Journal of Materials Processing Technology 229 (2016) 795–803

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Bi-directional dieless incremental flanging of sheet metals using a bar tool with tapered shoulders

Tong Wen*, Suo Zhang, Jie Zheng, Qian Huang, Qing Liu

College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China

ARTICLE INFO

Article history:
Received 29 June 2015
Received in revised form 29 October 2015
Accepted 7 November 2015
Available online 10 November 2015

Keywords:
Incremental forming
Flanging
Sheet metal
Deformation
Defect control

ABSTRACT

Flanging of sheet metals in a rapid and cost-efficient way is strongly needed in practice. This paper describes a flexible and versatile flanging method based on the single-point incremental sheet forming (ISF) technology utilizing simple bar tools with tapered shoulders in a two-stage procedure. The experiment and numerical simulation used Al 6061 sheets with a thickness of 1 mm. The results confirmed that forward/backward flanging of various open edges and hole rims of plates can be performed by this method without dedicated die. This gives a more complete flexible forming chain based on ISF. In contrast to conventional ISF, however, dieless incremental flanging gives particular force and deformation modes and might form different defects including plate warpage and buckling at flange onset. A larger inclination angle θ of the tool shoulder decreases the tendency of buckling but might incur larger warpage. The recommended θ-value for round-hole-flanging is 20–30°. Curved plates have less warpage versus planar ones because the curvature enhances structural stiffness. Moreover, control strategies of typical defects were presented mainly through the path optimization and geometry modification of tools.

1. Introduction

Flanging is a basic sheet metal forming process widely used in the production of thin-walled components. It involves bending sheet peripheries over a curved line using dedicated tooling on press. According to the state of circumferential strain or thickness variation of flange, there are two major classes of flanging—the stretch flanging with concave bending lines, and shrink flanging with convex bending lines (Fig. 1). Round hole-flanging can be regarded as stretch flanging with closed concave bending line. Up to now, extensive studies have been executed on various flanging processes. For example, Wang et al. (1995) studied stretch/shrink flanging on open edges of planar plates, Kacem et al. (2013) studied hole-flanging, Thipprakmas et al. (2007) investigated fine hole-flanging with wall thinning during forming, while Xu et al. (2004) examined curved flanging on non-planar sheets, with respect to the deformation features, formability, forming load, etc.

To continue meeting the diverse requirements of modern productions, especially those in small-batches, flexible manufacturing processes based on NC (Numerical Control) technologies such as incremental sheet forming (ISF) have attracted huge attention in the domain of sheet metal forming, as summarized by Allwood and Utsunomiya (2006). To date, ISF has mainly been applied to the formation of metallic sheets with a bi-stretching deformation mode. To fully take advantage of ISF, attempts have also been made to extend the technology into varying formations of sheet metals including flanging. For example, Cui and Gao (2010) studied the incremental forming process for producing prototype parts with round hole-flanges. They used a forming strategy that increased the part diameter in small steps until it reaches the final optimum part geometry. It can then produce a relatively higher neck height, uniform wall thickness, and maximum limiting formingratio LFR (defined as D/D_0, where D is the finished part diameter, and D_0 denotes the pre-cut hole diameter of blanks). Other researchers (Centeno et al., 2012) investigated the fabrication of conical and cylindrical hole-flanges by ISF. Aiming to reduce limitations in process time and geometric accuracy, Bambach et al. (2014) proposed a process design for performing hole-flanging operations by incremental sheet forming. Recently, Voswinckel et al. (2013) examined the incremental flanging of open plate edge. Generally, these studies were focused on a so-called "forward" flanging (Fig. 2a and b) in which the flanged wall is downward bent under the axial pressure of a bar tool. To attain higher accuracy, a partial die is usually used to support the blank from the opposite side (Fig. 2b), which belongs to a two-point ISF process.

* Corresponding author. Fax: +86 23 65101493.
E-mail address: wentong@cqu.edu.cn (T. Wen).

http://dx.doi.org/10.1016/j.jmatprotec.2015.11.005
0924-0136/

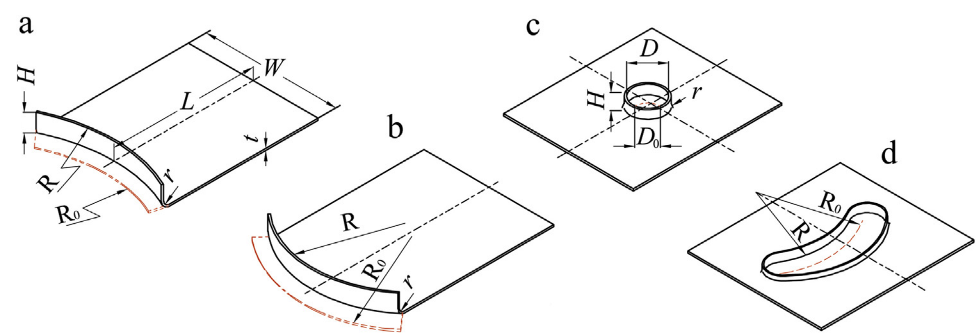

Fig. 1. Typical flanged shapes on planar blank: (a) open stretch flanging; (b) open shrink flanging; (c) round-hole-flanging; and (d) profiled-hole flanging.

Flanging is usually an auxiliary operation after deep-drawing and trimming (Maout et al., 2010). For some semi-finished products with a closed or half closed cross-section like a U shape, it is difficult to make an outward flanging/hole-flanging on the wall by conventional stamping because there is insufficient space for the tools to operate inside the workpiece. In light of this, Petek and Kuzman (2012) proposed a "backward" incremental round-hole-flanging approach as shown in Fig. 2c. Here, a bar tool with a ball head caused upward bending of the hole rim. Because the contact area between the tool and the blank is small and keeps changing during the course, it is hard to precisely control the deformation; therefore, a backup die is indispensable. Some groups have also studied the production of tubular parts by incremental forming. For example, Teramae et al. (2007) developed an incremental hole-flanging process for fabricating branched tubing without welding. However, the overall knowledge on incremental flanging is lacking and further studies are urgently needed.

The current study seeks to develop an agile, cost-efficient and versatile flanging approach based on the single-point ISF technology, with which various flanging and hole-flanging processes on planar or contoured plates along forward/backward direction can be performed, omitting either the dedicated die or punch. The method is extended from the former work on hole flanging of tubes conducted by the present author and coworkers' (Yang et al., 2014). Deformation characteristics and key points are reported. The goal is to validate the method and reveal fundamental rules of the process that are of great importance in industrial applications.

2. Method and analysis models

Fig. 3 illustrates the method of dieless bi-directional incremental flanging using a bar tool with tapered shoulders. The tool consists of three sections: the holding zone on the upper portion, the frustum pre-flanging zone(s) with an inclination angle of θ, and the columnar shaping zone. The flanging process is divided into two stages, i.e., the pre-flanging stage and the shaping stage. In the first, the inclined surface on the tool shoulder is employed to horizontally press the edge that is to be flanged after the blank sides that are not to be formed were firmly clamped on a fixture. This forces it to bend upwards or downwards under the control of the NC programs. The initial bending direction of the edge determines the manner of subsequent deformation, i.e., it is forward or backward flanging. As shown, two opposite-tapered shoulders are made to execute bi-directional flanging with a single tool.

After the required sides were preliminarily bent into a tilting state, the shaping zone of the tool is utilized to gradually and repeatedly squeeze the sheet edges until the desired shape and size of the flanges are obtained. Thus, forward/backward stretch and shrink flanging (depending on the curvature direction of the bending lines) as well as hole-flanging can be executed with the modified bar tool. A partial backup die can also be employed to attain higher accuracy. Nevertheless, to take full advantages of flexible manufacturing technology, the current study only considers the case of single-point flanging with vertical flanges (Fig. 1). To compare the effect of tool geometry on the forming process, the inclination angle θ is set to 8°, 16°, 23° and 30°, respectively. Diameter d_1 is 10 mm; d_2 is 16 mm for θ = 30°, and it is 12 mm for other θ-values.

The experiments were conducted on a NH3525 incremental forming machine. We used Al 6061 aluminum alloy plates with a thickness of 1 mm. The main material mechanical properties and dimensions of the blanks are presented in Tables 1 and 2. The con-

Table 1
Mechanical properties of Al 6061.

Density	ρ	(kg/m^3)	2900
Young's modulus	E	(GPa)	68.9
Poisson's ratio	ν	–	0.4
Yield stress	σ_s	(MPa)	55.0

Table 2
Dimensions of the experimental blanks (see Fig. 1).

Plate thickness	t	(mm)	1
Plate width and length	W × L	(mm)	100 × 60–90
Radius of bending line	R_0	(mm)	75
Diameter of precut hole	D_0	(mm)	20
Diameter of hole-flanging	D	(mm)	40, 60
Height of flanged neck	H	(mm)	6–15

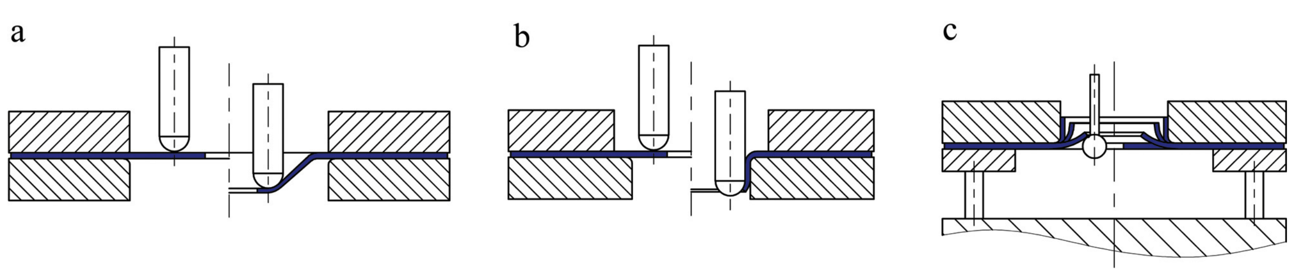

Fig. 2. Sketch of incremental hole-flanging: (a) single-point and forward; (b) two-point and forward; and (c) two-point and backward.