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The effect of partially cut-out blanks on geometric accuracy in incremental sheet forming

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ABSTRACT

Industrial requirements for accuracy in metal sheet components are typically ±0.2 mm where current incremental sheet forming processes are capable of an accuracy of only ±3 mm. Several approaches based on process design modifications or control strategies are being developed to overcome this problem, but none has as yet been entirely successful. This paper proposes and examines a new approach in which the area to be formed within the blank is "partially cut-out" using a water jet or laser cutter. The aim of this partial cut-out is to localise deformation to the area over which the tool travels and thus reduce the difference between a part made by a "contour tool path" and the target product geometry. Several design options are considered, and the approach is evaluated with one simple and one complex part. The results indicate that partially cut-out blanks lead to slightly more accurate forming than conventional blanks when unsupported, but that the accuracy improvement is less than that which is achieved by use of a stiff cut-out supporting plate. The results include an experimental investigation of residual stresses and springback in incremental sheet forming.

1. Introduction

Geometric accuracy has been a key concern for developers of the incremental sheet forming process since its inception. Allwood et al. (2005b) report that industrial users of sheet forming processes typically specify geometric tolerances of around ±0.2 mm over the whole surface of a part, and yet the performance of incremental sheet forming processes is typically more than 10 times worse than this.

In fact, three definitions of geometric accuracy can be given for this process, each of which has progressively worse tolerance:

- Clamped accuracy – is defined relative to the geometry of the part when still clamped within the blank-holder of the process. This is what would be 'seen' by on-line measurement of part geometry.
- Unclamped accuracy – is defined relative to the part when it has been released from the blank-holder, and is typically significantly worse than the clamped accuracy due to residual stress created in the process.
- Final accuracy – is defined relative to the part when it has been cut out from the unwanted material of the blank. In some cases, cutting out a shallow dish part can actually lead to a loss of all apparent curvature created while the part was clamped.

The degradation in unclamped and final accuracy arises due to residual stresses in the sheet but to date these have had very little attention in the literature. Accordingly it is currently not possible to compensate for residual stress by forming a part of a different geometry that will 'spring' into the target shape. One potential solution to this problem is to anneal the component after forming. Bambach et al. (2009) have shown that stress-relieving the part before trimming improves the accuracy significantly, reducing the geometrical error by a factor of 6–10. However, they also point out that the sheet may distort during annealing as well, and suggest that it may be necessary to constrain the sheet by clamping it in a set of dies which as they indicate, reduces the flexibility of the process. Dejardin et al. (2010) have performed some springback analysis to validate their numerical model. Tanaka et al. (2007) studied the residual stresses in more detail, using a simplified numerical model; only a segment of the sheet was modelled, but with eight elements through the thickness. This model was applied to study the effect of tool feed and tool radius on the residual stresses in the sheet, and to investigate the effect of through-thickness compression on the residual stresses. Through thickness compression was applied by a second hammering tool on the other side of the sheet. They conclude that the springback in ISF comes from residual moments in the sheet, that the tool radius has a sig-

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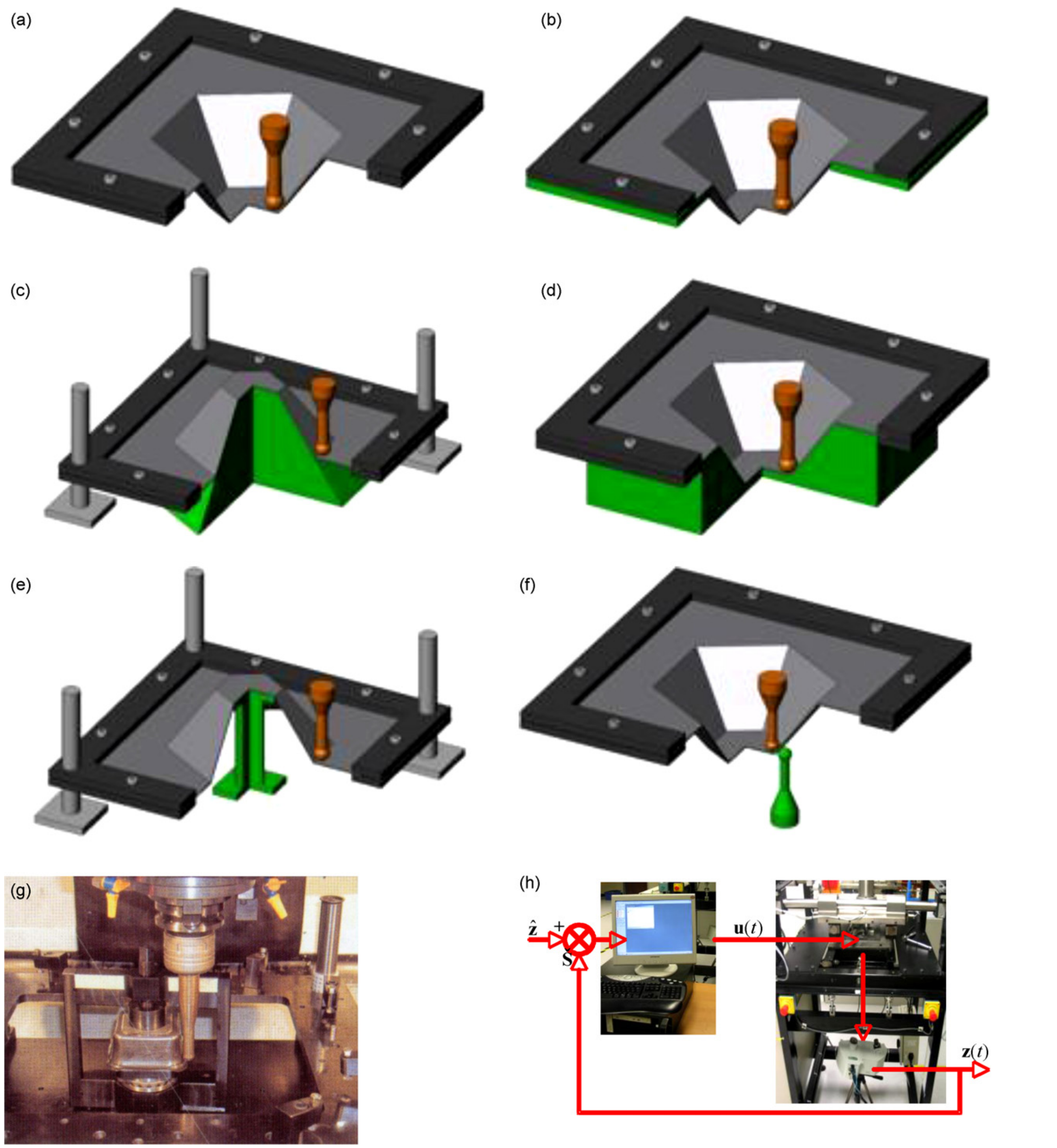

Fig. 1. Variants of the incremental sheet forming process designed to improve accuracy. (a) The simplest process. (b) Use of a backing plate with cut-out. (c) Forming over a male die. (d) Forming into a female die. (e) Two point forming, static lower tool. (f) Two point forming, both tools moving. (g) Male die with free edges. (h) Closed-loop feedback control.

nificant influence on the residual moment in the sheet and that compressing the sheet through the thickness reduces the variation of residual stresses through the sheet.

Current responses to the problem of accuracy in incremental sheet forming are mainly focused on modifications to the process configuration and strategies for adjusting the tool-path. These are illustrated in Fig. 1 and briefly discussed below:

Backing plate: Many authors dating back to the original work by Iseki et al. (1992) have used a stiff backing plate, as shown in Fig. 1b, with a cut-out shaped to match the outer perimeter of the desired part to support the workpiece and localise deformation. This moves one-step away from the vision of a tool-less process, but has proved effective.

Male die: Iseki et al. (1992) demonstrated that a part could be formed over a male die as shown in Fig. 1c