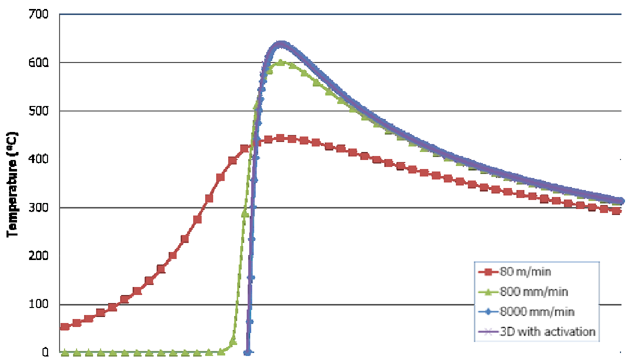

Figure 1: Temperature evolution according to the different welding speeds 80, 800 and 8000[mm/min]

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