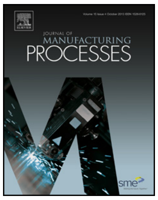
Journal of Manufacturing Processes xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro



Prediction of forming forces in single point incremental forming☆

Ankush Bansal[a], Rakesh Lingam[a], Sateesh Kumar Yadav[b], N. Venkata Reddy[a,*]

[a] Department of Mechanical and Aerospace Engineering, Indian Institute of Technology Hyderabad, India
[b] Department of Mechanical Engineering, Indian Institute of Technology Kanpur, India

ARTICLE INFO

Article history:
Received 17 November 2016
Received in revised form 14 February 2017
Accepted 3 March 2017
Available online xxx

Keywords:
Incremental forming
Thickness prediction
Force prediction
Analytical model

ABSTRACT

Incremental sheet forming (ISF) is a cost effective die-less forming process for low volume production. Achieving good accuracy using this process is a challenging task. Bending between clamped boundary and component opening, tool deflection, sheet spring-back and rigid body displacements are the major reasons for geometric inaccuracy in components formed using ISF process. In order to achieve desirable geometric accuracy, accurate prediction of sheet thickness, tool-sheet contact area and forming forces is important. In this article, modified analytical model is presented to accurately predict formed component thickness, contact area and forming forces during single and multi-stage incremental forming. Predictions of models presented in this work are compared with experimental work carried out during this work as well as experimental results available in the literature and they are in good agreement. Prediction models developed during the present work require very less computational resources compared to finite element analysis.

© 2017 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Incremental sheet forming (ISF) is a low cost die-less forming process in which a flat sheet is formed into a complex 3D component with minimal or no component specific tooling. Over the years, many variants of ISF such as single point incremental forming (SPIF) [1], two point incremental forming (TPIF) [2] and double sided incremental forming (DSIF) [3] were introduced and thoroughly examined. In SPIF, a metal sheet is clamped along its periphery and formed by one hemispherical ended tool. Forming tool moving in a pre-defined path deforms the sheet to desired geometry by a series of localized deformations. Formability in ISF process is higher than that of conventional forming processes but attaining good geometric accuracy has always been a challenge.

Primarily, the profile deviation in wall region of formed geometry from that of ideal part geometry can be attributed to sheet and tool deflections during SPIF process. Asghar et al. [4] studied the influence of forming forces induced during SPIF on geometrical accuracy and stated that the sheet deflection is mainly caused by axial force whereas the tool deflection is caused by radial force. Also, bending near the component opening in the absence of backing plate causes high geometrical inaccuracy. Therefore, a fair estimation of these forming forces is required in order to compensate for various deflections and achieve desirable geometric accuracy. Jeswiet et al. [5] developed an experimental setup having spindle mounted force sensor to measure all three components (i.e. radial, tangential and axial direction) of forming forces. They formed components with conical and truncated pyramid geometries using AA3003-O material and measured forces for both SPIF and TPIF process. They observe peak force while forming 60° based on which they concluded that the material is reaching forming limit. Petek et al. [6] also designed a system to measure forming forces in SPIF and experimentally examined the influence of wall angle, tool diameter, incremental depth, tool rotation and lubrication through a set of experiments. They concluded that the forming forces in SPIF are very less in comparison to that in conventional deep drawing process and are highly sensitive to change in wall angle, tool diameter and incremental depth. They also concluded that rotation of tool and lubrication do not have significant influence on forming forces but have large influence on the component surface quality. Duflou et al. [7] made a systematic study based on central composite design of experiments for annealed Al3003-O material. They conducted experimental study and obtained second order regression expressions to obtain forming forces from process parameters(wall angle, incremental depth, tool diameter and sheet thickness). Henrard et al. [8] conducted finite element analysis (FE analysis) of SPIF process using both shell and solid elements. They reported that the predicted force is significantly dependent on

---

☆ 45th SME North American Manufacturing Research Conference, NAMRC 45, LA, USA.

* Corresponding author.
E-mail address: nvr@iith.ac.in (N.V. Reddy).

http://dx.doi.org/10.1016/j.jmapro.2017.04.016
1526-6125/© 2017 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.

Please cite this article in press as: Bansal A, et al. Prediction of forming forces in single point incremental forming. J Manuf Process (2017), http://dx.doi.org/10.1016/j.jmapro.2017.04.016

the type of element and the constitutive law used. They concluded that, in case of low wall angle (20°), FE analysis using both solid and shell elements could produce accurate result because of limited through thickness shear. Whereas in case of higher wall angle (60°), FE analysis using only brick elements and fine mesh could produce results with good accuracy. Aerens et al. [9] also studied the influence of various process parameters such as tool diameter, incremental depth, component wall angle and sheet thickness on the forming forces for five different materials (AA3003, AA5754, DC01, AISI 304 and 65Cr2). They derived regression expressions to obtain forming forces in ISF. This model is capable of predicting forces for a broad range of process parameters and material properties. However, the error in predicted force can be as high as 27%.

As forming force is proved to be sensitive to sheet thickness and tool-sheet interaction [4], an efficient prediction of part thickness variation and contact geometry is essential to model an analytical force prediction methodology. Finite element analysis and sine-law are the two broadly used methods to predict part thickness variation. However, these two approaches are either highly time consuming or of limited accuracy.

Single-stage SPIF can successfully form a component with wall angle of 60–70° for various materials such as aluminium and steel with sheet thickness of 1–1.2 mm using suitable process parameters [10]. But, forming component with 90° wall angle using single-stage SPIF is difficult. Duflou et al. [11] proposed a multi-pass forming strategy (MSPIF) with five stages and were able to form a component having 90° wall angle. However, un-wanted stepped features are formed due to rigid body displacement of material. Here, out-to-in tool path strategy was used for all the forming passes. Later Skjødt et al. [12] proposed two five-stage strategies, Down–Down–Down–Up (DDDU) and Down–Up–DownDown (DUDD), to form a cylindrical component with 90° wall angle and height (h) to radius (r) ratio of one ($h/r = 1$). Component fractured in 4th stage of DUDD strategy. Whereas, the component is formed using DDDU forming strategy. However, the un-wanted features caused by rigid body displacements could not be avoided in their strategy. To overcome this problem, Abhishek [13] and Malhotra et al. [14] proposed to use the combination of out-to-in and in-to-out tool paths to form a 90° cylindrical geometry with h/r = 1. In this strategy, the component depth is increased using out-to-in tool path and material is pushed outward to highly strained region using in-to-out tool path. Using this strategy, a 90° cylindrical component is successfully formed without additional features. Liu et al. [15] designed muti-stage paths to form hemispherical geometry by assuming the deformation occurs only by shear deformation. Material outside the component geometry is pushed in ward using multi-stage forming to successfully form the hemispherical geometry with 90° wall angle at opening. However, the thickness calculation by assuming pure shear deformation does not consider the material flow from outside the component region into it. Moser et al. [16] developed two multi-stage strategies to form cylindrical cup using DSIF. First one has alternative out-to-in and in-to-our tool passes without considering the rigid-body displacement. In this strategy, component fractured in 8th stage (out of 11) which has maximum wall angle of 72°. In the second strategy combination of out-to-in and in-to-out passes is used in some stages and rigid-body displacement is considered during tool path planning. Using the second strategy, they were able to form up to 86° wall angle with near flat base. They also noted that, thickness prediction using sine law resulted in squeezing of material between forming and support tools at high wall angles. To avoid squeezing, they calculated the tool gap using an empirical expression for thickness strain developed by constraining minimum thickness strain in sine law. They considered only wall angle in thickness prediction in multi-stage forming, neglecting the deformation history in previous stages. Lingam et al. [17] proposed a computationally efficient methodology to analytically predict this rigid body displacement and validated it for two different materials (Al5052 and Al8011). Using this methodology, formed component geometry can be predicted and tool path for MSPIF could be designed to avoid or minimize the unwanted feature in the bottom of component.

Bhattacharya et al. [18] proposed overlap based (some part of the material in ISF gets deformed repeatedly due to overlap) methodology to predict the component thickness. They used predicted thickness to estimate forming stress using force equilibrium method. Abhishek [13] calculated the thickness in MSPIF by assuming that the material getting deformed in a stage moves normal to the profile in previous stage. Predictions using this strategy are in good agreement with the experimental measurements. Mirnia et al. [19] proposed a technique to predict part thickness distribution using sequential limit analysis. Their results are in good agreement with experimental data. Also, the technique is proved to be faster than FE analysis but still requires 15–20 min of computation time. Cao et al. [20] developed an analytical model for the prediction of thickness variation and intermediate shape of a formed component based on an assumption of plain-strain deformation in plane perpendicular to the tool motion direction. The proposed model is validated with experimental results for various axisymmetric and non-axisymmetric part geometries. This method is computationally efficient but fails to incorporate the effect of material property in intermediate profile prediction.

In this work, existing analytical model [3,4] is modified to accurately predict the contact area and forming forces in single point incremental forming.

2. Methodology

With the aim of developing an analytical model for the prediction of forming forces, methodologies to predict thickness distribution and tool-sheet contact area are developed as follows:

Analytical prediction of part thickness is carried out using overlap methodology, similar to that proposed by Bhattacharya et al. [18]. In ISF, it is well accepted that near plain-strain deformation takes place in the plane perpendicular to tool movement direction [20–22]. In addition, effect due to bending near the component opening is neglected and material incompressibility is assumed in the thickness prediction model. In SPIF, hemispherical ended tool deforms the sheet material incrementally while moving in spiral path. Material movement along a cross-sectional profile, when tool moves down by a depth of Δz is depicted in Fig. 1(a). Let i and $i+1$ be two consecutive tool positions along the cross-sectional profile with O^i and O^{i+1}as forming tool centres (Fig. 1 (a)). The cross sectional profile shown in Fig. 1 (a) can be divided into three regions: Deformed wall region S_eA^i, tool-sheet contact region A^iC^i and undeformed region C^iD^i with respect to tool position in ith segment of spiral.

When the tool moves down to $(i+1)$th position from ith position, $A^iB^iC^iD^i$ region plastically deforms and moves to $A^iA^{i+1}B^{i+1}C^{i+1}$. Material in region D^iE^i moves down rigidly to $C^{i+1}D^{i+1}E^{i+1}$ and remains undeformed. Here, material movement is assumed to be normal to the previously formed profile ($S_eA^iB^iC^iD^iE^i$ in this case) and the tool-sheet contact region changes from $A^iB^iC^i$ to $A^{i+1}B^{i+1}C^{i+1}$. Region A^iB^i leaves the plastic deformation zone while region C^iD^i joins the further deformation.

Material in the un-deformed sheet is divided in to several small elements and their movement is traced using the methodology explained above. Thickness of each element after deformation is calculated by applying volume constancy between initial and final positions of the elements. While doing so, thickness is assumed to be uniform in each element. In case of multi-stage forming

Please cite this article in press as: Bansal A, et al. Prediction of forming forces in single point incremental forming. J Manuf Process (2017), http://dx.doi.org/10.1016/j.jmapro.2017.04.016

Download English Version:

https://daneshyari.com/en/article/5469254

Download Persian Version:

https://daneshyari.com/article/5469254

Daneshyari.com