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Experimental investigations and numerical analysis for improving knowledge of incremental sheet forming process for sheet metal parts

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ABSTRACT

The paper is related to the analysis of shape distortions and springback effects arising in single point incremental sheet forming in order to study the use of a FE model based on shell elements to perform simulation of the process. A comparison between numerical and experimental results is made to assess the suitability of the model. The measurements of geometrical profile of a truncated cone and springback of cut rings show that the FE model allows to predict accurate results for a set of well defined process parameters. The deformation mechanism of ISF is taken into consideration to determine the limits of the model studied.

1. Introduction

The requirements associated with customized production and cost reduction are still growing and new technologies seem to offer a sustainable approach to answer to such requests. This is a reason for the increasing interest in flexible forming processes like incremental sheet forming (ISF). Indeed, the ISF concept consisting in a progressive and localized deformation of a sheet metal part is flexible because no specialized tooling is required. The movements over the surface of the sheet of a simple forming tool cause to a highly localized plastic deformation. Regarding the concept of such a technology, a wide range of 3D shapes can be formed with a correct definition of the forming tool path controlled by a CNC machine. In addition to this, ISF also leads to a higher material formability in comparison with conventional forming processes like stamping. These advantages bring to a growing interest in both academic and industrial research centers as it is demonstrated in literature. Automotive panels manufactured by Amino et al. (2002) using ISF or customized medical products produced by Ambrogio et al. (2005a) are relevant examples. A global review of works and achievements made in incremental sheet forming has been proposed by Jeswiet et al. (2005).

Despite numerous researches in ISF during the last decade, the deformation mechanism is not fully determined. A deep understanding of the deformation mechanism is important to allow an accurate numerical modelling of the process to predict the sheet behaviour and to make possible the process control. In this sense, recent results obtained by Jackson and Allwood (2009) clearly show that there is a relevant amount of shear in ISF. So it becomes clear now that the deformation mechanism of ISF is not "almost pure stretching" as it has been described in Filice et al. (2002) or Hirt et al. (2003) for example. Therefore, these results have raised the question of the validity of numerical model based on shell elements to simulate the process. Despite the previous considerations, the reported study is focused on the possibility to use an adapted FE model of the process based on shell elements to predict accurate results associated with a well defined set of process parameters. A short review of previous works in ISF is given in Section 2 in order to clearly define the proposed study.

2. Review

Many types of incremental sheet forming processes have been investigated, including the use of a flexible support or a counter pressure, the development of multipoint incremental forming as it is described in Micari et al. (2007), but the most widely used tool is a hemispherical punch. The main configurations of ISF are single point incremental sheet (SPIF) and two-point incremental sheet forming (TPIF). In SPIF, a sheet is clamped around its edges

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and deformed by a simple forming tool (generally of hemispherical shape) which presses on one side of the sheet and moves around from a proper forming tool path, whereas in TPIF, the sheet is formed against a die or a second mobile tool. In both cases, the most common forming strategies used are contours or spirals combined with an increasing depth, following the profile of the product. Associated with these different versions of ISF, the numerous process parameters play an important role in material formability and deformation mechanism. Jackson and Allwood (2009) have recently reviewed the previous research made into the deformation mechanics and have demonstrated, by a rigorous measurement of a cross-section of a 3 mm thick copper plate, that the deformation mechanisms of both SPIF and TPIF are increasing stretching and shear in the plane perpendicular to tool path direction and shear in the tool path direction. This conclusion has been already experimentally demonstrated by Jackson et al. (2008) through the detection of the presence of through-thickness shear in the direction of punch movement by measuring the relative displacement of both surfaces of a sandwich panel deformed by SPIF. Bambach et al. (2003) have also remarked through numerical analysis, that the occurrence of shear through the thickness and have observed that the level of shear depends both of the forming tool diameter and the vertical forming step increment.

Such results have to be taken into account to develop accurate models of the process. Numerical modelling of ISF based on the idealized deformation mechanism seems to be questionable. Until now, it has been accepted that the deformation mechanism resulting from ISF is largely one of plane and in plane stretching has been noticed for a straight sided pyramid formed by TPIF by Bambach et al. (2003), for a truncated cone formed by SPIF from various materials by Fratini et al. (2004), and for various shapes formed by SPIF by Jeswiet and Young (2005).

Considering recent results demonstrated by Jackson and Allwood (2009), shell elements seem not to be the best choice to predict shear mechanism deformation on the thickness of the sheet metal part. Bambach et al. (2003) suggested using a 3D FE model with four continuum elements through the thickness. This model predicted that shear in the plane perpendicular to the tool direction dominates in TPIF. In the sheet metal plane parallel to the tool direction, it was predicted that shear strains occur, increasing when decreasing the head forming tool diameter, which is in contradiction with the plane strain assumption. However, the model used also predicted that stretching is significant in the plane perpendicular to the tool direction in SPIF but also that all strain components are negligible in the direction parallel to tool path. Jackson and Allwood (2009) mentioned that it is not necessarily a contradiction to the experimental measurements of Allwood et al. (2007) because the tool path used by Bambach et al. (2003) alternated in direction. This forming strategy leads to cancel any shear on successive laps as a result of friction, whereas the tool always moved in the same direction in the strategy used by Allwood et al. (2007).

In addition, the results described by Jackson and Allwood (2009) have been obtained through an experimental campaign performed on a 3 mm thick copper plate which represents the thickness limit for thin metal part.

2.1. Context of present work

This paper is focused on the necessity to define a reliable relationship between ISF parameters, including both material parameters (thickness, flow stress, hardening, friction) and process parameters (forming tool path or forming tool diameter), to develop suitable models for the process. Despite the previous considerations, the reported study analyses the possibility to use a simple FE model of the process based on shell elements to predict accurate results in terms of geometrical accuracy (final shape,

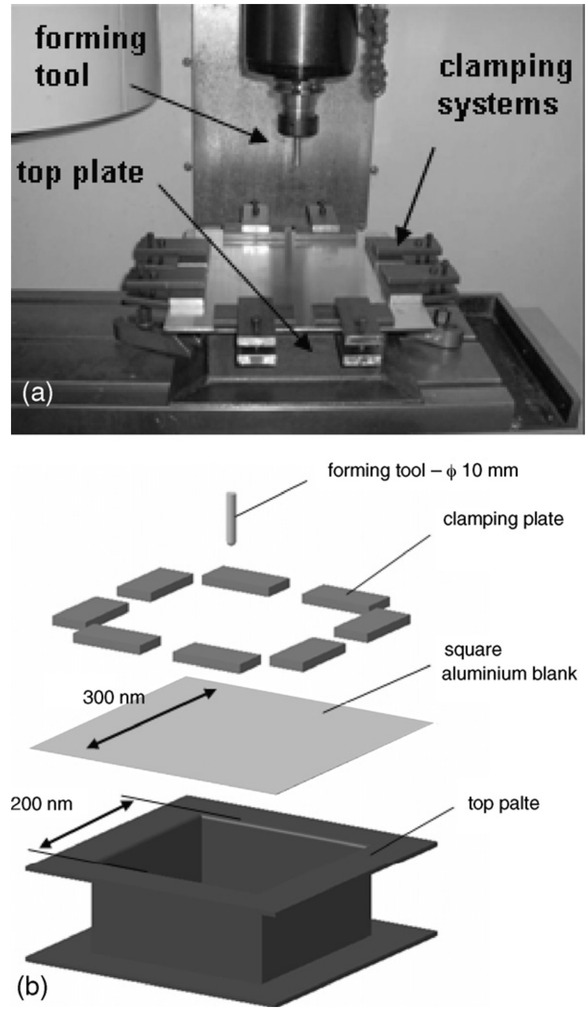

Fig. 1. (a) Experimental setup for SPIF experiments (three-axis milling machine tool—SPIF tooling system). (b) Tooling system used for SPIF experiments.

springback), in the case of thin metal sheet. The forming strategy is also investigated to underline its influence on the resulting formed part. The first aim is to measure geometrical profiles of truncated cones resulting from SPIF and to compare the experimental results with the numerical ones. The study is then completed by a springback analysis of circumferential rings by focusing on the influence of the forming tool path on the resulting parts.

The investigations that are related in this paper result from the previous work carried out at FEMTO-ST Institute and from the Dejardin (2008) PhD thesis.

3. Experimental investigations

3.1. Experimental platform

Experiments were carried out using a three-axis CNC milling machine as a platform to develop the ISF process. An experimental tooling system, where the sheet metal part is supported around its contour, was fixed on the horizontal movable table of the milling machine. Simple clamps allow to maintain the sheet metal blank in position during the movement of the tooling system (Fig. 1).

The forming tool consists in a barrel with 10 mm diameter and hemispherical end shape. A subroutine has been developed to describe tool path from CAM procedure for simple geometries. In order to compare experimental and numerical results, this