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Temperature conditions during ‘cold’ sheet metal stamping

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ABSTRACT

This paper investigates the friction and deformation-induced heating that occurs during the stamping of high strength sheet steels, under room temperature conditions. A thermo-mechanical finite element model of a typical plane strain stamping process was developed to understand the temperature conditions experienced within the die and blank material; and this was validated against experimental measurements. A high level of correlation was achieved between the finite element model and experimental data for a range of operating conditions and parameters. The model showed that the heat generated during realistic production conditions can result in high temperatures of up to 108 °C and 181 °C in the blank and die materials, respectively, for what was traditionally expected to be ‘cold’ forming conditions. It was identified that frictional heating was primarily responsible for the peak temperatures at the die surface, whilst the peak blank temperatures were caused by a combination of frictional and deformation induced heating. The results provide new insights into the local conditions within the blank and die, and are of direct relevance to sheet formability and tool wear performance during industrial stamping processes.

1. Introduction

The increased use of advanced high strength steels (AHSS) in the automotive industry has resulted in an increase in formability and wear issues during stamping production. To successfully stamp AHSS, experience from the stamping press shop shows that press speeds and production rates often need to be reduced to minimize work-piece splitting and/or tool wear problems. This indicates that friction and deformation-induced heating are of significance to the stamping of higher strength sheet steels, for what is expected to be ‘cold’ forming conditions.

The phenomena of deformation-induced heating and frictional heating are well known and have been discussed in the literature for many years. For example, the early work by Farren and Taylor (1925) showed that approximately 90% of the work done is converted to heat during the rapid plastic deformation of several metals. Archard (1959) described the theoretical maximum flash temperatures that occur at the surfaces of rubbing materials, where nearly all the energy dissipated by friction appears as heat. The effect of this deformation-induced and frictional heating on the lubrication and wear performance for sheet metal ironing processes has been studied recently, with temperatures in the order of 100 °C observed near the tool surface for the ironing of stainless steel sheet (Nielsen et al., 2011). However, the analysis of friction and deformation-induced heating during room temperature sheet metal stamping has received little attention in the literature. Due to the increased work and contact pressures required to form the higher strength sheet materials (Pereira et al., 2008), significant temperatures can be generated at the blank and tool surfaces during stamping processes.

Recently, there have been a few studies that have used finite element analysis (FEA) to examine the temperatures generated in the blank and/or die during continuous bending-under-tension-type processes. Groche et al. (2008) predicted that small temperature rises (less than 20 °C) can occur at the die radius region during the strip drawing of aluminum at 100 mm/s. For a draw-bending process, Kim et al. (2011) predicted that temperatures of up to 100 °C can occur in dual-phase (DP) steel blank material during industrial-type deformation rates (approximately 50 mm/s). Groche et al. (2008) showed that the peak temperature regions corresponded to regions of galling on the tool surface, while Kim et al. (2011) concluded that the deformation heating has a significant influence on the failure behavior of the sheet material.

The effects of friction and deformation-induced heating during discontinuous stamping-type processes have received less attention in the literature. Considering an axisymmetric cup forming process, Kim et al. (2009) used finite element modeling to predicted that a dual phase steel (DP590) blank and D2 tool steel die could reach maximum temperatures of 86 °C and 46 °C, respectively.

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Pereira et al. (2010a) predicted that temperatures of over 100 °C can occur at the die radius when stamping AHSS sheet grades (DP590 and DP780) using D2 steel tools. Interestingly, the results by Pereira et al. (2010a) showed that the peak temperature rise would occur at the beginning of the die radius, with the largest temperature rise occurring at the die (not blank) surface. The results presented by Kim et al. (2009) showed the opposite behavior – i.e. the maximum temperature on the die was predicted to occur toward the end of the radius, while the maximum temperature rise on the blank was more than double that on the die. It is evident that further work is required to understand the temperature behavior in both the sheet and die material during sheet metal stamping. This is particularly important when considering the high temperatures predicted to occur when forming high strength steels and the high process speeds used in many automotive stamping press lines.

The studies discussed in the preceding paragraphs do not provide quantitative comparison of the finite element model temperature predictions to experimental temperature measurements. Therefore, there is also a need to provide experimental validation for the temperatures predicted, to provide confidence in the numerical models.

This study examines the friction and deformation-induced heating of high strength sheet steels during sheet metal stamping. A novel semi-industrial stamping test facility was instrumented to provide temperature measurements at the die radius region, both at the die-to-blank interface and below the die surface. A thermo-mechanical finite element model of the semi-industrial channel forming process was developed. The model demonstrates good agreement with experimental measurements of punch force, blank and die surface temperature and die bulk temperature during a low speed stamping operation for two blank material grades. The developed finite element model was then applied to replicate the true ram speed during production-type operating conditions – i.e. when the rate of the mechanical press is 32 strokes per minute. Consequently, the results provide new insights into the temperatures that occur within the die and blank material during industrial cold sheet metal stamping conditions. Finally, the model was utilized to highlight some of the factors that strongly influence the temperature rise in the blank and die during sheet metal stamping.

2. Experimental setup

2.1. Process, geometry and operating conditions

Fig. 1a shows a schematic of the tooling setup for the semi-industrial stamping test, which forms the basis of this study. A single-action mechanical press was used to stamp the channel-shaped components, with the geometric and process parameters (detailed in Table 1) closely representing that of a typical automotive structural member. This section provides aspects of the experimental set-up relevant to this study. A full description of the experimental set-up is available in Pereira et al. (2013).

Table 1
Summary of the main geometric and process parameters used in the stamping tests.

Parameter	Value	Unit
Average blank holder force	27.2	kN
Average ejector pin force	1	kN
Blank length, l	150	mm
Blank width	26	mm
Blank thickness, t	1.8, 2.0	mm
Die corner radius, r_d	5	mm
Draw depth	40	mm
Press stroke length	203	mm
Punch corner radius, r_p	5	mm
Press rate	1, 32	min^{-1}
Punch width, a	30	mm
Punch-to-die gap, g	2.35	mm

The tooling setup permitted control of the blank holder force, via gas springs. The magnitude of the blank holder force was chosen to be sufficient to maintain closure of the blank holder during the forming stroke, as determined from finite element model calculations. The punch force was recorded during the stroke using a piezoelectric load cell that was located below the punch. For all stamping tests, the blank material was lubricated with a thin film of anti-corrosive oil, as delivered from the steel mill.

The mechanical press operated continuously at 32 strokes per minute. At this press rate, the punch speed is approximately 300 mm/s at the beginning of the forming operation and reduces to 0 mm/s at the end of the 40 mm forming stroke (see Fig. 2a), as governed by the geometry and kinematics of the press and tooling system and the press crankshaft rotational speed. The mechanical press could also operate at a much slower speed of approximately 1 stroke per minute (normally used for process setup, etc.). This press rate resulted in a punch speed of approximately 8 mm/s and 0 mm/s at the beginning and end of the sheet metal forming operation, respectively (see Fig. 2b). For convenience, the two press operation modes will be subsequently denoted as ‘high speed’ and ‘low speed’. As shown in Fig. 2, the duration of the forming stroke is approximately 0.25 and 8.9 s for the high and low speed modes, respectively.

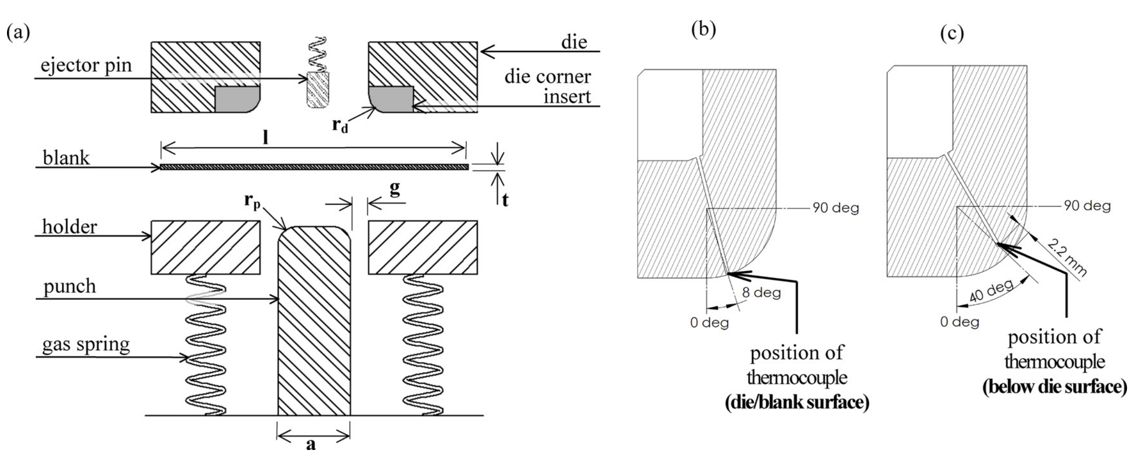

Fig. 1. (a) Schematic of the tooling setup for the sheet metal stamping process. (b and c) Schematic of thermocouple placement, showing section view of die corner inserts (not to scale).