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Development of a Model for Predicting Cycle Time in Hot Stamping

R Muvunzi[a*], DM Dimitrov[a], S Matope[a], TM Harms[b]

[a]Department of Industrial Engineering, Faculty of Engineering, Stellenbosch University
[b]Department of Mechanical and Mechatronic Engineering, Faculty of Engineering, Stellenbosch University, Stellenbosch 7600, South Africa

Abstract

In manufacturing, reducing the cycle time results in lower production costs. The cycle time in a hot stamping process affects the quality characteristics (tensile strength) of formed parts. A faster cooling rate (>27 K/s) of the blank guarantees the production of a part with the required microstructural properties (martensite). This compels researchers to continuously develop ways of increasing the manufacturing speed. On the other hand, it is important to predict the minimum cycle time for a given set of parameters which does not compromise the quality of formed parts. In this paper, a model for predicting the cycle time for a hot stamping process is presented. The lumped heat capacitance method is used in formulating the model since the temperature gradient across the blank and heat transfer within the plane of the blank are considered negligible. To validate the equation, a finite element simulation was conducted using Pam-Stamp software. The results show that the proposed model can be useful in further studies targeted towards cycle time reduction in hot sheet metal forming processes.

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Keywords: hot stamping; cycle time; model; blank

1 Introduction

In hot stamping, a thin metal sheet (blank) is heated to a high temperature (between 900 to 950 ^{o}C) and transferred to a press where it is formed and quenched. This results in the production of components with high tensile strength

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[*] Corresponding author. Tel.:+27633955078.
E-mail address: rmuvunzi@sun.ac.za

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(1500 MPa) [1]. Figure 1 summarizes the hot stamping process.

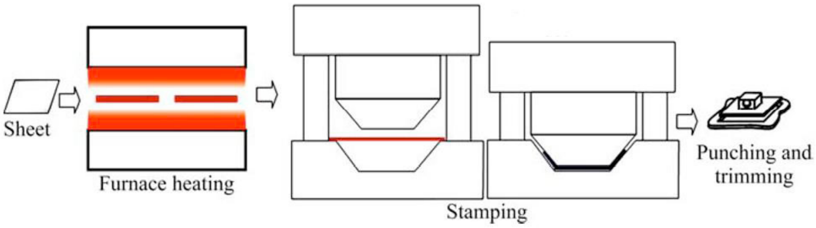

Figure 1: Hot stamping process [2]

The cooling stage occupies more than 30 % of the total cycle time [3]. Hot stamping tools are manufactured with an in-built cooling system in the form of channels in which a coolant flows to extract heat from the tool. An increase in the cooling rate results in improved productivity. Research efforts are targeted towards the reduction of the cycle time. This involves design of more effective cooling systems with improved heat transfer capabilities. Shan *et al.* [4] suggested a method for calculating optimum cooling system parameters based on theoretical analysis and numerical simulation. Lim *et al.* [5] proposed two approaches for designing cooling systems. The first approach is focused on reducing maintenance costs and the other is centred on the reduction of cycle time. A reduction of cycle time by 25 % was achieved. Liu *et al.*[6] used the evolutionary algorithm to design a hot stamping tool with optimized cooling channels and this resulted in a cooling rate of 40 °C/s. Lin *et al.* [7] developed another method based on simulation.

Another strategy for reducing the cooling time involves the use of tool steels with improved thermal conductivity [8]. Ghiotti *et al.* [9] investigated the application new tool steels with thermal conductivity of up to 60 W/m°C. Further information on the use of high thermal conductivity tool steels (30-45 W/mK) was presented by Escher and Wilzer [10]. Despite all the above-mentioned efforts, there has not been much study focused on determining the minimum cycle time. It is important to identify the minimum possible cycle time which does not compromise the quality of parts as this will be used in further research as a benchmark for seeking opportunities for further reducing the cycle time. The paper presents a model which was developed to predict the minimum cycle time in hot stamping. The cycle time is considered as the total time for transfer, forming, cooling and extraction of the blank.

In developing the model, the thermal gradient across the blank is assumed to be negligible because of the small blank thickness (0.6-3.0 mm), high thermal conductivity (40-45 W/mK) and large surface area to volume ratio of the blank [11]. Hence, the lumped heat capacity method was considered since it is applicable for situations when the thermal gradient is negligible. Abdulhay *et al.* [11] calculated the Biot number using a blank with a thickness of 1.55 mm at different contact pressure values (0-30 MPa). Although the range for the Biot number obtained from the calculations varied between 0.05 and 0.25, they considered the blank as having uniform temperature. According to experiments conducted by Zhao *et al.*[12] using a 2 mm blank, the maximum Biot number was 0.2. Similarly, the temperature gradient across the blank is assumed to be negligible. For situations in which there is significant thermal gradient in a solid, the finite difference method becomes applicable. External heat transfer modes might include convection (q_{conv}), radiation (q_{rad}), surface heat flux (q) and internal heat energy generation ($\dot{E}_g$) [13]. The general lumped capacitance analysis can be summarized using equation 1 as stated by Bergman *et al.*[13].

$$q + \dot{E}_g - (q_{conv} + q_{rad}) = \dot{E} \tag{1}$$

The lumped heat capacitance method has been applied for the transfer and cooling time. In this case, the total cycle time is regarded as the sum of transfer (t_1), placement, extraction (t_2) and cooling time (t_3) as shown in equation 2.

$$t_c = t_1 + t_2 + t_3 \tag{2}$$