3-D CONTACT ALGORITHM FOR THERMOMECHANICAL ANALYSES OF CASTING PROCESSES

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This paper presents a new 3-D contact algorithm suitable for the fully coupled thermomechanical simulation of casting processes of industrial metal parts. In order to predict accurate temperature evaluation, residual stresses and dimensional stability of cast parts, it is crucial to implement a strong coupling between contact and heat transfer calculation in the thermomechanical casting simulation software CASTS.

Firstly, this paper focuses on a model to describe the heat transfer between mould and casting as local function of either gap or contact pressure. In presence of gap formation, the heat transfer can be split in two components: one arising from radiation, the other one from gaseous heat conduction. As the forming gap is very small, the metal and mould surfaces are assumed to be locally plane and parallel, leading to a simple expression for the radiative heat transfer coefficient. The conductive one depends on the gas thermal conductivity, the gap itself and the mean free path of the gas molecules. In the contact case, a power law is adopted which leads to a smooth transition between contact and gap situation.

Secondly, frictionless normal contact has been modeled between two deformable 3-D bodies, e.g. mould and cast part, undergoing small deformations. The developed algorithm is based on the classical master/slave concept. To impose the non-penetration of a slave node into the master surface, a penalty regularization suitable for solidification processes is implemented. The penalty factor is a function of the temperature dependent elasticity of both contacting materials in order to have small contact forces at temperatures near solidus. This factor is also slightly increased at each Newton-Raphson iteration to enforce accurately non-penetration. Further specificities of the developed contact algorithm are the description of the master surface by macro-planes and the closest point projection algorithm. In order to reduce the master surface faceting due to tetrahedral enmeshment, macro-planes are introduced. These planes have the particularity that their normal varies continuously near wedges in order to ensure contact surface smoothness. For thin cast parts, the updating of the master surface is limited by the thinnest wall, thus leading to smaller increments. Usually, after closest point projection, a contact element is generated for the plane having the smallest gap. But, if the projection leads in an unreachable domain, the nearest master node is adopted as projection point and contact elements are generated for all planes to which this node belongs to. In the special case where several master points have the same distance from a slave node, the master point with the greatest number of connecting planes is selected.

To simulate casting processes, specific features have been introduced in the contact algorithm:

- the mould surface is specified as master and the casting one as slave;
- as long as metal is liquid, tied contact between metal and liquid is assumed. The master/slave algorithm is activated for a slave node only if all connecting metal nodes are solidified;
- at the beginning of the solidification, small solidified parts are surrounded by liquid metal. In this case, to avoid numerical instabilities, the penalty formulation is extended so that some residual values exist for small clearances. This is equivalent to introduce a local artificial damping.

The developed contact algorithm is first validated with pure mechanical benchmarks: Crisfield patch test, Hertz problem. Then, the strong thermomechanical coupling is assessed for a turbine blade whose mould is subjected to an imposed heating/cooling cycle. Finally, the shrinkage during solidification of a complex aeronautical part realized by investment casting is predicted and compared with experimental measurements of the final shape.