Progress on the Finite Element Simulation of the Hot Stamping Process

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Abstract

The simulation of hot stamping is rather complex and challenging, and requires information about properties of die and sheet materials, heat transfer, and friction between the deforming material and the dies. A large number of researchers use different commercial codes, such as LS-Dyna, PAMSTAMP, AUTOFORM, and DEFORM to conduct hot stamping simulations with various levels of success. In this study, DEFORM, a commercial code widely used for the analysis of hot, cold and warm forging operations and die design, has been used. This code can consider elastic and plastic deformations of the sheet material, friction, heat transfer and elastic deflections of the dies. Several part geometries have been analyzed, using information provided in the literature as well as that obtained from various companies that produce hot stamped parts. The results indicate that it is possible to predict the deformation and temperatures in the part and in the dies by considering the variation of interface heat transfer in function of interface pressure. Using this approach it is also possible to optimize the design of cooling channels in the dies. It appears that the approach, used in this study, is quite promising for use in industrial environment to optimize die and process design for hot stamping.

1 Introduction

Manganese boron steel when hot stamped can give very high strength of 1500MPa which improves the crash resistance and reduces the weight of cars. A typical hot stamping line includes: a) blank heating, b) blank transfer, c) forming, d) quenching, and e) air cooling of the part. In all these processes, mechanical deformation, heat transfer, and microstructure evolution occur simultaneously. In this study, we used the FE code DEFORM to simulate the entire hot stamping process. Currently, the effect of microstructure evolution is not considered in our simulations. This research is being supported by National Science Foundation of USA [1] and industrial partners of the Center for Precision Forming at The Ohio State University, USA, namely, IMRA [2], POSCO [3], VERBOM [4] and COSKUNOZ [5]. The following material and process parameters, developed in various literature [1-7], are required as input to the FE codes for simulating the process with reasonable accuracy.

1.1 Material Properties as a Function of Temperature

Properties of the blank material used in hot stamping have to be given in function of temperature in order to develop an accurate finite element model for hot stamping. The material properties that have to be defined are a) Flow stress in function of strain and strain rate, b) Young's modulus, c) Poisson's ratio, d) Emissivity, e) thermal conductivity (sheet and die), f) specific heat capacity (sheet and die), g) coefficient of thermal expansion (sheet and die).

1.2 Process Parameters

Apart from the material parameters listed above, several process parameters have to be defined for accurate modeling of hot stamping. These are a) Final austenitisation temperature, b) blank transfer time, c) temperature of the blank at the beginning of forming, d) die stroke versus time, e) contact heat transfer coefficient between blank and tool as a function of pressure and distance between tool and die surface, f) coefficient of friction between sheet and dies as a function of pressure, g) initial die temperature for non isothermal simulation/average die temperature for isothermal simulation, h) temperature of the cooling medium needed to cool dies, i) blank holder force (which is nearly zero in most cases), j) closing pressure of the tools, k) quenching times (dwell time of the press at Bottom Dead Center-BDC), and l) time required for air cooling.

1.3 Simulation Procedure for Hot Stamping

Blank heating and blank transfer are simulated by conducting heat transfer simulation to calculate the temperature distribution in the blank and the volume change due to thermal effects.

The forming process is simulated by considering heat transfer between blank and dies and with environment. Dies are assumed to be rigid. However, during quenching elastic die deflection should be considered to estimate local interface pressures. The effect of cooling channels is neglected and the tool is assumed to be at a homogeneous initial temperature. Blank holder force is assumed to be zero. Based on the simulation results, material flow and temperature distribution are studied and the die surface modification is done on the critical regions (areas of local thinning and high temperature).

Quenching and cooling channel design uses the results of the thermo mechanical forming simulation as the starting step for the heat transfer simulation during quenching. Initial diameter of cooling channel and minimum distance of the cooling channels from the tool surface are selected from the literature or from the experiments. The flow rate of the cooling medium is assumed to be such that it maintains the temperature of the cooling channel surface constant and at room temperature. Heat transfer simulation is conducted for the given quenching period. To study the temperature build up in the dies during production, simulations of multiple strokes are conducted. If the cooling is inadequate for martensitic transformation in the part, cooling channel location is adjusted accordingly. Based on the temperature distribution, and cooling history from the simulation, we can predict the final microstructure of the component. Thickness distribution is measured from the final part.

2 Case Studies

2.1 Simulation of a Hat Shape

Information about this part is obtained from reference [8]. The die and part dimensions are given in Figure.1. During the experiment, the strip at 827°C as shown in Figure 1, is formed into a hat shape. Forming force and temperature at a point were measured during the experiment [8]. The flow stress data of sheet material was taken from Numisheet-2008, bench mark problem [7]. The sheet material type is chosen as plastic and meshed with brick elements and the die is meshed with 4-node tetrahedral elements. Only one quarter of the geometry is modeled due to symmetry. Non isothermal forming simulation is conducted to consider the heat transfer between the dies and the blank [9]. The results (Figure 2) showed that the simulation is able to predict the experimental results [9].

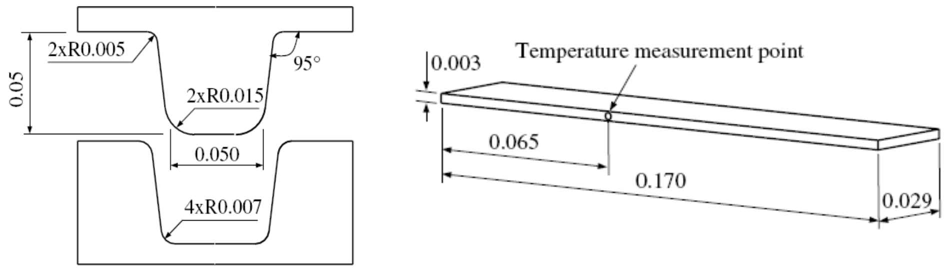

Figure 1*: Die geometry for hat shape, All dimensions are in m [8]*

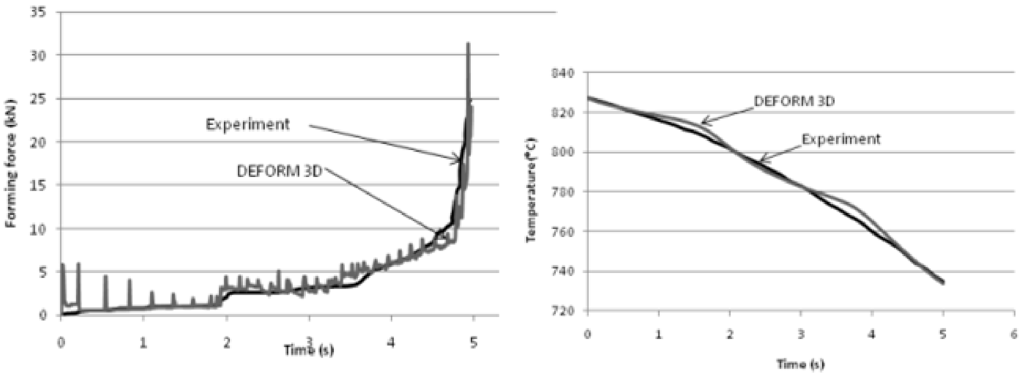

Figure 2*: Comparison of experimental and simulation results [9]*

2.2 2D Simulation of B-Pillar sections

This case study was taken from Numisheet-2008, Benchmark problem-3 [7].The material and process parameters are given in the problem statement. A 2D section of the section-3a is chosen for this study, to closely study the effects like thermal expansion and shrinkage of the part, varying contact conditions between die and tool, heat transfer between tool and the part.

The blank is considered to be elasto-plastic to capture the thermal effects and the dies are modeled as rigid objects with constant uniform temperature. The entire hot stamping (blank heating, blank transfer, forming, quenching and air cooling of part) process was simulated and the final thickness distribution in the part is given in Figure 4. The results have slight discrepancies at few locations due to simplifying assumptions and for neglecting the 3 dimensional metal flow.

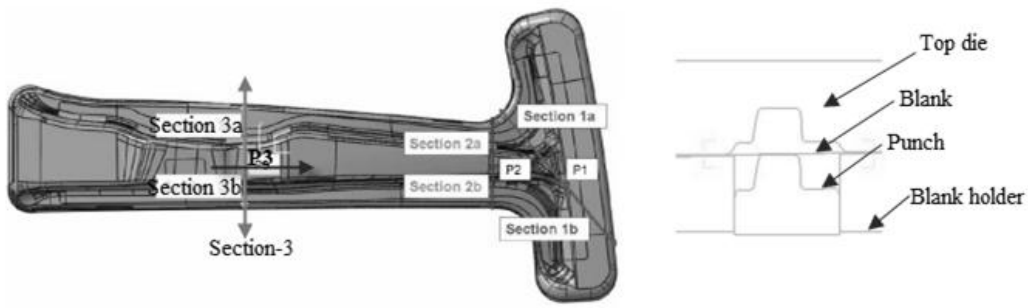

***Figure 3**: Section-3 as given in [7] and initial forming simulation setup for section-3*

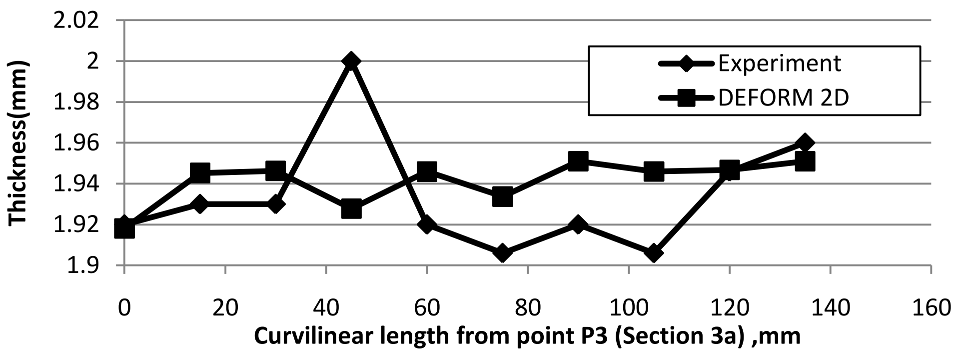

***Figure 4**: Comparision of thickness distribution from experiment and simulation for section- 3a*

2.3 Influence of Cooling Channel Configuration

For the section-3 defined in [7] and shown in Figure 3, a cooling channel configuration is assumed in the dies. From the reference [10], an initial cooling channel diameter of 8 mm and 10 mm distance from the die surface are chosen. The cooling channels were assumed to have a constant surface temperature. Quenching simulation was conducted for 20s under a constant closing pressure of 35 MPa with rigid dies. Figure 5 shows the temperature distribution on the die and punch after 10 forming cycles. The temperature was observed at three critical points in the formed part (Figure 6) to check the cooling rate achieved.

The maximum and minimum temperatures encountered in the blank are 193 and 74 °C respectively. The point at which the maximum temperature is observed at the end of the quenching cycle becomes the point at which the lowest cooling rate occurs. Thus, it is useful to know if this lowest cooling rate is above the minimum cooling rate required for martensitic transformation (27 °C/s) since it indirectly corresponds to the amount of martensite formed [11]. The cooling rate at the maximum temperature (193 °C) point on the blank is approximately 29 °C/s which is higher than minimum required cooling rate for martensitic transformation.

Figure 5*: Temperature distribution in the die (left) and punch (right) at the end of 10 forming cycles*

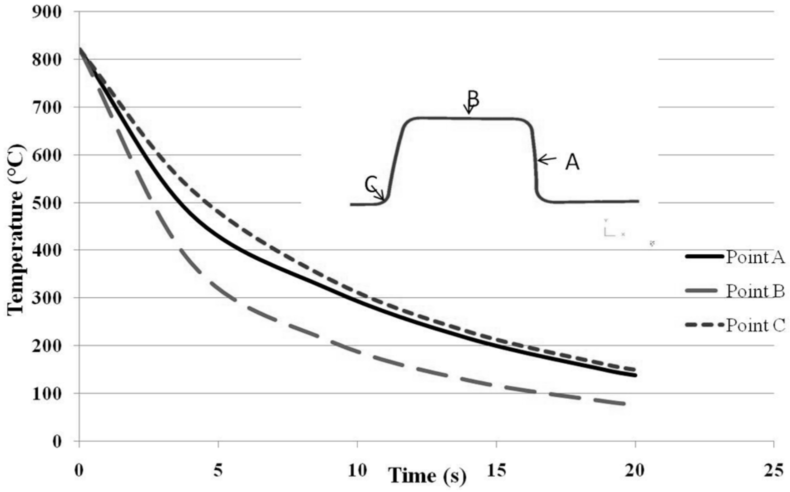

Figure 6*: Variation of temperature at points A, B and C during quenching (20 s)*

3. Conclusions, Ongoing and Future Work

In this study, we came to the following conclusions

a) Using a commercial FE code “DEFORM™”, hot stamping of simple part geometry (e.g. hat shape) can be simulated. This code is currently suitable for simulating simple laboratory experiments for hot stamping. It is useful for validating the material, interface condition and process parameters for hot stamping simulation.

b) For industrial complex geometries, forming simulation can be conducted faster and more robust using other commercial FE codes, specially developed for sheet metal forming (e.g. PAMSTAMP™, LS-Dyna™, etc). Figure 7 shows hot stamping simulation of a B-pillar using PAMSTAMP™. However, almost all FE codes for sheet metal forming model the blank using shell element and the dies as surface objects (not solid). As a result, calculation of through-thickness heat transfer, both in the blank and dies, may not be accurate.

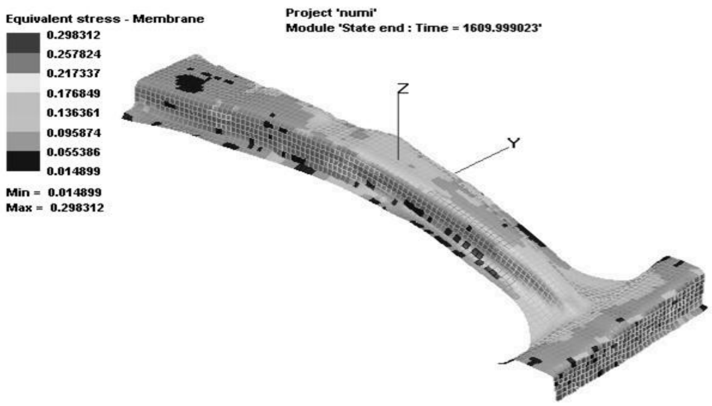

Figure 7*: Preliminary forming simulation of NSBM-3 using PAMSTAMP*

c) Using the forming simulation results (local necking, hot spots), critical sections are selected and quenching process at the 2D cross section are simulated using DEFORM™ to correct die surface geometry for improved contact and cooling channel optimization. Die are considered elastic.

d) At the Center for Precision Forming (CPF), we recently proposed to use both DEFORM™ and PAMSTAMP™ for robust modeling of hot stamping. First, simulation process starts with DEFORM™ for heat transfer analysis of the blank, considering thermal expansion during blank heating and shrinkage during blank transfer. Second, the blank object is transferred to PAMSTAMP™ for simulation of metal flow. Third, the blank information from PAMSTAMP™ (temperature, shell profile, thinning distributions) is transferred back to DEFORM™ for thermal analysis on quenching of the blank as well as heat transfer in cooling channels. Due to major differences in both FE packages such as shell vs. solid elements, it is necessary to develop a practical interfacing software module in order to convert blank information that provides seamless transfer between DEFORM™ and PAMSTAMP™. This research strategy will be implemented to facilitate modeling of hot stamping for the geometries selected by sponsors (as listed in item (e)).

e) CPF is currently working on proprietary projects to analyze hot stamped components for 3 different companies.

- Case 1: All stages of the hot stamping, i.e. heating of the blank, transfer of the blank from furnace to die, forming and quenching were simulated using DEFORM-2D and 3D. Results of quenching simulation are obtained. Simulations of forming were also conducted in PAMSTAMP. The results indicate PAMSTAMP provide better prediction of thickness distribution, when comparing to experimental data provided by the company.
- Case 2: Preliminarily PAMSTAMP simulations were conducted for holding and forming operations. The results shows that with sufficient blank holder force the blank can be suc-

cessfully formed, with acceptable thinning and small wrinkling. However, blank temperature during forming varies from 850 to 950 °C, as shown in Figure 8.

- Case 3: Part geometry at the 2D cross section was provided. Simulations were conducted using DEFORM-2D to gain understanding of thickness and temperature variations. Several inputs (initial blank and die temperatures, etc.) were assumed using literature data. Additional process information will be acquired to improve the FE model.

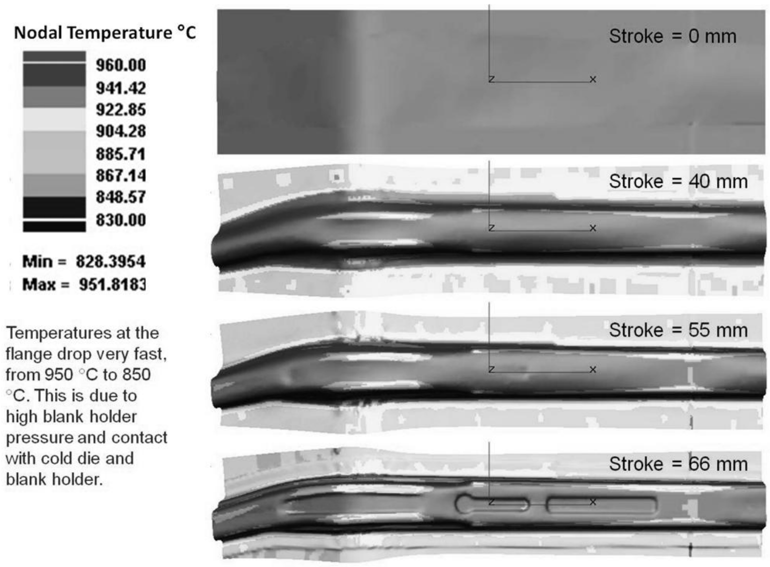

Figure 8: *Preliminary forming simulation of a part geometry (Case 2) using PAMSTAMP™*

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