DEFORM™ Application #117

Rotary Tube Piercing Simulation

Introduction:

Rotary tube piercing is a hot-working process for making long, thick-walled seamless tubes. It is based on the principle that when a round bar is subjected to non-uniform radial compressive forces, tensile stresses are produced at the center of the bar. When subjected to cyclic tensile loading, a cavity forms at the center of the bar.

Rotary tube piercing uses a pair of rotating rolls, whose axes are skewed to one another, to pull the round bar through the rolls. An internal plug assists the operation by expanding the hole and sizing the inside diameter of the tube, as shown in Figure 1. The diameter of the tube can be further reduced by tube rolling, drawing or pilgering operations. These processes allow the production of tube with different diameters and thicknesses from a common stock size.

Historically, the simulation of this process was prohibitively time consuming, using any commercial software. Rotational motion, number of revolutions and changing contact require a large number of time steps to accurately simulate the process.

Methodology:

Two numerical formulations are commonly used in the simulation of mechanical processes - the Lagrangian formulation and the Eulerian formulation. The Lagrangian formulation, particularly suitable in cases of unconstrained flow over free boundaries, attaches the mesh to the material flow. The Eulerian formulation, which is common in modeling fluid mechanics processes, uses a fixed mesh in space while the material flows through the mesh.

The Eulerian formulation is not well suited to this process due to the presence of free surfaces. The Lagrangian formulation is also not well suited to this process due to the rotational motion of the workpiece, changing contact and simulation time. An ALE method was developed for this process to allow the radial and longitudinal motions to use the Lagrangian formulation and the circumferential motion to use the Eulerian formulation.

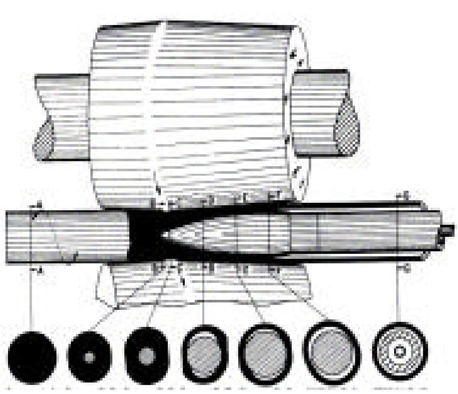

Figure 1: This schematic illustrates the tube deformation resulting from the rotary piercing rolls and center plug.

Simulation Conditions:

The rolls and plug were treated as rigid objects, since their deformation was negligible. The workpiece was modeled as a deformable body with a rigid-plastic constitutive model. This model does not consider elastic deformation, which is negligible compared to the plastic deformation. The workpiece was comprised of 15,000 brick elements (18,000 nodes) and rotational symmetry was used so that only half of the part needed to be modeled. The simulation was carried out using an isothermal assumption.

Simulation Results:

Predicted radial cross-sections of the workpiece, at an intermediate stage of piercing, are shown in Figures 2(a) – 2(e). Figure 2(f) shows a longitudinal slice of the predicted deformation. Location (b) is the section near the plug tip and (c) is the location where the roll gap is smallest. Prior to contacting the plug, the rotating workpiece is deformed as the roll diameter decreases. The center of the workpiece is subjected to tensile stress and a fracture is initiated. At z = -2", the plug tip initiates the piercing process. At z = 4", a slight oval shape from the compression of the rolls is observed. The wall thickness of the pipe is continuously reduced between the plug and rolls. At z = 10", a finished tube shape is produced.

The simulation predicted that the diameter of the pierced tube was 10.71" and the thickness was 1.23". These results compare very closely to the experimentally determined diameter of 10.75" and thickness of 1.19".

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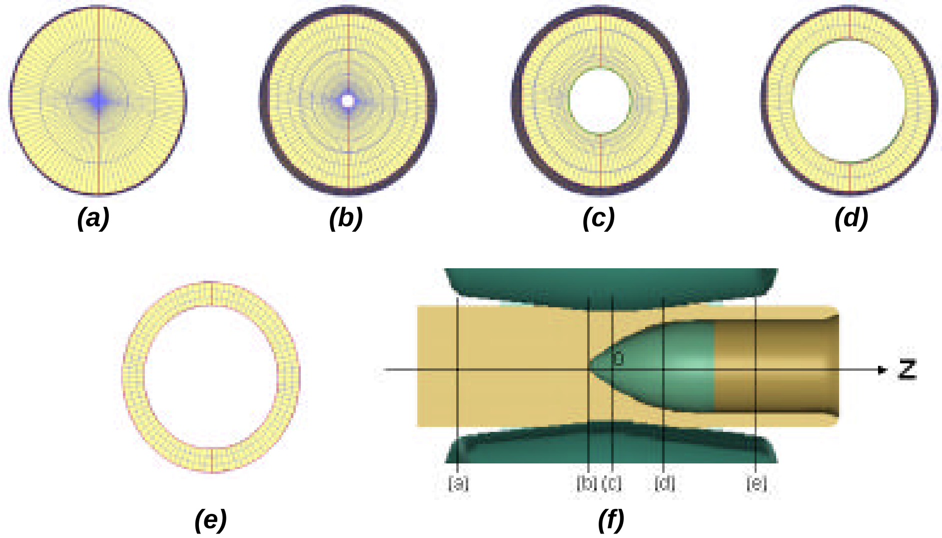

Figure 2: Cross-sections are shown at (a) z = -14″, (b) z = -2″, (c) z = 0″, (d) z = 4″ and (e) z = 10″ at the start of piercing. A longitudinal section is shown in (f).

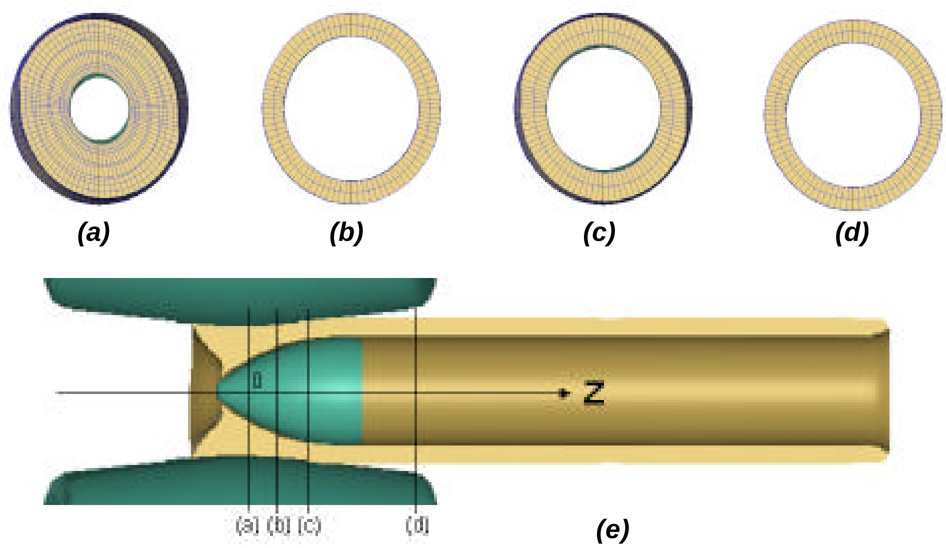

Figure 3: Radial cross-sections are shown at (a) z = 0″, (b) z = 2″, (c) z = 4″ and (d) z = 10″ at the end of piercing. A longitudinal section is shown in (e).

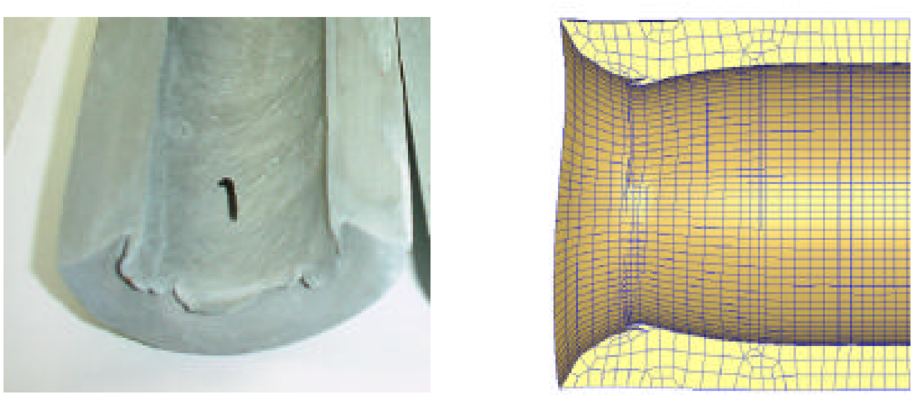

Figure 4: The backend defect is shown on the 10.5″ billet on the left. The DEFORM-3D simulation shows the same behavior on the right.

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Figure 3 shows the cross-sectional shapes when the plug had reached the rear end of the workpiece. A suck defect and a backend defect were both predicted in the simulation, as seen in Figure 3(e). Figure 4 compares the defects observed on the rear end of the experimental tube with those predicted in the simulation.

Further Discussion:

A number of forming processes have been time-consuming and challenging to simulate in the past. These processes include tube piercing, as well as flat die extrusion, ring rolling and thread rolling. The main difficulty involved with these processes is the long run time required when using an implicit Lagrangian formulation. Other formulations and solution techniques have yet to meet the resolution, speed and accuracy requirements.

New techniques are being investigated to efficiently speed up solution times. ALE and specialized updating algorithms are among the options being investigated. This example demonstrates how a custom methodology can be used to solve a very challenging process.

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