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Numerical explicit analysis of hole flanging by single-stage incremental forming

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Abstract

The use of Single-Point Incremental Forming (SPIF) technology in hole flanging operations using multi-stages strategies have been widely studied in the last few years. However, these strategies are very time-consuming, limiting its industrial application. In a very recent work of the authors, the capability of SPIF process to successfully perform hole-flanges using a single-stage strategy has been experimentally investigated. The aim of the present work is to develop a numerical model of this process to be able to predict the sheet failure as a function of the size of the pre-cut hole. The numerical results are compared and discussed in the light of experimental tests over AA7075-O metal sheets with 1.6mm thickness.

Keywords: Incremental Sheet Forming (ISF); Single-Stage; Hole Flanging; Numerical Analysis

1. Introduction

Conventional hole-flanging is a forming process used to manufacture circular or asymmetric flanges. In this process, a clamped sheet with a pre-cut hole is plastically deformed by bending and circumferential stretching with a punch. As described in [1], the magnitude of deformation in conventional circular hole-flanging can be easily characterized by the Hole Expansion Ratio (HER), which is defined as the ratio of the inside diameter d_f of the

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finished flange to the initial hole diameter d_0. Accordingly, the formability is quantified by the Limiting Forming Ratio (LFR), i.e., the maximum HER attainable by the material (see Eq. (1)).

$$HER = \frac{d_f}{d_0} \qquad\qquad LFR := HER_{max} = \left(\frac{d_f}{d_0}\right)_{max} \tag{1}$$

There is a variety of parameters affecting the LFR, such as the mechanical properties of the metal sheet, the punch geometry, the punch-die clearance and others regarding the quality of the pre-cut hole edges and lubrication.

Single-point incremental forming (SPIF) is a novel technology that has been used for the last few years to obtain a variety of industrial parts due to its benefits in formability compared with conventional sheet metal forming processes [2]. In circular hole-flanging by SPIF, a flat sheet with a pre-cut hole is deformed by a forming tool that, following a pre-established trajectory using a CNC machine, progressively produces a smooth round flange. The material is now mainly deformed by a combination of circumferential and radial stretching and bending.

The use of Single-Point Incremental Forming technology in hole flanging operations using multi-stages strategies have been widely studied in the last few years [3-6]. Despite of their inherent advantages in terms of simplicity, flexibility and sustainability, these strategies are very time-consuming, so its industrial application is limited. In a very recent work, the authors experimentally investigated the capability of SPIF process to successfully perform hole-flanges using a single-stage strategy [7,8]. This version of the process allows reducing production times.

The aim of the present work is to develop a numerical model of the hole-flanging process by single-stage SPIF to analyze the material deformation and to predict the sheet failure as a function of the size of the pre-cut hole (d_0). The numerical results are compared and discussed in the light of experimental tests over AA7075-O metal sheets with 1.6mm thickness.

2. Experimentation

2.1. Setup and tools

The single-stage hole-flanging tests were carried out on a 3-axis milling CNC machine. The experimental setup consist on a blank holder and a backing plate with a 100 mm diameter hole, both fixed to the machine table through a rigid rig (see Fig. 1). The forming trajectories were modelled and simulated in CATIA V5 using the machining workbench. The step down was set to 0.2 mm per pass.

To study the deformation and failure mechanisms, the strains in the sheet surface were obtained using circle grid analysis. Specimens were previously electro-etched with a dot grid of 1 mm initial diameter and spaced by 2 mm (see circle grid in Fig. 1). The optical 3D forming analysis system ARGUS was used to automatically compute the principal strains in the sheet surface. Further details about the experimental procedure can be found in [7].

2.2. Specimens

A series of experimental tests of incremental hole-flanging by SPIF has been carried out over AA7075-O aluminum test pieces. Square sheet blanks of 170 mm side and 1.6 mm thickness with a hole milled in the center (pre-cut hole) were used. For the sake of clarity, in this work only the results of the tests with ϕ63.5 mm and ϕ65 mm pre-cut holes and a ϕ12mm hemispherical forming tool are analyzed here. As shown in Fig. 1, this pair of tests corresponds to a failed and a successful flange respectively. The inner diameter intended to achieve was always 95.8mm.

3. Numerical model

The Finite Element analysis has been performed using the ANSYS™ software, through its explicit dynamic solver LS-DYNA™.