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Fast and Accurate Simulation of Manufactured Parts with Defects

Computed tomography (CT) is used as an effective inspection tool.

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Unwanted porosity is typical to many manufacturing processes — from traditional casting to additive manufacturing (3D printing) — and is difficult to avoid entirely. Manufacturers need to know what amount of porosity is tolerable inside a part without affecting its strength and performance.

Computed tomography (CT) is increasingly being used as an inspection tool that captures the full three-dimensional geometry of porosity in high resolution without destroying the component. While CT data can be used as a basis to simulate realistic part geometries to guide design and/or manufacturing corrections, using classical finite element analysis (FEA) can be extremely time-consuming. The main bottleneck is the conversion of the often complex geometry seen in the CT data to a faithful mesh representation suitable for simulation, which often involves tedious manual work.

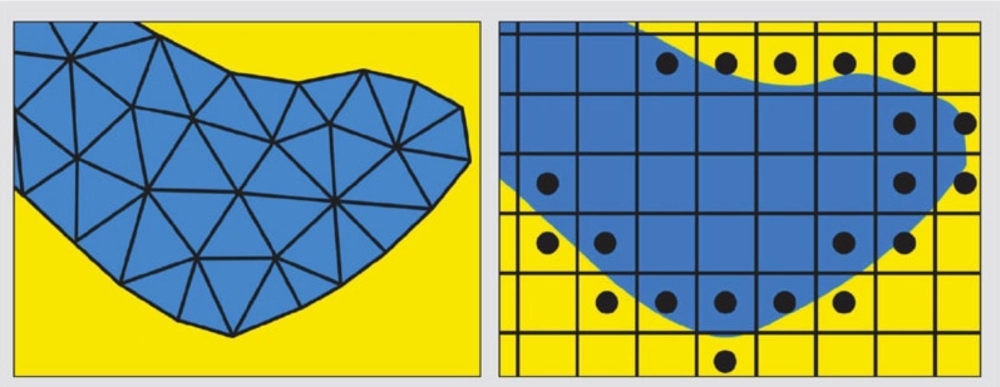

Figure 1. (Left): Classical FEA. The blue area is a detail of a larger simulated object. It is represented by a geometry-conforming mesh (black lines). (Right): Immersed-boundary finite element method. The simulation domain is extended beyond the object borders and discretized by a trivial quadrilateral mesh (black lines). Mesh cells intersecting the object boundary (marked with dots) are treated specifically to reflect the exact object surface.

Immersed-boundary finite element methods overcome this problem. Such methods do not require the generation of a boundary-conforming mesh and are thus well-suited for simulating complex geometries (Figure 1).

An efficient immersed-boundary finite element code is available in the CT analysis software VGSTUDIO MAX. The code processes CT image data directly and works with structured models like surface meshes or CAD data. In a recent study, this code was compared to a leading classical FEA code; an example from this study is presented here.

A cylindrical test specimen was additively manufactured from an aluminum alloy, with a deliberately inserted elliptic pore in the center of symmetry. Due to manufacturing limitations, the ideal pore shape turns into a complex surface in the real part. A CT image was acquired and the image was segmented with sub-voxel precision using the surface determination algorithm of VGSTUDIO MAX. The part was simulated in linear-elastic uniaxial stress by VGSTUDIO MAX and by ANSYS Workbench. For the classical FEA analysis, the surface data was exported and a volume mesh generated using ANSYS Workbench.

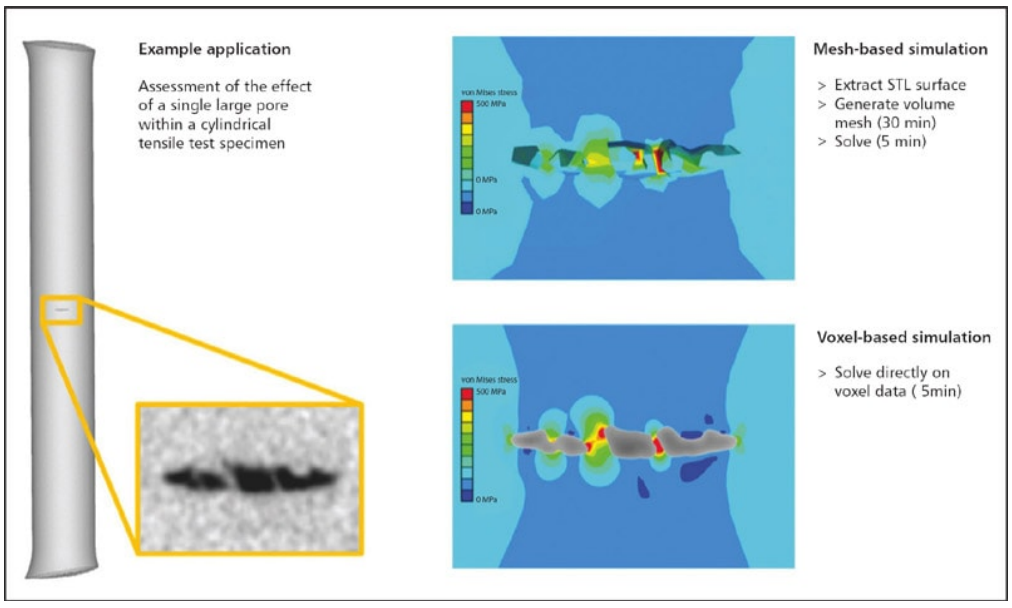

Figure 2. (left): CT scan of cylindrical test specimen with single pore defect (semitransparent 3D rendering). Ellipse-shaped pore shown enlarged in 2D section. (right, top): With classic FEA, most of the simulation effort goes into the mesh generation. Still, the mesh does not fully capture all details seen the image. (right, bottom): Immersed-boundary method computes much faster and shows the pore (grey) and the stress concentration around it in greater detail.

Stress predictions around the pore were then compared and the level of detail of the immersed-boundary method was found to be much greater than that of classical FEA (Figure 2) and revealed more pronounced stress variations. With the immersed-bound-ary method, the spatial accuracy of the solution is only limited by the resolution of the CT image, whereas in the classical method, accuracy is lost in the additional discretization step of volume meshing.

In this study, which was conducted on a single pore, the immersed-boundary solver already outperforms the classic FEA workflow in terms of computational effort. In real parts, there are typically hundreds or sometimes thousands of individual pores. Yet with the immersed-boundary solver, unlike with classical FEA, the computational effort does not increase with the number of simulated pores.

In conclusion, the immersed-boundary finite element method is an accurate and efficient tool for the simulation of mechanical effects of porosity in real parts. A more extensive study comparing simulation versus physical experiments in complex parts supports this work.

This article was contributed by Volume Graphics GmbH. For more information, visit here.