Hot-stamping boron-alloyed steels for automotive parts

FE simulation of the process

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Editor's Note: This article discusses the recent advances made in the simulation of the hot-stamping process. A three-part article providing an overview of this growing technology appeared in the December 2006, January 2007, and February 2007 issues of STAMPING Journal®.

The use of ultrahigh-strength steel (UHSS) in the automotive industry has increased in the last few years as manufacturers try to improve crash safety and reduce weight. Parts such as B-pillars, side impact reinforcement beams, and bumpers are increasingly manufactured from UHSS by hot stamping.[1]

In hot stamping, the blank is heated in a furnace to its austenitization temperature (about 900 degrees C), formed in an internally cooled die set, and quenched under pressure at a minimum cooling rate of 27 degrees C per second. This minimum cooling rate ensures the formation of martensitic microstructure in the part, which gives it strength of about 1,500 MPa.

Finite element (FE) simulation of the hot-stamping process can help manufacturers predict such final part properties as thickness, temperature, and hardness distribution.

Properties, Parameters for FE Simulation

Mechanical deformation, heat transfer, and microstructure evolution occur simultaneously during hot stamping (see **Figure 1**). This makes FE simulation of the process challenging. Most researchers use a combination of different FE codes to capture what occurs during hot stamping.

When using FE simulation, making suitable assumptions while ignoring the effects of some of the less significant parameters can help shorten the time needed to obtain reasonably accurate results. Some parameters, however, are required as input to the FE codes.

The essential material properties include emissivity and flow stress as a function of temperature, strain, and strain rate. Also required are Young's modulus, Poisson's ratio, thermal conductivity, specific heat capacity, and coefficient of thermal expansion, each as a function of temperature.

The essential process parameters are final austenitization temperature; blank transfer time; blank temperature as forming begins; die stroke versus time; contact heat transfer coefficient between the blank and tool as a function of pressure and distance between the tool and die surface; coefficient of friction as a function of pressure; initial tool temperature for nonisothermal simulation; average tool temperature for isothermal simulation; temperature of the cooling medium needed to cool dies; blank holder force; closing pressure of the tools; and time required for quenching and air cooling.

In the hot-stamping process, forming and quenching simulation are most important, since most of the deformation and heat transfer take place during these two operations.

Forming Simulation

The Center for Precision Forming (CPF) is developing an FE-based procedure for the simulation of hot-stamping operations, applying the process to the design of various hot-stamping dies. For instance, CPF

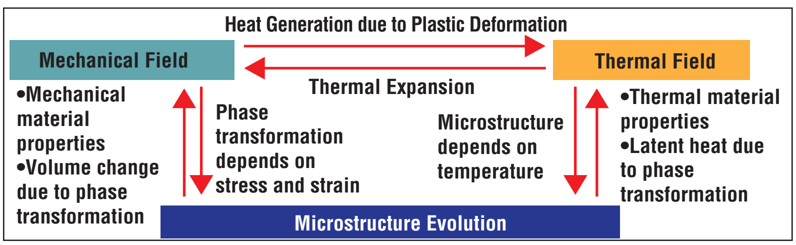

Figure 1

The effects of deformation, heat transfer, and microstructural evolution are inter-related.[2]

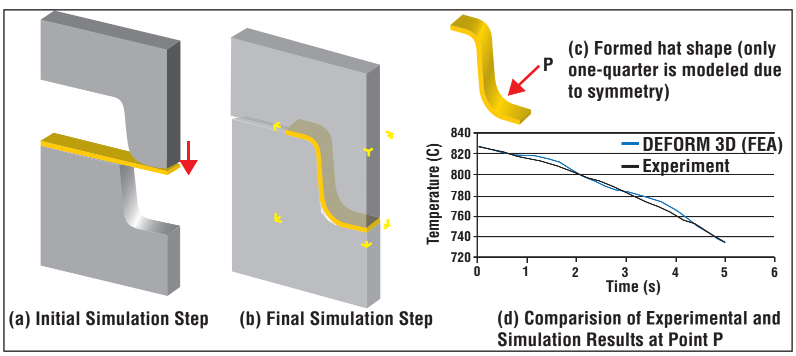

Figure 2

An example hat shape was simulated using DEFORM-3D.[3]

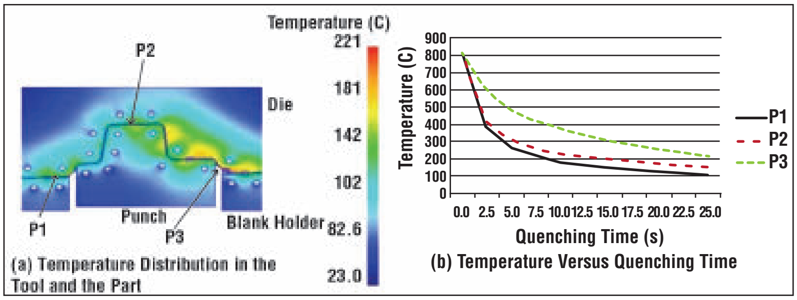

Figure 3

Quenching was simulated in a B-pillar section after 10 hot stampings.[4]

used DEFORM™-3D to simulate the forming of a simple hat shape from a 22MnB5 blank at an initial temperature of 827 degrees C.[3] During the experiment, temperature was measured at Point P (see **Figure 2**) using a thermocouple. This thermocouple measurement was later compared with the simulation.

Quenching Simulation

Determining the optimal size and location for cooling channels is very important in hot-stamping tool design. During the design of cooling channels for complex parts like a B-pillar, heat transfer simulations can be used on critical 2-D sections of the part to determine cooling channel size and location. Based on the results obtained from the 2-D simulations, the initial cooling channel configuration can be selected for the whole part.

Figure 3 shows the temperature distributions in the tool and part during quenching simulation for a selected section in a B-pillar after 10 hot stampings.

FE simulation of hot stamping poses many challenges:

•The need for reliable material data for manganese boron steel at high strain rate values

•The inability of commercial sheet metal forming codes to handle combined thermal and mechanical simulation

•Predicting exact contact conditions between the tool and part

•Elastic deflection of the dies during forming and quenching

•Volumetric change caused by microstructure evolution

CPF, other research groups, and software companies are addressing these issues to develop software design tools to improve die and process design.

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Notes

1. T. Altan, "Hot-stamping boron alloyed steels for automotive parts, part 1: Process methods and uses," STAMPING Journal, December 2006, pp. 40-41.

2. M. Eriksson, "Modelling of forming and quenching of ultra high strength steel components for vehicle structures," Doctoral thesis, Lulea University of Technology, 2002.

3. P. Akerstrom, "Modelling and simulation of hot stamping," Doctoral thesis, Lulea University of Technology, 2006.

4. N. Pierschel, A. Naganathan, and T. Altan, "Thermal simulation and die design in hot stamping tools," CPF Report No. CPF-5.5/10/02, ERC/NSM, The Ohio State University, 2010.