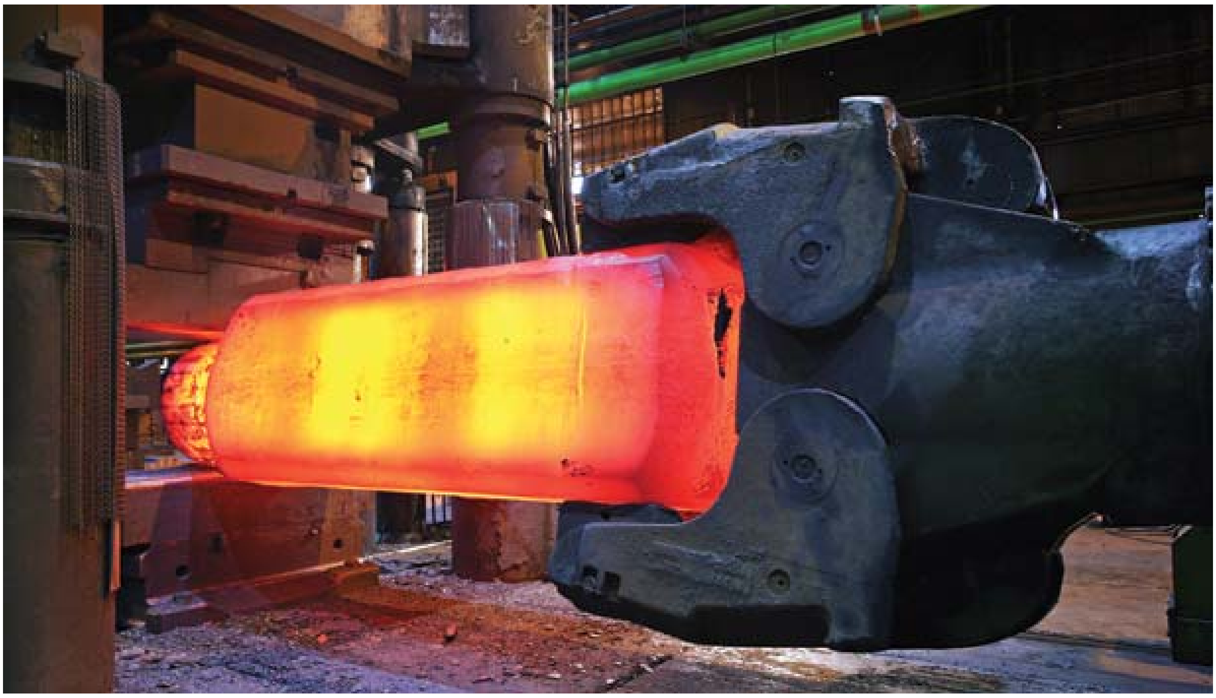


Open-Die Forging Simulation

KEYWORDS alloy / material properties / software / steel

Open-die forgers use computer simulations to maximize their material yield, design dies, establish process procedures and more. Using simulation technology, forgers wield a powerful tool that helps them make high-quality parts efficiently and without trial-and-error.

Open-die forging is a flexible methodology allowing for the production of forged, homogeneous, high-strength, long-life components that are optimal in mechanical properties and structural integrity. The process enables the manufacture of individual units and short-run parts. The open-die forging process is, in fact, considered the ultimate option in custom-designing parts for demanding applications in steel mills, nuclear applications, turbo machinery, power-generation systems, aerospace components, defense and heavy equipment. Typical open-die forged parts produced for these industries are rolls, shafts, impellers, disks, rings and gun barrels.

In open-die forging, a heated workpiece is systematically deformed by a series of strokes from an upper die while supported on a lower die. The dies are typically simple in shape – flat, concave or convex. The position and orientation of the workpiece are changed between the strokes, using one or two manipulators. A typical open-die forging process is shown in Figure 1.

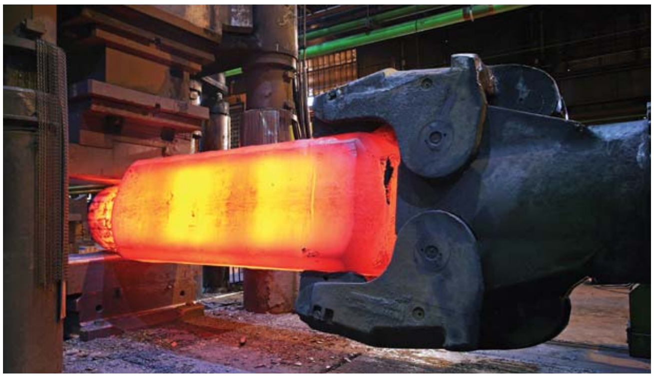


Figure 1: Typical open-die forging process (Courtesy of Saarschmiede, Germany)

Simulation of the Open-Die Forging Process

The goal of every open-die forger is to maximize throughput and achieve the highest material yield possible while producing the highest quality material properties.

The best way to achieve this delicate balance is by minimizing the time-consuming and costly process of physical tryouts. With the Simufact.forming software package, open-die forgers apply finite-element simulations to find the best forging recipes. They are able to reduce development and lead times, reduce scrapped billets, reduce heating times and optimize the number of strokes and re-heats. In addition, by using simulation, they get a deeper process understanding, improve process stability and quality, and are able to predict component properties.

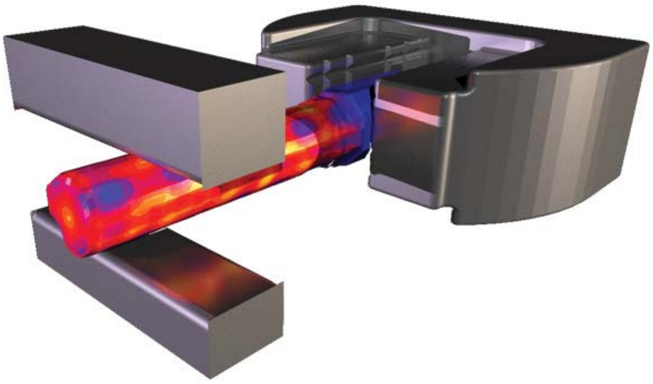
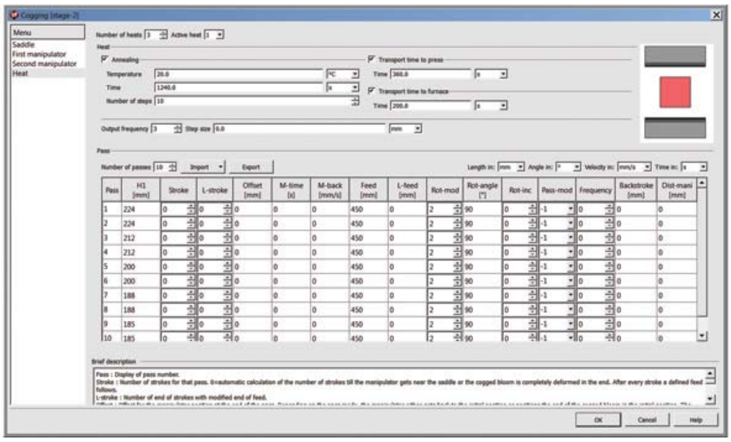


Figure 2: Simulation of a typical open-die forging process

As shown in Figure 2, the simulation model provides a realistic representation of the shop floor in the virtual world. All aspects of the process are taken into consideration, including the shape of the dies, the shape of the manipulators, the material behavior of the workpiece, the heat generation inside the workpiece during deformation, the heat transfer from the workpiece to the dies, the movement of the manipulators, the spring-loaded control of the manipulators, and many more parameters.

To define the simulation model, the dies and the manipulators are imported from CAD files. The initial shape of the ingot can be imported either from CAD, defined directly within the software or imported from a casting simulation.

The material of the ingot is selected from the extensive material library that is included with the software. The material library contains data for carbon steels; low- and high-alloyed steels; austenitic steels; nickel alloys (Inconel, Hastelloy, Waspalloy, Nimonic); and nonferrous metals like titanium, aluminum and copper.



Number of heats 3 Active heat 1

Heat

☑ Annealing
Temperature 20.0 °C
Time 1240.0 s
Number of steps 10

☑ Transport time to press
Time 360.0 s

☑ Transport time to furnace
Time 200.0 s

Output frequency 3 Step size 0.0 mm

Pass

Number of passes 10

Length in: mm Angle in: ° Velocity in: mm/s Time in: s

Pass	H1 [mm]	Stroke	L-stroke	Offset [mm]	M-time [s]	M-back [mm/s]	Feed [mm]	L-feed [mm]	Rot-mod	Rot-angle [°]	Rot-inc	Pass-mod	Frequency	Backstroke [mm]	Dist-mani [mm]
1	224	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
2	224	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
3	212	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
4	212	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
5	200	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
6	200	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
7	188	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
8	188	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
9	185	0	0	0	0	0	450	0	2	90	0	-1	0	0	0
10	185	0	0	0	0	0	450	0	2	90	0	-1	0	0	0

Brief description

Pass : Display of pass number.
Stroke : Number of strokes for that pass. 0=automatic calculation of the number of strokes till the manipulator gets near the saddle or the cogged bloom is completely deformed in the end. After every stroke a defined feed follows.
L-stroke : Number of end of strokes with modified end of feed.

Figure 3: Screen capture of inputs for a typical cogging or breakdown process simulation

To complete the simulation model, the open-die forger then specifies the details of the forming sequence in a table, as shown in Figure 3. The inputs include the number of heats, the annealing temperature, the transport time from furnace to press, and the transport time to the furnace. It is specified how many passes are performed for each heat, and the detailed motion of dies and manipulator are defined for each pass. The software will handle fully automatic runs through the defined forming sequence.

Intelligent Control of the Kinematics

When designing a breakdown/cogging sequence, the forger does not know up front how many strokes will be required to reach the end of a pass. The reason for this is that the workpiece elongates during the forming process, and the exact amount of elongation is simply not known ahead of time. The simulation will predict the elongation of the workpiece and automatically determines how many strokes are needed. At the end of each pass, an intelligent control logic will re-position the manipulators over the correct distance to start the next pass.

The automated, intelligent control of the kinematics allows process designers to routinely use the software for their forming-sequence design and optimization.

Support for All Open-Die Forging Processes

The aforementioned described the simulation approach for a typical cogging or breakdown process. However, the open-die forger is not limited to just these processes. Simufact.forming is also used to simulate upsetting, radial forging, shell forging, partial translational forging and partial rotational forging/whipping.

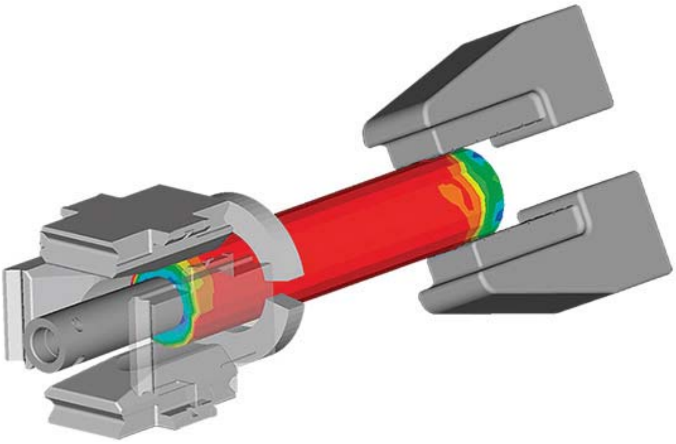


Figure 4: Typical radial-forging process, simulated with Simufact.forming

Gyratory forging machine (GFM) is a precision forging process that produces cylindrical bar shapes by hot forging while the bar is rotating. Figure 4 shows the simulation of a typical radial-forging process.

Prediction of Material Properties

Key aspects of open-die forging are the high-strength mechanical properties of the final product. The simulation will predict the material properties based on phase transformation and grain-size calculations. Figure 5 shows an example of hardness prediction in a steel mill roll.

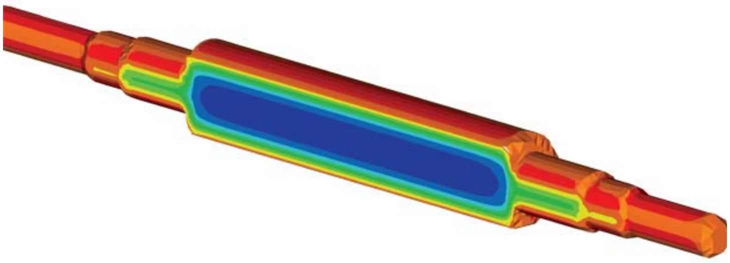


Figure 5: Simulated hardness of a steel mill roll (Courtesy of Saarschmiede, Germany)

Prediction of Void Closure via Relative Density Function

During the casting process, both large and small voids are generated inside the material. These voids are often referred to as blowholes. One objective of the open-die process is to close these voids and ensure integrity of the part.

There are multiple ways to study this within the software program. One method is to include the shape of a blowhole in the actual geometry of the ingot and study how the geometry changes during the breakdown process. This method works well for large, macroscopic blowholes.

For smaller, microscopic blowholes, we developed a special method to monitor void closure. Since voids are closed due to hydrostatic pressure, a relative density function was introduced that predicts how much the voids are closing. Once the relative density reaches 1.0, all blowholes are considered to be closed. The densification happens when the material is under plastic deformation.

HPC, Hardware Requirements and CPU Time Considerations

The software uses the most modern programming concepts for high-performance computing (HPC), which includes vectorization and parallelization of the computations on the latest hardware. Through partnership with hardware vendors and chip manufacturers, it is ensured that the latest methods are efficiently being applied.

All simulations in Simufact.forming are fully coupled. This means that both thermal and mechanical aspects are calculated simultaneously. In addition, a fully elastic-plastic approach is used for the material modeling. This is the only way to get accurate prediction of shape, stress, strain and microstructure. Even with this level of sophistication, a typical breakdown simulation of 50 blows takes only several hours on a modern desktop computer.

Summary

Using simulation technology, open-die forgers achieve more flexibility in their production planning and analysis for complex part geometries. They are able to maximize throughput and part quality while minimizing material use and energy consumption.

This article has been released in the FORGE magazine.

FORGE