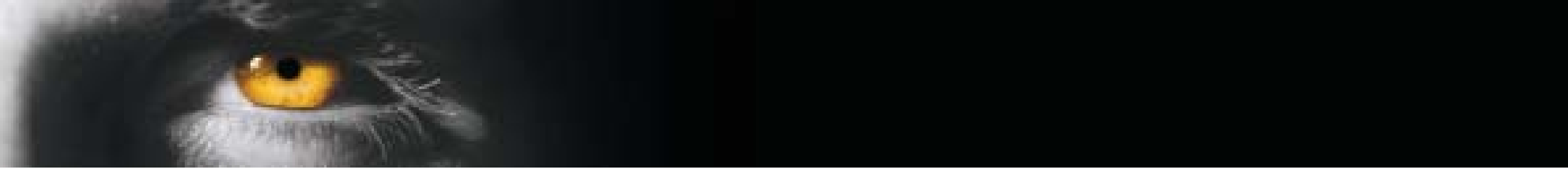

Can a process modelling software also be a predictive tool for the metallurgist ?

The ultimate goal of a simulation software is to provide accurate results in a limited time. The challenge, however, is that information is requested on the scale of the casting (macroscopic - heat and fluid flow for instance), on a casting sub-scale (mesoscopic - grain structure for instance) as well as on the scale of the microstructure (microscopic). Indeed, the process engineer will emphasise on dimensional tolerances, distortions, stability of the process, yield, whereas the metallurgist will concentrate on microstructural features such as defects, grain structure and phase compositions, see Figure 1. A comprehensive tool needs therefore to cover the dimensions ranging from meters to microns (6 order of magnitudes), which represents a true challenge from a simulation point of view.

The goal of this e-Tip is to present the concept of using multi-scale meshes for multi-scale problems.

Multi-scale meshes for multi-scale problems

In order to get thermal, flow, stress and macrosegregation results with minimum computing power, a coarse mesh is used. Finite element meshes are highly suited for these applications, as this category of mesh enables precise description of complex geometries, with a reduced number of elements. However, as evidenced in Figure 2, the initial finite element mesh is too coarse to tackle detailed microscopic features. The coarse mesh cannot be used as a 'microscope', as its resolution is too small.

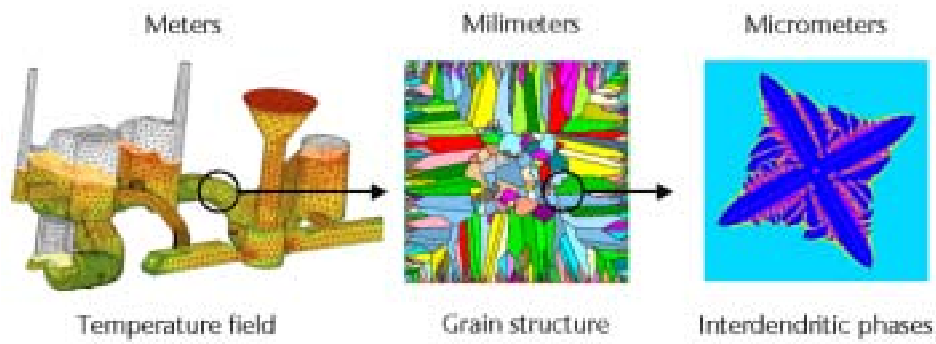

Figure 1: Orders of magnitude involved in microstructure modelling.

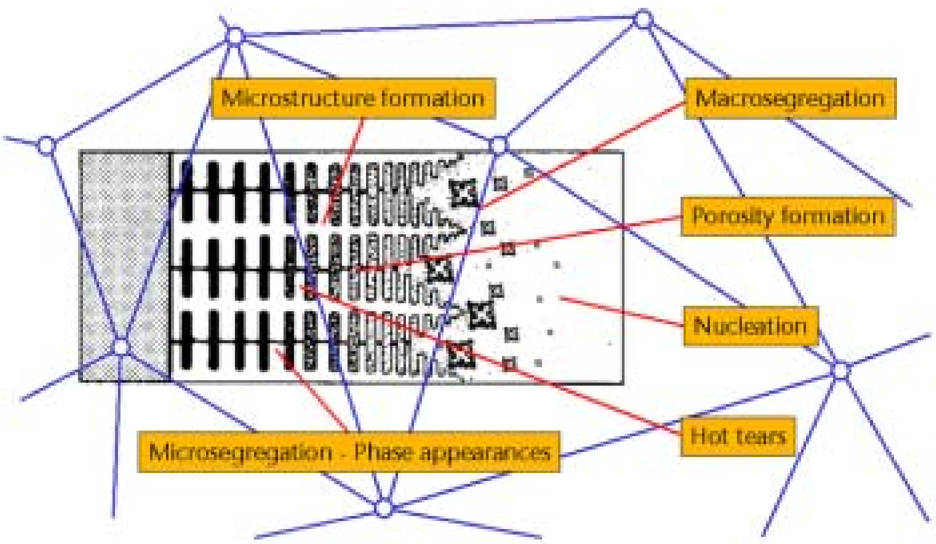

Figure 2: Microstructures are formed within the mushy zone, whereas finite meshes are traditionally on a larger scale (optimised for macroscopic calculations).

The simplest solution in order to achieve sufficient resolution is to have initially a fine mesh over the complete casting. The major drawback of this technique is that it increases accordingly the computation time for macroscopic calculations. More advanced solutions consist in providing a multi-scale mesh for multi-scale problems. As presented in Figure 3, a coarse mesh is used for macroscopic phenomena, and simultaneously, a refined mesh is used for microscopic calculations. Essentially two techniques are used by commercial software tools. The first solution is to use dynamic mesh refinement, where the mesh size is adapted at each time step. Indeed, the fine mesh is essentially required at the level of the mushy zone, as most microstructural features are developed during solidification within this zone. Therefore, mesh refinement can cope for an increased mesh density at a specific location, when this location falls within the mushy zone. The advantage of this technique is to provide high resolution only where it is required. The disadvantage of this technique, which is widespread in many mechanical simulation tools treating large deformations, lies essentially in the size of the result files (the new mesh needs to be saved at each remeshing step) and in the numerical complexity that is inherent to remeshing.

The second solution, which is widely used in advanced solidification packages, is the cellular automaton. This technique uses two meshes initially: a coarse mesh (finite elements) for macroscopic calculations, and a fine mesh (cells) for microscopic calculations. The second mesh is however only activated when the cells fall within the mushy zone. This technique does not increase significantly the size of the result files, is extremely robust (no remeshing) and enables calculations to be performed either simultaneously with the macroscopic calculation (coupled), or as post processing based on available macroscopic results (un-coupled).

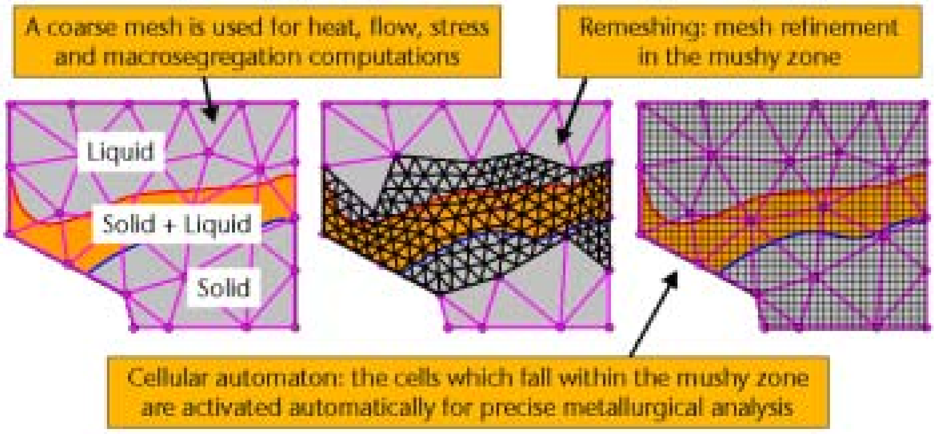

Figure 3: Schematic description of multi-scale / multi-mesh. The mushy zone is identified during calculation, and a refined mesh is automatically activated.

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