Computer Simulation Improves Quality and Reduces Cost of Aluminum Extrusions

*By Inge Skauvik, Hydro Aluminum
Håvik, Norway*

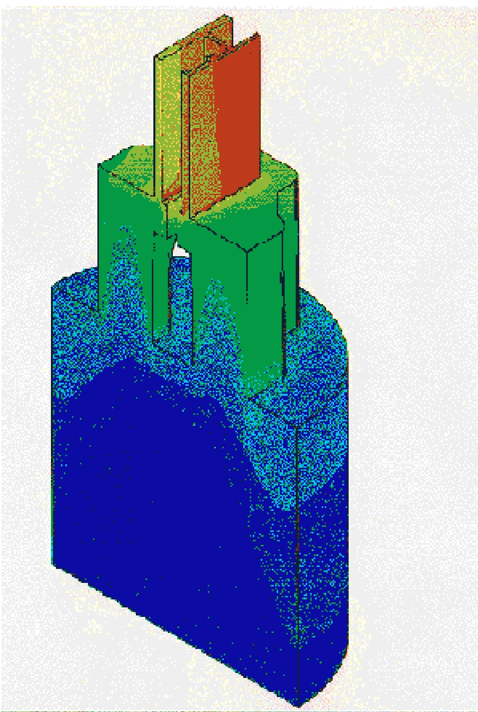

Fig 1. The same case viewed from the end. Here the section shape is clearly seen. Due to symmetry only half of the aluminum is included in the model domain.

Introduction

Hydro Aluminum has improved the quality and reduced the cost of aluminum extrusions by using computer simulation to improve porthole die design. Critical studies have been made of the flow in the outlet region and the welding zones in order to get a better idea of how these factors influence the process stability. The temperature and deformation history of the material through the forming process have been evaluated to improve the physical properties of the extruded material. These simulations were performed using finite element analysis based computational fluid dynamics (CFD) software that models the moving free surface of the extrusion and provides for simple modeling of complex geometries. Aluminum extruding is a highly competitive business where relatively small improvements in cost or quality can have a major impact.

Aluminum extrusions are manufactured by pressing cylindrical billets of aluminum through heated dies. Hollow extrusions can be made by using dies with one or more mandrels supported by webs that split the metal flow into different channels. Extrusion of hollow sections requires quite complex dies with portholes, channels and welding chambers. Physical measurements of the process are both expensive and difficult to make without affecting the parameters under measurement.

Simulating the Extrusion

Hydro Aluminum began several years ago using computer simulation to get a better understanding of the mechanism involved in extruding aluminum in order to assist its 20-plus plants around the world in making process improvements.

CFD involves solving the basic equations for momentum, mass and energy balance. A CFD simulation provides fluid velocity, pressure and temperature values throughout the solution domain for problems with complex geometries and boundary conditions. As part of the analysis, a researcher may change the design of the system or the operating conditions such as the die design, flow rate, etc. and view the effect on fluid flow patterns or temperature. Hydro

Aluminum researchers selected FIDAP CFD software from Fluent Inc., Lebanon, New Hampshire, as their modeling tool. This software package uses the finite element approach and has the advantage of using non-structured grids. Non-structured grids provide considerably greater flexibility in modeling the complex and irregular geometries involved in aluminum extruding.Non-structured grids also automate the otherwise impractically tedious process of fitting elements to the complex geometries used in extrusion dies.

Simulated temperature distribution in extrusion ingot, die and section.

A mathematical model for simulating extrusion must represent the geometry of the die very closely, particularly in the regions with the highest gradients in flow velocity and temperature. In addition to the aluminum phase within the die, it is also necessary to include the billet and a part of the section in order to obtain a correct representation of the inlet end exit flow patterns, as well as the temperature distribution in the material flowing through the die. To reduce computational time, models contain the aluminum phase only. The heat exchange rate between the die and the aluminum is specified as a boundary condition based upon results of simple models where the steel phase was included.

Hydro Aluminum analysts have found that 27-node triquadratic brick elements provide satisfactory results in modeling aluminum extrusions. In order to achieve a satisfactory velocity profile over the outlet, at least four elements must be used over the wall thickness. If the ratios between the lengths of element sides are to be kept within accepted limits, this means that the number of nodes needed to cover a 10 cm piece of the section will be in the range of 10,000 to 25,000.

For the entire modeled volume, the number of nodes is considerably above 100,000.

The same case as previous figure but viewed from the end. Hydro Aluminum analysts used this technique to model the weld zone, the area where aluminum coming from different portholes in the die is recombined. A good weld zone is planar and stable over time and located midway between the two ports. Analysts use particle tracing from a selected region of the extrudiate to visualize whether or not all three of these conditions are met by a particular die design. In one case, the weld zone had shifted over to near one of the portholes and the aluminum almost reached the output before parallel flow was obtained. Such a flow pattern is likely to cause problems, so the die design in the CFD model was changed in an effort to improve it. The new die design changed the location of the weld zone to midway between the portholes and the flow was stable and parallel over a considerable distance.

Another very critical area is the outflow region which has the highest values of velocity, strain rate and temperature. Waves, bending and twisting can occur as a result of local stress levels exceeding the yield stress. In other cases, tearing of the section surface can occur. If the outflow velocity is nonuniform, the extruded sections will be bent or twisted. Analysts have used simulation to predict all of these conditions and to evaluate the performance of alternate designs at minimal cost. Simulations cannot fully replace die trials because die operation is highly dependent on marginal factors that are difficult to fully capture in the simulation such as bearing angle, surface roughness, gap opening, etc.

Results

Simulation can also provide insights into the mechanical properties of the extrudate. During the extrusion process, the material is exposed to violent changes in temperature and strain rate. A particle moving closely to the walls of the die and the bearing surface will experience the most abrupt changes in thermal conditions. Material elements moving near the central axis of the ports and passing midway between the bearing surface will have different thermal histories and may have different mechanical properties as well. The information from the simulation provides the velocities, temperatures and pressures versus time for any material element. The simulation shows, for example, that particles near the surface stay in a comparatively hot region for much longer period of time than a particle in the interior of the material.

Hydro Aluminum originally got involved with CFD because of the difficulty performing experimental studies, particularly with complex geometries. The simulation method has proven extremely valuable in predicting the performance of alternate die designs without the time and expense required to actually build and test the die. In addition, simulation provides analysts with far more information than can be obtained from physical tests, providing a better understanding of the extrusion process and its sensitivity to various design parameters than it was ever possible to obtain in the past.

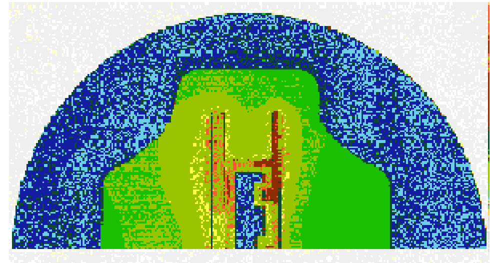

Fig 2. Simulated temperature distribution in extrusion ingot, die andsection. The cylindrical part (bottom) is the extrusion ingot. The materialis heated as the extrusion die is passed, and reaches a high temperature level at the exit. There is a notable temperature variation along the section perimeter. Modeling can contribute to reduce this variation and minimize the maximum value, which limits productivity.