Thermo-mechanical simulation of continuous casting processes

CALCOM SA has gained a lot of expertise in the thermo-mechanical modelling of continuous casting processes, e.g. the vertical direct chill (VDC) casting of aluminium billets and slabs or horizontal direct chill (HDC) casting of magnesium. In addition to thermo-mecanical aspects such as the development of butt curl and rolling faces pull-in, the determination of cooling characteristics and the prediction of hot tearing sensitivity has also been treated successfully.

Aluminium rolling sheet ingot.

butt-curl

rolling face pull-in

cooling characteristics

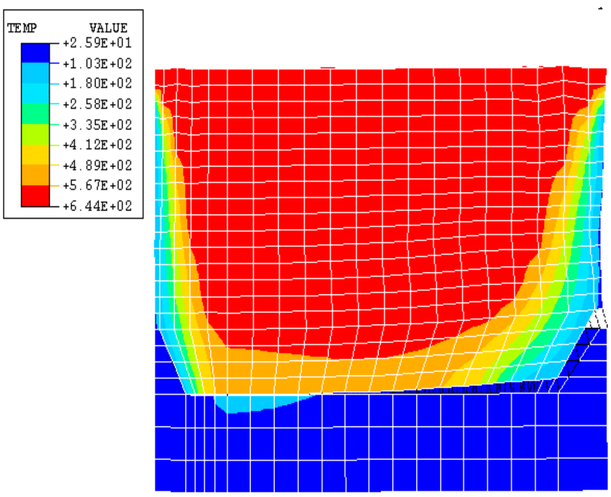
hot tearing

user interface

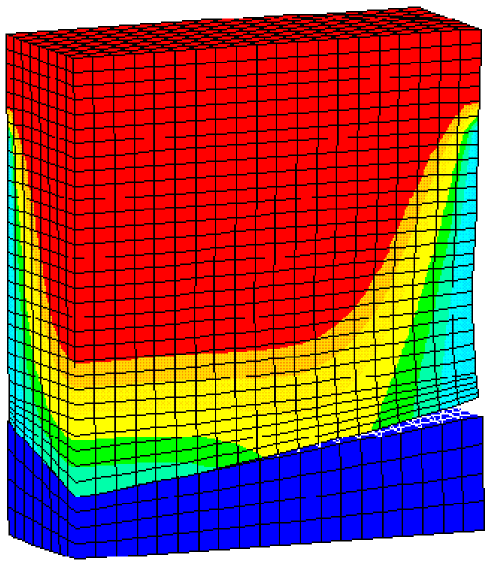
calcom

Computation of butt-curl during start-up

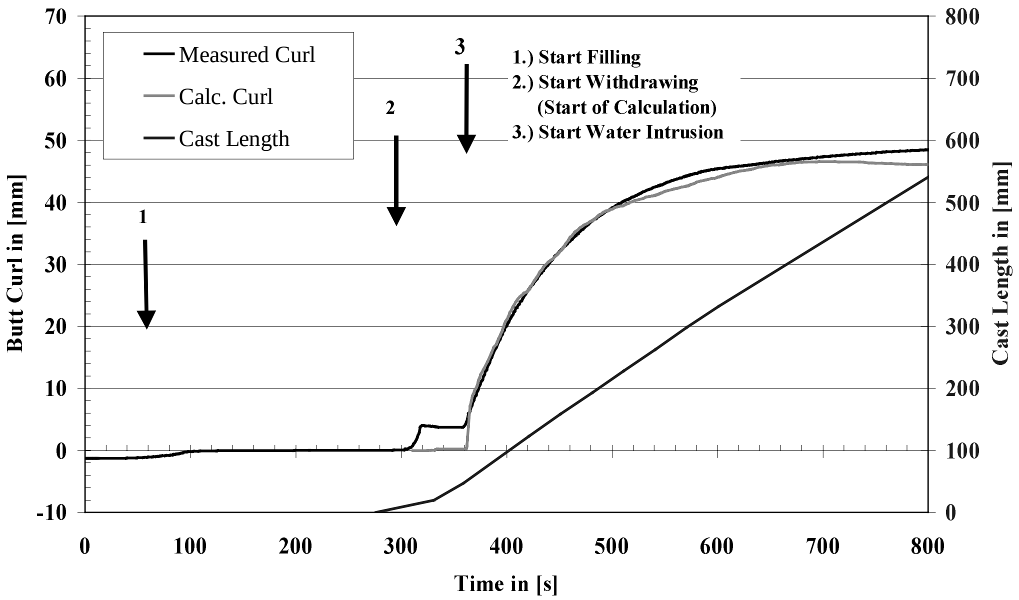
Transient models built in ABAQUS allow to compute the stress build-up and associated ingot deformations such as butt-curl during the start-up phase. Precise bottom block geometries and casting recipes are taken into account. A space and time-dependent heat conductance between the dummy block and the ingot butt is used to properly model the water intrusion.



Butt-curl development obtained with a classic bowl shaped bottom block



Butt-curl development obtained with an almost flat bottom block



Comparison with measured butt-curl (courtesy VAW aluminium AG)

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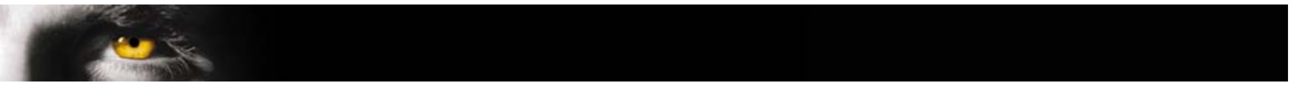
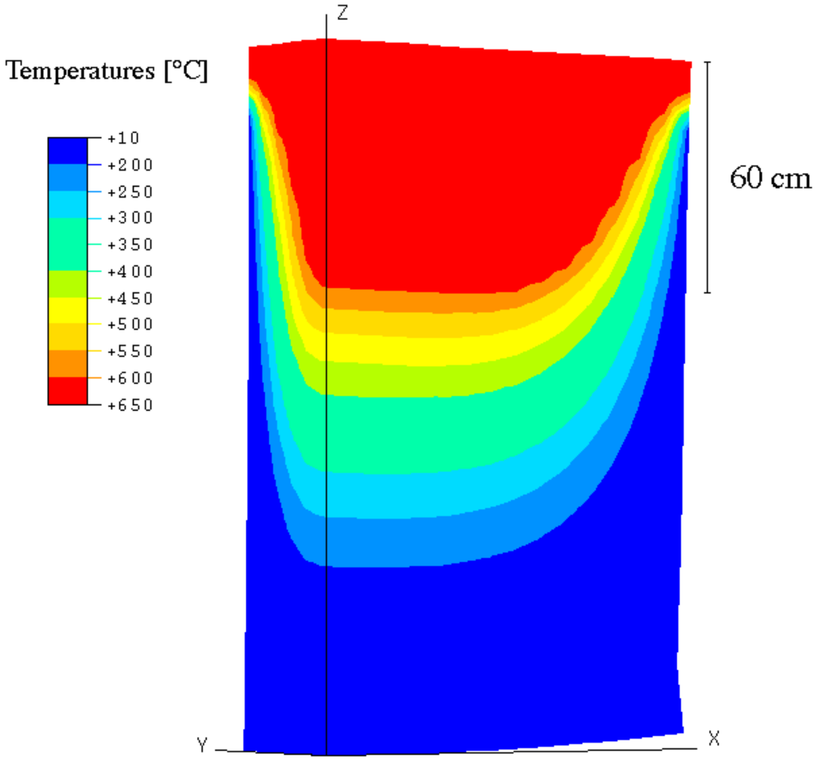


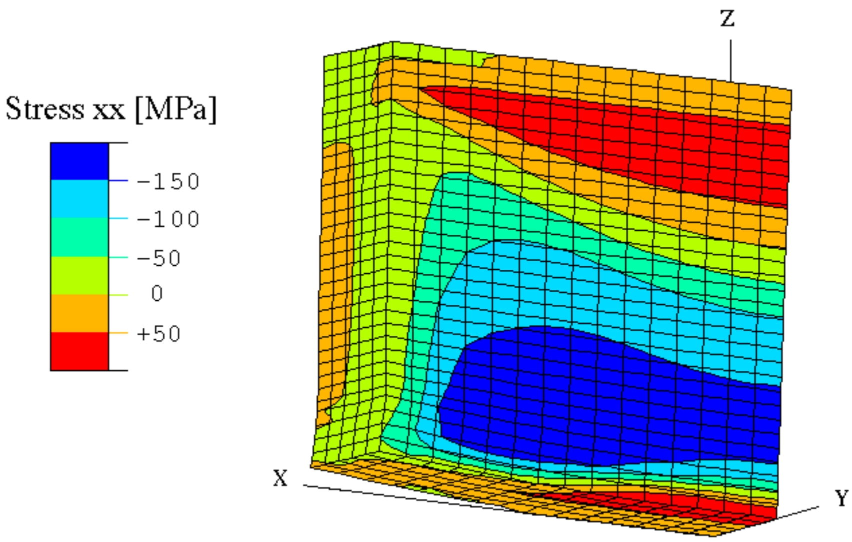
Rolling faces pull-in in sheet ingots

A thermo-mechanical model built in ABAQUS is used to compute the rolling faces pull-in the steady state regime for a given mould design, alloy and casting recipe (casting speed, cooling characteristics,...). This model is particularly helpful in designing or optimising the mould opening in order to get ingots as flat as desired.

Many quantities are obtained with the thermo-mechanical model, such as the thermal field and the deformation, stress and strain fields.



Temperature field in the steady state regime of casting (one fourth of the slab).



xx stress component in the steady state regime of casting (skin view).

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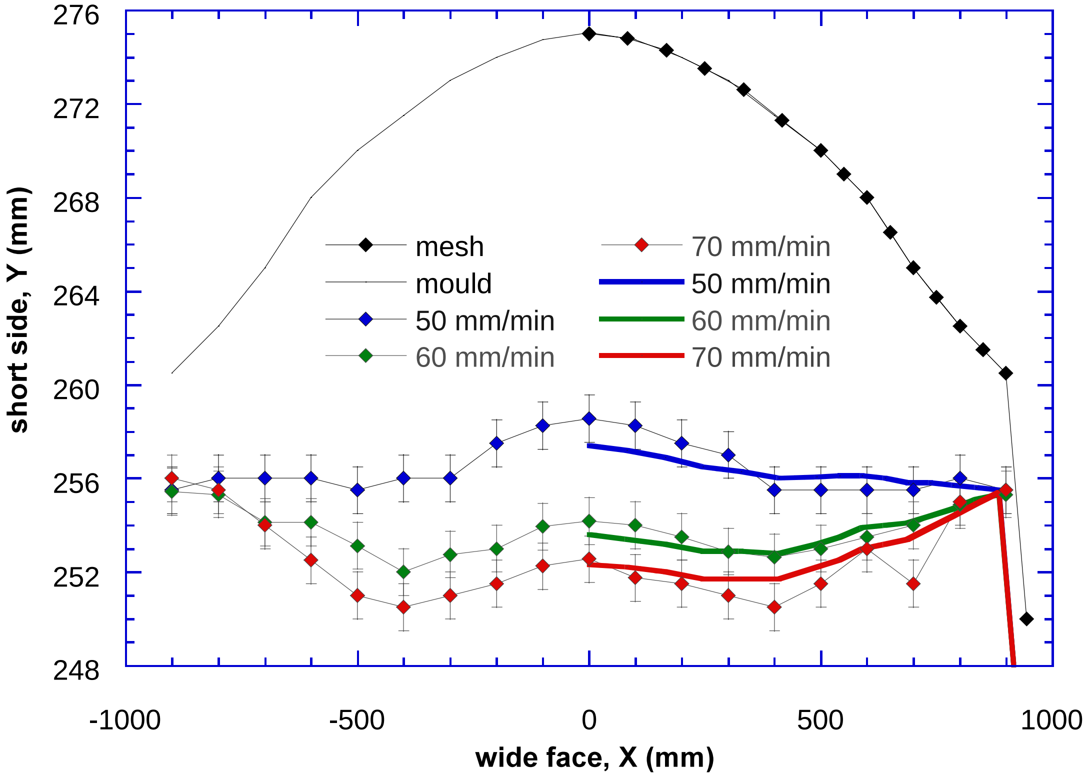
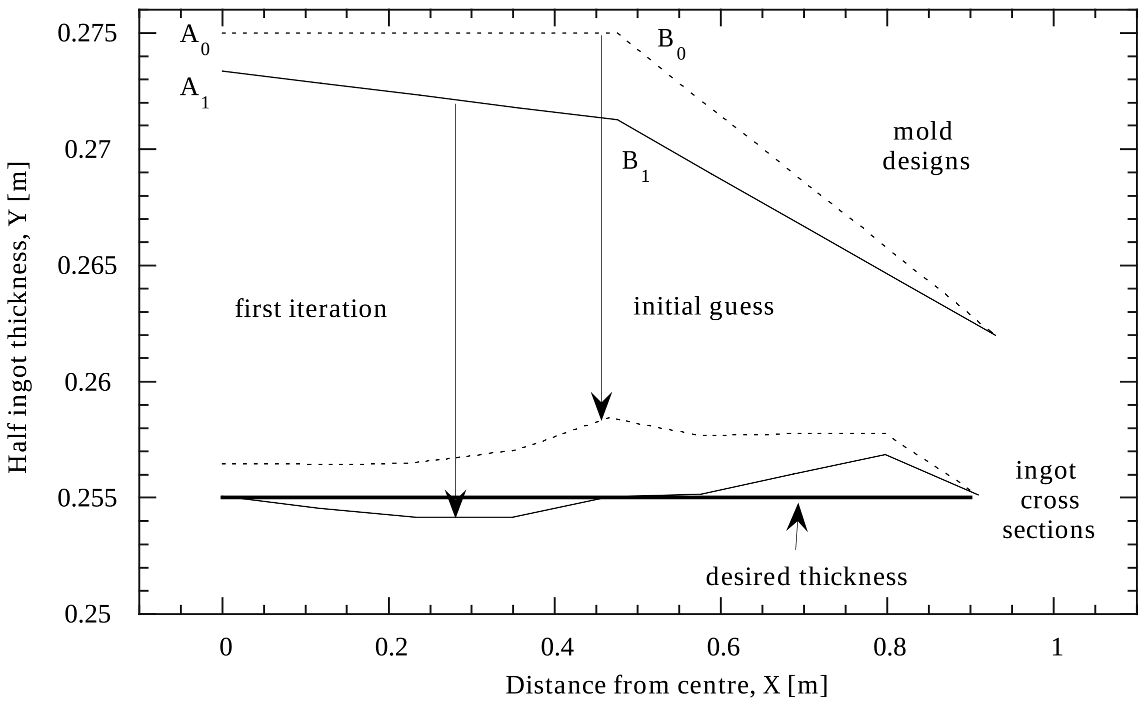


Computed and measured ingot cross sections for three casting speeds



Optimisation of a segmented mould design

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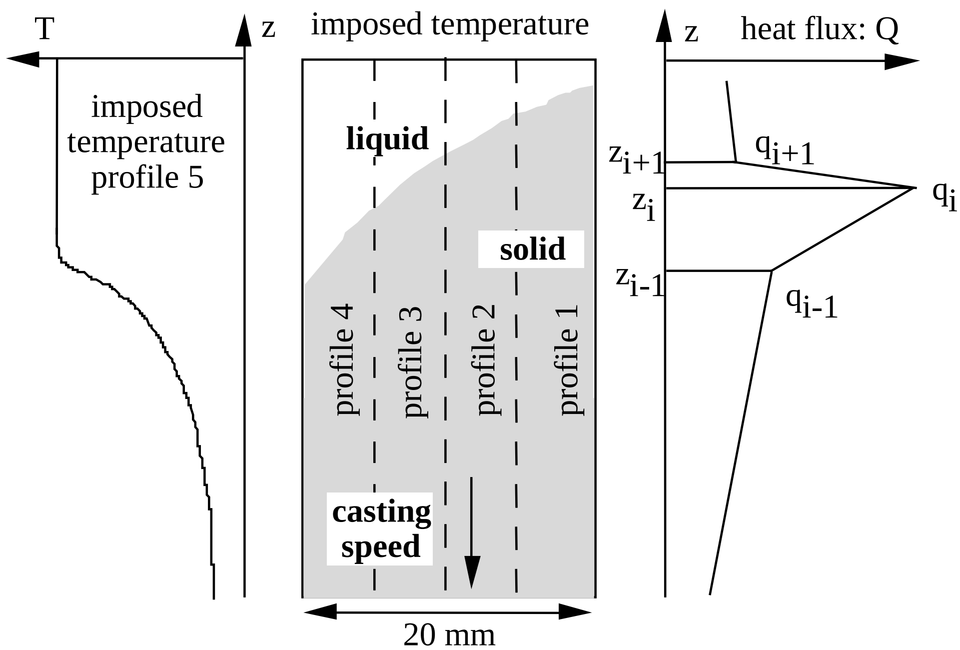
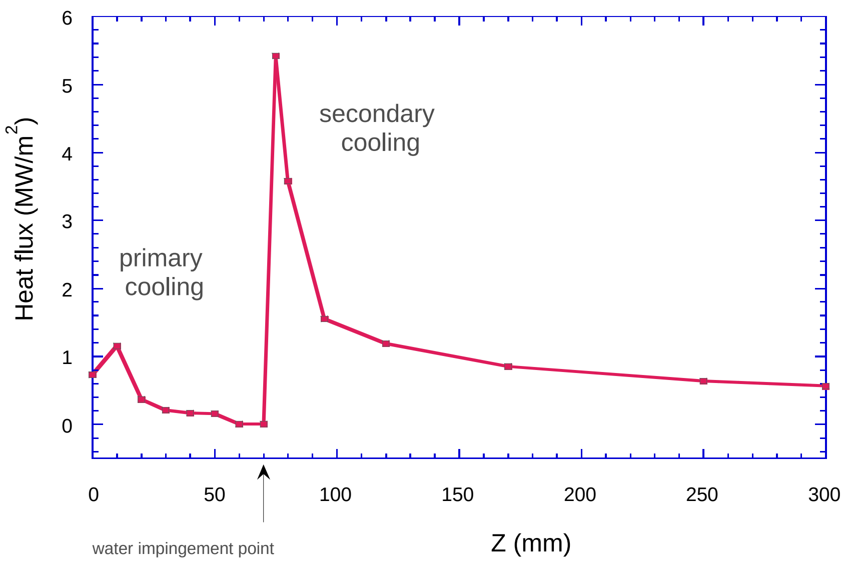
Computation of the cooling characteristics

The thermal conditions typical of the casting process such as primary and secondary cooling can be determined by the use of an inverse method associated with temperature measurements (Calco*Soft*2D inverse module). This allows to define the boundary conditions to be used in the thermo-mechanical models.



Principle of the inverse steady state method

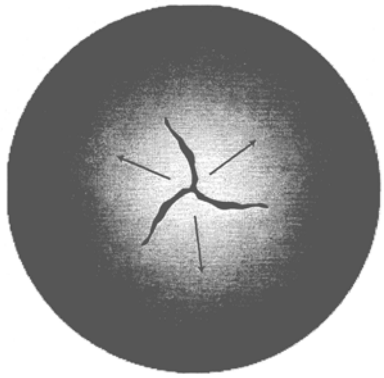


Distribution of the heat flux along the ingot surface

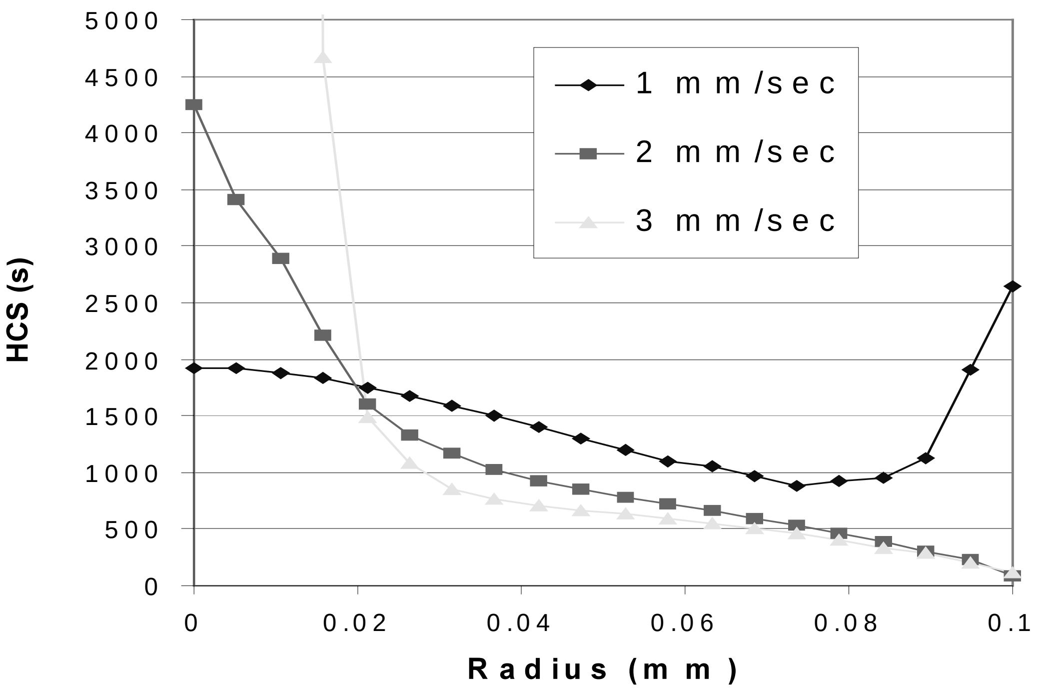
Prediction of hot tears in billets and sheet ingots

The thermal and mechanical Rappaz-Drezet-Gremaud (RDG) hot tearing criterion have been implemented in CalcoSoft and in Abaqus, respectively. This allows to predict the location sensitive to hot cracking.

casting of extrusion billets



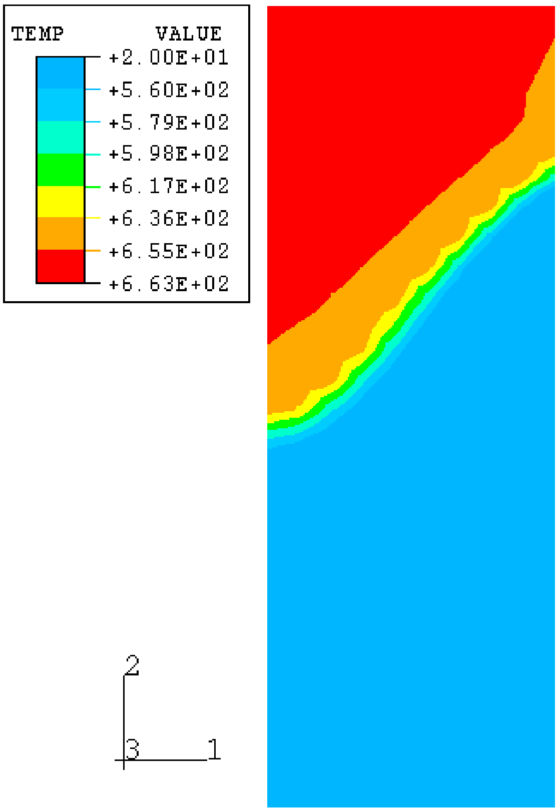
typical centre crack found in extrusion billets



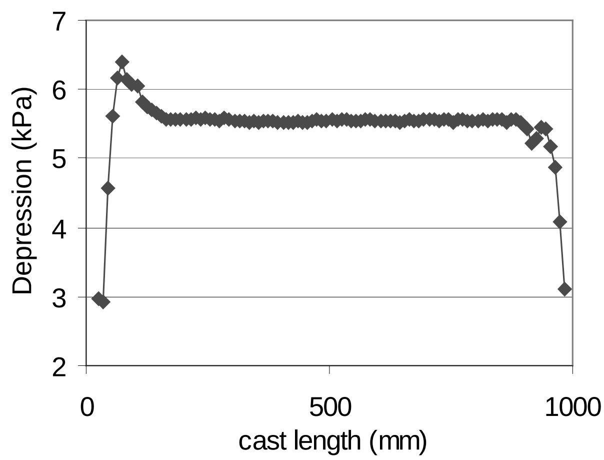
Hot tearing susceptibility as a function of the casting speed (CalcoSOFT2D)

The mechanical RDG hot tearing criterion coupled with thermo-mechanical calculations has been implemented in Abaqus.

3D view of the computed depression in the mush



sump profile in steady state regime



depression in the mush as a function of cast length

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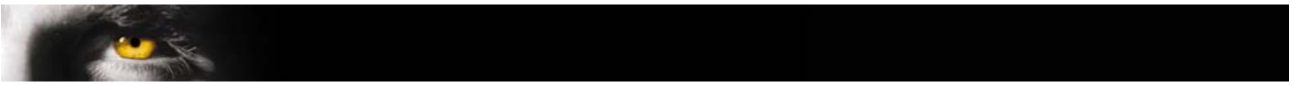
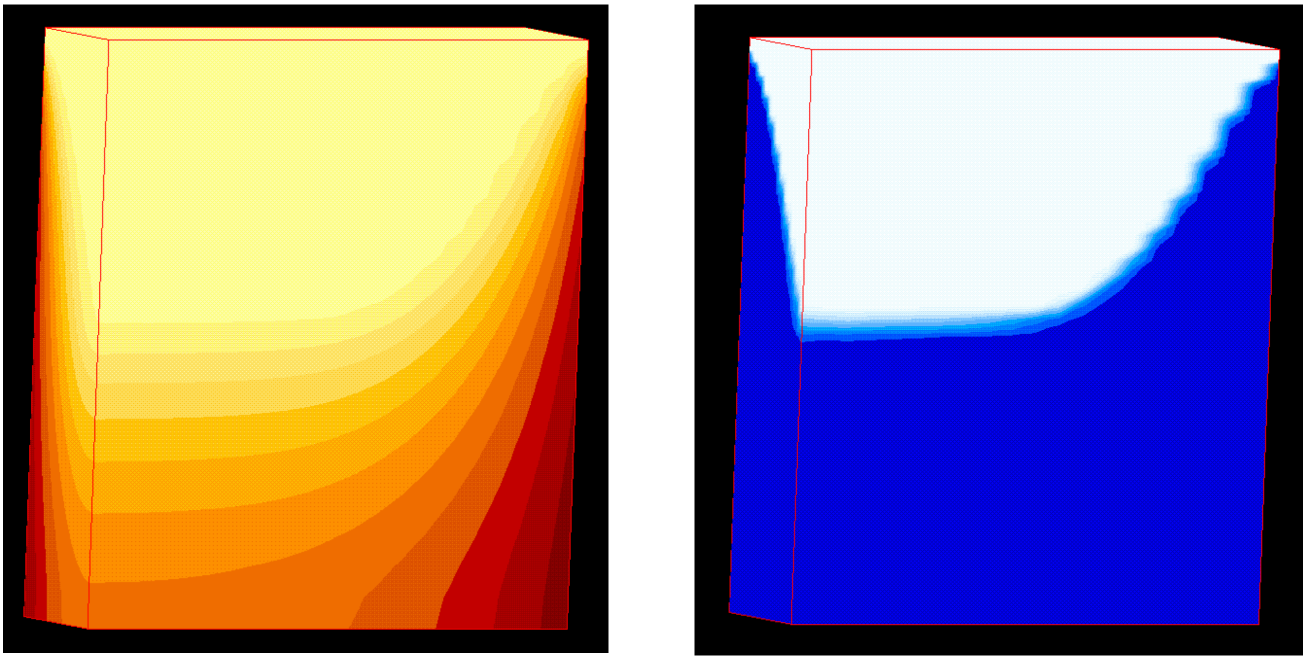
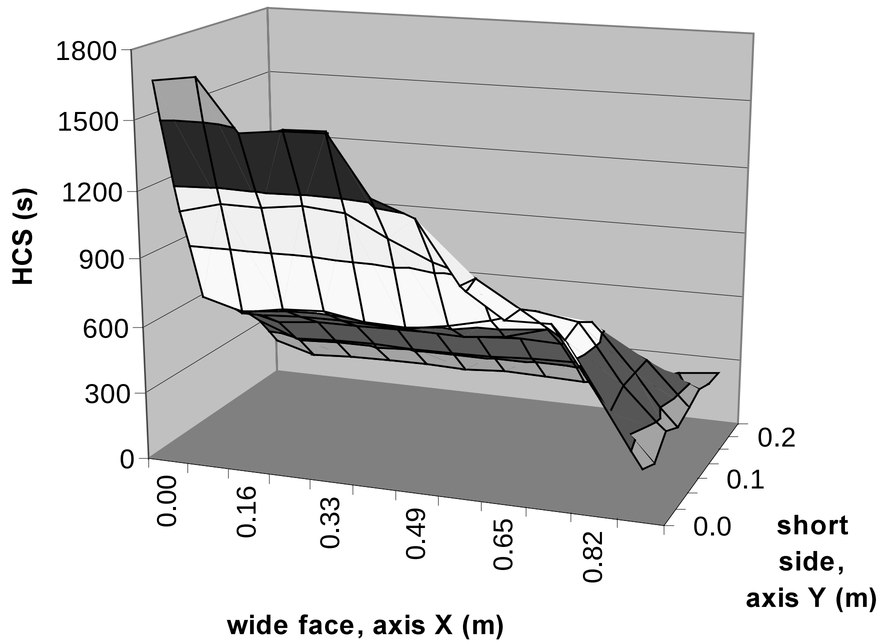


The thermal RDG hot tearing criterion has been implemented in CalcoSOFT3D to study the appearance of cracks in rolling sheet ingots.



Steady state thermal field (left) and solid fraction (right) in a slab (CalcoSOFT3D).



3D view of the Hot Cracking Sensitivity computed for a slab: the centre is very sensitive.

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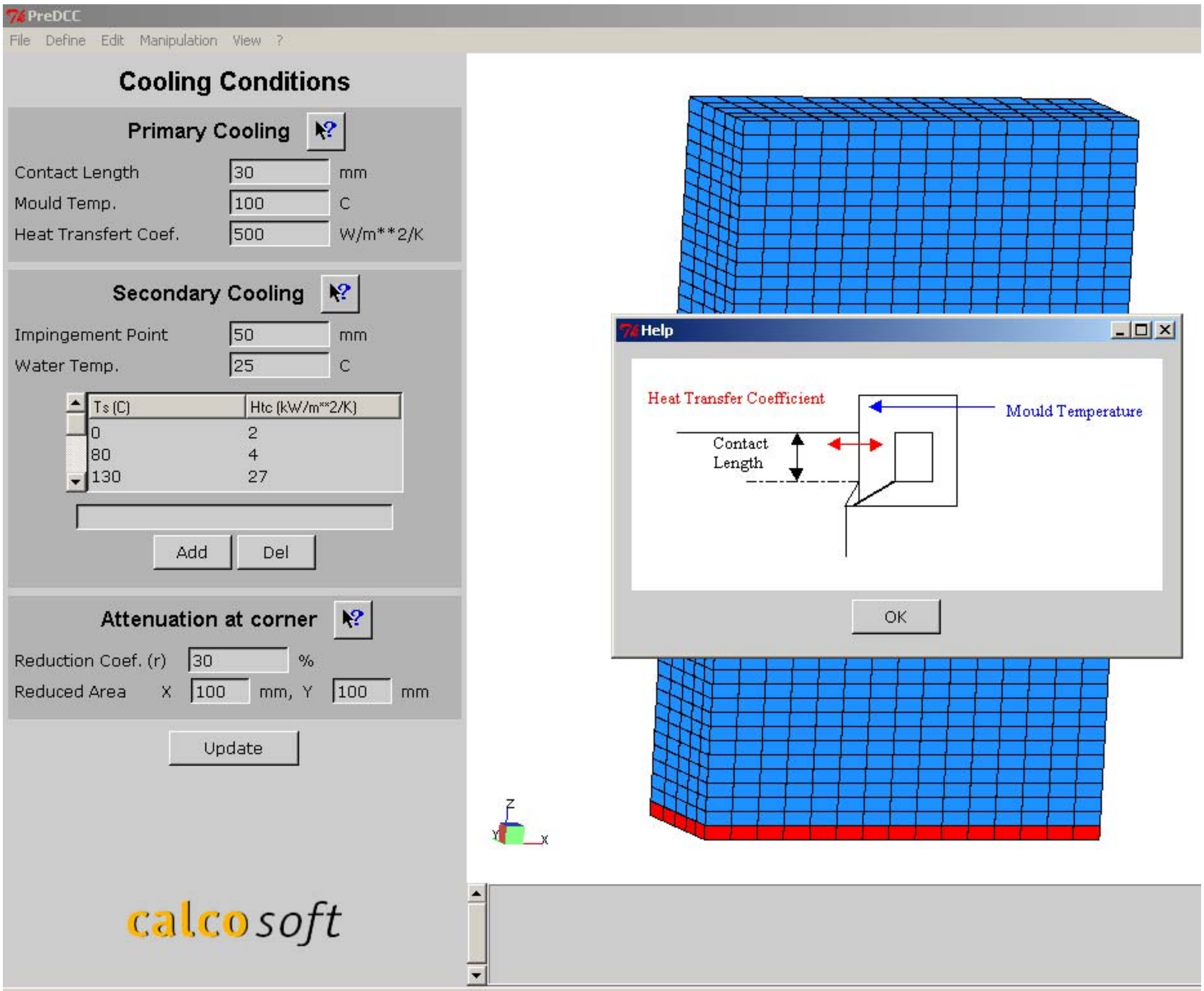
User Interface

A pre-processor allows to build an ABAQUS model to compute the rolling faces pull-in the steady state regime, by choosing a mould design, an alloy and a casting recipe (casting speed, cooling characteristics,…).

Material database are available for common aluminium alloys and particular cooling conditions (primary and secondary cooling zones) are defined with the help of the pre-processor.



Definition of the cooling conditions (primary and secondary cooling zones) with the user-interface.

References:

J.-M. Drezet, M. Rappaz, B. Carrupt and M. Plata: "Experimental investigation of thermomechanical effects during direct chill and electromagnetic casting of aluminum alloys" in Metallurgical and Materials Transactions 26B, August 1995, pp. 821-829.

J.-M. Drezet and M. Rappaz : "Modelling of Ingot Distortions during Direct Chill Casting of Aluminium Alloys ", in Metallurgical and Materials Transactions, vol. 27A, no. 10, October 1996, pp. 3214-3225.

M. Rappaz, J.-M. Drezet and M. Gremaud: "A New Hot Tearing Criterion", in Metallurgical and Materials Transactions, vol. 30A, February 1999, pp. 449-455.

J.-M. Drezet, M. Rappaz, G.-U. Gruen and M. Gremaud: "Determination of thermophysical properties and boundary conditions of DC cast aluminium alloys using inverse methods" in Metallurgical and Materials Transactions. Vol. 31A, June 2000, pp. 1627-1634.

J.-M. Drezet, B. Commet, HG Fjaer and B. Magnin: "Stress-strain computations of the DC casting process of Al. Alloys: a sensitivity study on material properties" in MCWASP IX, Eds. R. Sahm, N. Hansen and G. Conley, Shaker Verlag, Aachen 2000, pp. 33-40.

A. Burghardt, B. Commet, J.-M. Drezet and HG Fjaer: "A numerical study of the influence of geometry and casting conditions on ingot deformation in DC casting of Al. Alloys" in MCWASP IX, Eds. R. Sahm, N. Hansen and G. Conley, Shaker Verlag, Aachen 2000, pp. 25-32.

J.-M Rabenberg, I.-J. Opstelten, J.-C. Storm and J.-M Drezet: Determination of Material Properties and Thermal Boundary Condition from Casting Trial on Alloy AA7075, in Continuous Casting, Eds: K. Ehrke and W. Schneider, DGM, Wiley-VCH, Frankfurt 2000, pp. 71-76.

H.-G Fjaer, A. Buchholz, B. Commet, J.-M Drezet and D. Mortensen: Investigation of the Primary Cooling in Sheet Ingot Casting, in Continuous Casting, Eds: K. Ehrke and W. Schneider, DGM, Wiley-VCH, Frankfurt 2000, pp. 131-137.

W. Droste, J.-M Drezet, G.-U Gruen and W. Schneider: 3D Modeling of Ingot Geometry Development of DC-cast Aluminium Ingots during the Start-up Phase, in Continuous Casting, Eds: K. Ehrke and W. Schneider, DGM, Wiley-VCH, Frankfurt 2000, pp. 175-183.

J.-M. Drezet and Michel Rappaz: "Prediction of hot tears in DC cast billets" in Light Metals, Ed. J.-L. Anjier, TMS, 2001,New Orleans, pp. 887-893.

Project EMPACT: European Modelling Programme on Aluminium Casting Technology, Brite-Euram project 1996-2000 with the major European aluminium industries.

Project VIRCAST: Virtual Cast House Proegramme, Brite-Euram project 2000-2003.