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Research Paper

Numerical modeling of the thermal deformation during stamping process of an automotive body part

Junghwan Choi [a], Beomjoon Choi [a], Soojeong Heo [b], Youkeun Oh [c], Seungwon Shin [c,*]

[a] *Department of Mechanical Engineering, Hongik University, Seoul 121-791, Republic of Korea*
[b] *Advanced Body Manufacturing Engineering Team, Hyundai Motor Company, Republic of Korea*
[c] *Department of Mechanical and System Design Engineering, Hongik University, Sangsu-dong, 72-1, Mapo-gu, Seoul 121-791, Republic of Korea*

HIGHLIGHTS

- Thermo-mechanical FEM was developed for thermal deformation during stamping.
- Experimental measurement for benchmarking numerical model was performed.
- Detailed analysis was performed during sub steps of stamping process.
- Thermal deformation was comparable to overall spring back distance.
- Plastic deformation plays critical role compared to frictional heat generation.

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ABSTRACT

In this study, a thermo-mechanical finite element model was developed to investigate the thermal deformation during a stamping process of an automotive body part. The stamping process was decomposed into the 6 sub-steps to reflect the physical boundary conditions found in an actual stamping equipment. The temperature distributions of the actual stamping process were measured by two thermography cameras. The developed numerical procedure was then validated against the measured temperature distributions. Due to the limited accessibility to the actual equipment and high reflectivity of the involved material, the reflectivity index for the thermal imaging device (i.e., emissivity) was experimentally determined. A sample specimen made of the same material with the die material was built. The thermocouples were placed underneath the specimen surface through holes and used to directly measure the surface temperature distribution. The emissivity for the sample specimen was then determined by comparing the temperature measured by the thermocouples to the temperature measured by the thermographic camera. When the lubrication oils were spread on the sample specimen, the emissivity was set to a value 0.7. The thermal images were corrected based on the emissivity experimentally obtained and used to validate the finite element model simulation for the stamping process. With the validated finite element model, the investigation on the variation in the temperature and stress during each sub-step was performed. With the zero thermal expansion rate, the pure thermal effect on the temperature distribution was simulated. The pure thermal deformation in the Blank (i.e., target surface) was similar to the spring back distance after the blank was released from the molds. During the stamping process, the heat generation was obtained due to either friction between surfaces and plastic deformation of the target surface. We found that the plastic deformation played a critical role in the final temperature rise.

1. Introduction

Stamping is widely used in various industries due to its massive manufacturing capability. Flat metal sheet can be formed into a designed component with complicated 3-dimensional shape [1]. In the automotive industry, many individual parts including outer frames are manufactured from the stamping process. These stamped parts then are assembled into a final product in a systematic way. Thus, any dimensional deviations of each component from its intended specifications could directly affect the productivity or product yield rate. The dimensional deviation usually represents an induced error in length, width, hole location, curvature, etc., when compared against its target dimension. Even with a

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* Corresponding author.
E-mail addresses: power_y@naver.com (J. Choi), cb8878@naver.com (B. Choi), Soojeong.Hoe@hyundai.com (S. Heo), youkeun@hongik.ac.kr (Y. Oh), sshin@hongik.ac.kr (S. Shin).

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Nomenclature

T	temperature [K]	μ	viscosity [kg/m·s]
P	pressure [Pa]	α	thermal diffusivity [m^2/s]
u	velocity [m/s]	Re	Reynolds number
ρ	density [kg/m^3]	Ra	Rayleigh number
k	thermal conductivity [W/m·K]	g	gravitational acceleration [m/s^2]
c	specific heat [J/kg·K]		

small deviation on individual assembly parts, overall assembly process could be significantly hindered. To minimize the dimensional discrepancy and manage individual parts within an allowable tolerance range, it is warranted to identify the source of the dimensional deviations and its effect on overall manufacturing process.

This study investigates how much the dimensional deviation can be affected by the temperature during a stamping process. While a metal sheet is stamped, the temperature over the metal work piece can be raised up due to friction between the metal piece and mold or due to its plastic deformation thereby resulting in a noticeable temperature difference compared to the surrounding environment [2]. The stamped metal pieces are then usually stacked in a rack and stored in an open space. It would not be feasible to control the environmental temperature to a fine level. Moreover, the difference in the ambient temperature between a hot summer and cold winter season could reach 50 °C in the region of South Korea. The temperature difference may significantly affect the dimensional deviation over the entire stamping and storing process. Sometimes, the stamped parts during the assembly process have to be moved from a factory to another factory resulting in being exposed to the uncontrolled ambient temperature for a relatively long period. In case of the significant temperature difference between a product and surrounding space, a final product from the stamping process can be significantly deviated from the intended dimensional specification hindering its efficient assembly process afterward. In general, the dimensional deviation is randomly distributed throughout product surfaces. So it would be a cumbersome task to control the dimensional deviation within its tolerance range.

It has been empirically observed that the dimensional deviations between seasons could be related to the seasonal difference in the ambient temperature. This is partly because the ambient temperature can affect the ductility of a metal sheet to be stamped. Based on the previous meteorological records in South Korea, the lowest temperature during winter and highest temperature during summer were recorded to be −10 °C and 40 °C, respectively. So, the seasonal temperature difference could be up to 50 °C. This implies that the ambient temperature might have a significant effect on the thermal deformation in the final product. Hence, it is important to identify the effect of the seasonal changes in the ambient temperature on the thermal deformation in order to manage the product tolerance within its desired range.

Due to the complexity associated with the stamping process, it is a formidable task to identify the thermal effect in a theoretical manner. It is required that the overall association between the temperature and stress variation during the stamping process should be investigated to better understand the thermal effect on the final deformation. When a metal sheet is stamped, its temperature change can be induced not only due to the friction between the metal sheet and molds, but also due to the plastic deformation while it is permanently stretched and deformed. The heat generation causes the temperature rise of the product which results in the increased temperature difference from the ambient condition. The importance of the temperature change was already pointed out by several researchers. Archard [3] confirmed that most friction loss between die surfaces would be converted into heat during stamping process. Kim et al. [4] found that heat generation during stamping process caused significant effect on formability of metal sheets. The heat generation is also randomly distributed throughout space and time affecting the dimensional deviation of final products in an unexpected way. Stamping process especially in automotive body parts operates on a large scale with heavy moving parts. Thus, it is difficult to experimentally investigate the process due to the limited access and cost related issues. So, the numerical simulation could be a good candidate for the detailed analysis [5,6].

Direct numerical simulations on stamping process have been carried out by several researchers. van der Lugt and Heutink [7] developed a combined Eulerain-Lagrangian FEM formulation for coupled thermos-mechanical problem of metal-forming process. Both of the displacement and temperature during a wire-drawing process were obtained using the combined Eulerain-Lagrangian approach. Kim et al. [8] developed a finite element numerical model to identify the lubrication effect on stamping process. The developed numerical model was applied to the manufacturing process of axisymmetric cup and predict maximum temperature and pressure distribution of the subject material and mold. They found that both maximum temperature and pressure were located at the die corner radius. Pereira et al. [9] utilized the finite element analysis to model the contact pressure evolution during the metal stamping process for automotive industry. Their focus was made to identify the wear effect in relation to the contact pressure. They then updated their model by including the sliding distance in the formulation and thus completely characterized the time-dependent contact condition between the Blank and die surfaces [10]. Recently, Pereira and Rolfe [11] proposed a thermo-mechanical finite element model for the sheet metal stamping process to investigate the temperature condition generated by the friction between a blank and die materials and the deformation-induced heat. A commercial finite element analysis software (ABAQUS) was utilized for their numerical study. A relatively simple geometry for the channel shaped components was considered for a single-action mechanical press in comparison with its matched experiment. The detailed geometry and process parameters for the numerical simulation were carefully devised. The temperature evolutions at two local points were compared between the results from simulation and experiment for the benchmark. Due to the delay in measurement temperature response, proper comparison was possible only in low speed operating condition. They found that stamping high strength steel at realistic condition could generate high temperature rise between the blank and die surfaces and increased temperature could affect the formability and tool wear performance directly.

Temperature effect on stamping process has been mostly focused on wear of the tool. Groche et al. [12] studied temperature variation in adhesive wear for deep drawing process of aluminum sheet. They also found correspondence between the location of the maximum temperature and adhesion wear. Gaard et al. [13]