# DECREASING DRILL DAMAGE

Machining expensive corrosion-resistant materials is tough on the cutting equipment. Researchers at the Technical University of Dortmund used fluid flow and structural analysis tools from ANSYS to analyze process coolant flow distribution and achieve longer tool life.

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Life can be short for a drill. Machining materials such as Inconel, which is a group of superalloys made up primarily of nickel, chromium and iron, can be challenging. Inconel is part of a generation of superalloy materials used in gas turbines, heat exchangers, chemical reactors and rocket engines that can resist high temperatures, pressures and corrosion due to the hardening processes used to forge them. Because the act of working on

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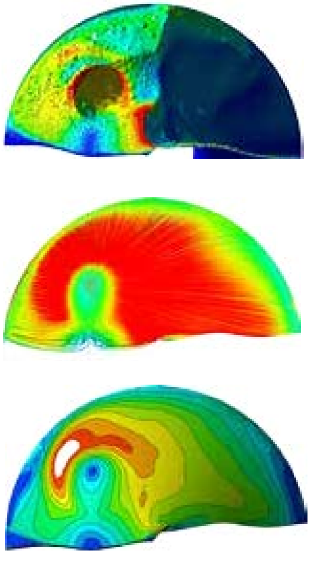
them actually makes them stronger through plastic deformation, cutting or drilling into an Inconel alloy has to be carefully managed to prevent rapid wear and damage to the machine tools.

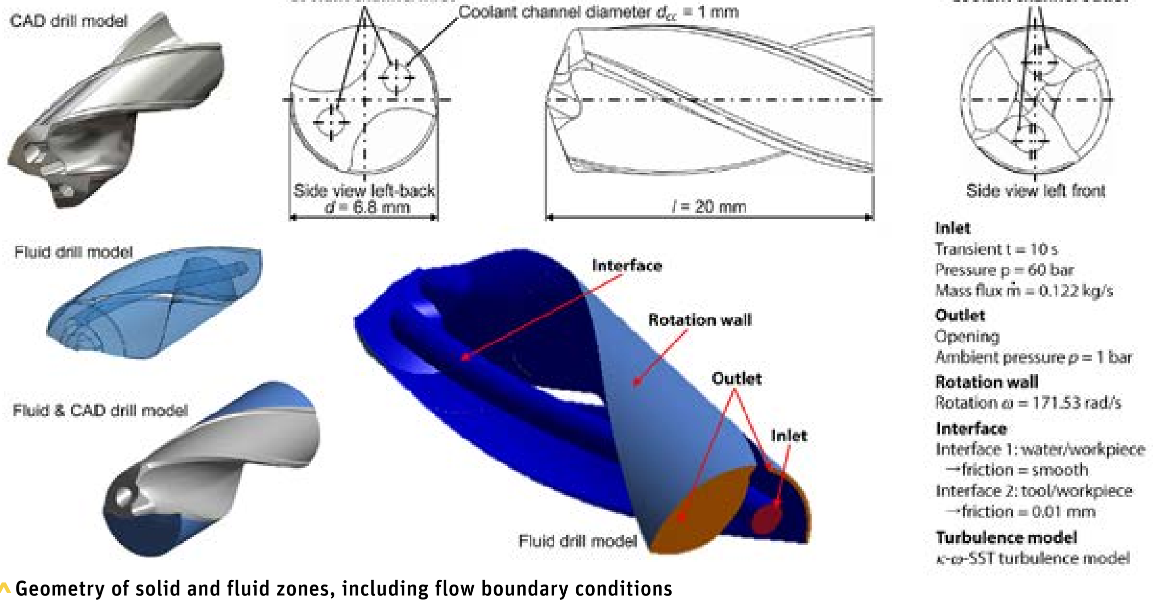
At the Technical University of Dortmund's Institute of Machining Technology (ISF), a research team analyzed methods to extend the life of drills for use on the superalloy Inconel 718. The low thermal conductivity of this alloy means that a large amount of heat must be transported away from the boring zone using external methods, or the tool can become deformed. This can lead to poor bore quality or breakage of the carbide drill bit. Relatively low drill speeds under 50 m/min are used to keep temperatures lower in the cutting zone, but a liquid coolant is still required. To direct the coolant fluid where it is needed, it is pumped through two tiny channels inside the land. (The land is the solid, helical pattern of the drill bit, while the flutes are the negative space through which the metal chips and fluid are evacuated from the bore hole.) If coolant is not distributed properly, dead zones can form along parts of the cutting edge, and the heat transport will not be as effective, which can lead to damage or burned coolant deposition.



^ End view of cutting area showing velocity contours of the coolant on the cutting tool surface (top), streamlines (middle) and velocity contours on the bore surface (bottom).

## FLUID–STRUCTURE INTERACTION

Due to the extremely small diameters of the coolant channels, experimental measurements of the coolant flow distribution are not feasible. To understand the complex interaction between the drill structure, the coolant fluid and the Inconel workpiece, the ISF team used simulation

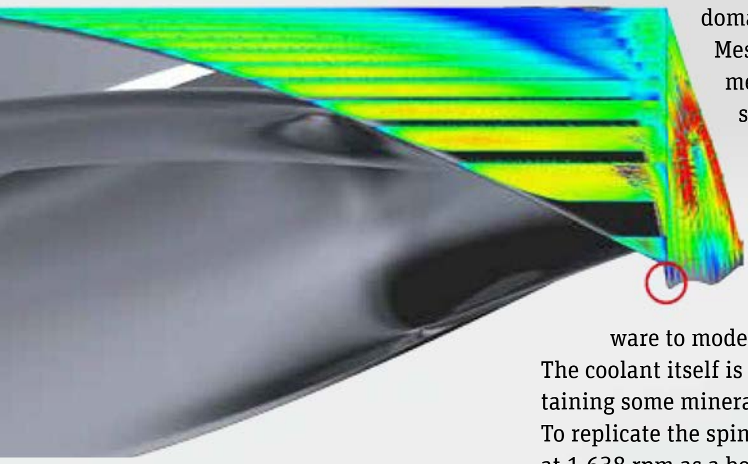



^ Geometry of solid and fluid zones, including flow boundary conditions

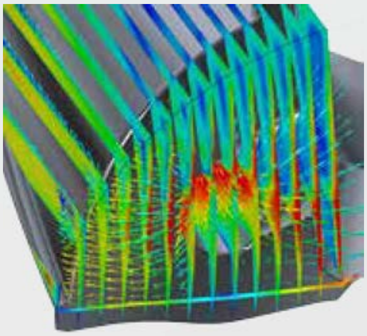
**"Drilling into an *Inconel alloy* is carefully managed to prevent *rapid wear and damage* to the machine tools."**

tools from ANSYS for process optimization by performing a fluid–structure interaction (FSI) analysis. To begin the process, ISF researchers built a 20-mm-long model of the interlocking solid and fluid domains by importing a CAD geometry file into ANSYS Meshing. For the fluid domain, the team created two mesh zones: a uniform coarse mesh generated by the sweep method for the flute space, and a very fine mesh to resolve the space at the main cutting edge between the drill's flank face and the bore bottom. Two variations were considered, with coolant channel diameters of 1 mm and 1.25 mm.

With completed fluid meshes, the engineers used ANSYS CFX computational fluid dynamics (CFD) software to model the distribution of coolant through the fluid domain. The coolant itself is typically a water-based metalworking lubricant containing some mineral oil, but the team modeled it as water for simplicity. To replicate the spinning of the drill, the entire flow domain was rotated at 1,638 rpm as a boundary condition corresponding to the drill's cutting speed of 35 m/min. The k-ω shear stress transport turbulence model was applied because of its accuracy in predicting both near-wall and far-wall distributions under such a flow regime. Further, the ISF team considered three different fluid inlet pressures (25, 40 and 60 bar) for both channel diameters. They assumed the flow field to be isothermal, because the heat transfer is strongly dependent on the flow characteristics, which are independent of the fluid temperature.



^ Side view of vertical planes showing the coolant velocity vectors



^ End view of vertical plane showing the coolant velocity vectors

On the structural side, the ISF engineers wanted to determine the impact of different coolant pressures and channel diameters on both the tool wear and the bore quality. In the cutting process, the downward force on the rotating drill translates into a mechanical load, or feed force, at the bottom of the bore hole. The team used ANSYS Mechanical with an added boundary condition of the coolant forces calculated by CFX to complete the FSI analysis. Including all of the different CFD and Mechanical simulations, ISF completed its computational analysis within four weeks.

## USING SIMULATION TO DETERMINE DESIGN CHANGES

The fluid flow predictions indicated that increasing the channel diameters from 1 mm to 1.25 mm nearly doubled the coolant mass flow rate inside the channels. Increasing the inlet pressure led to increased coolant velocity in the direction of the flutes and higher flow rates near the cutting edge. This created better turbulent flow conditions for convective heat transport. But larger channel diameters did not lead to significantly greater heat transport, no matter what the pressure. The team's scanning electron microscopy

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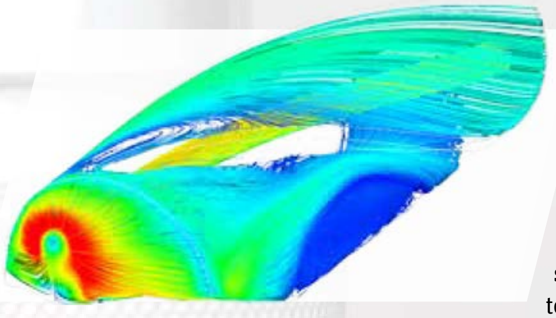

^ Simulation of flow distribution colored by velocity

(SEM) measurements of the tool wear and burned coolant deposition supported the simulation results, confirming that a higher coolant pressure achieved longer tool life and improved bore quality by producing better cooling conditions.

Complementing the CFD results, the Mechanical analysis showed that the highest stresses on the bore bottom occurred on the outer side of the coolant channels, where coolant velocities were highest. The team’s comparison of the simulated and measured feed forces showed good agreement, indicating that a larger channel diameter caused much higher feed force due to the increased coolant flow rate. Such higher feed forces on the bore bottom were not desirable, and provided a further argument in support of using the smaller channel diameters.

At the conclusion of its work, the ISF team investigations proved that, when physical measurements reach their limits, simulation software is a suitable tool to support the design work for complex drilling processes. Because of the flow distributions predicted by the CFD simulation, the team was able to modify its cooling process to direct coolant to the cutting edge more effectively, and thus improve the tool life by about 50 percent. This insight into the machining process would not have been possible otherwise, and directly saved ISF 50 percent in tool material costs. Future studies will aim to increase the coolant flow rate in the vicinity of the highly stressed areas of the cutting edge to avoid the presence of dead zones as much as possible. This may further help the team when it considers strategies such as varying the clearance angle or redesigning the flank face to achieve additional cooling improvements.

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**Fluid–Structure Interaction**
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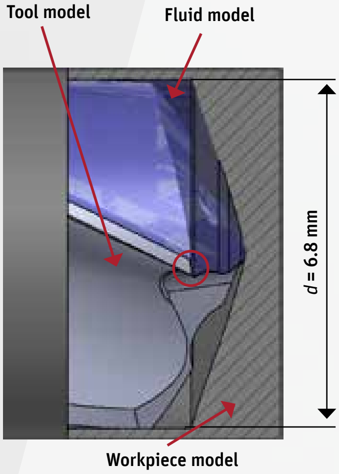
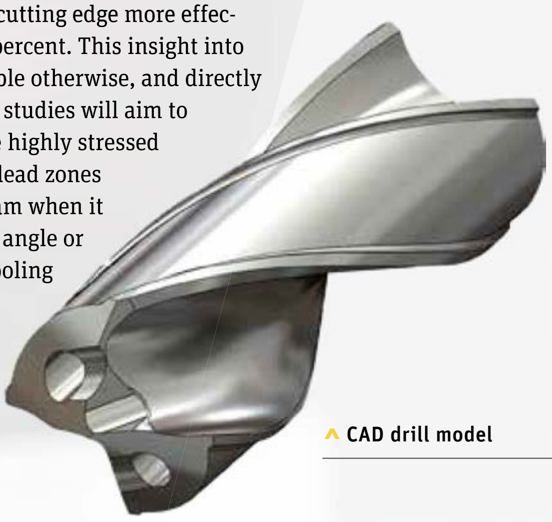



^ Close-up view of cutting edge, including the solid tool zone, fluid zone and Inconel 718 solid workpiece zone



^ CAD drill model