Journal of Materials Processing Technology 234 (2016) 228–242

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Analysis of geometrical parameters and occurrence of defects in the hole-flanging process on thin sheet metal

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ARTICLE INFO

Article history:
Received 19 August 2015
Received in revised form 21 March 2016
Accepted 26 March 2016
Available online 29 March 2016

Keywords:
Hole-flanging
Thin sheet metal
Finite element
Geometrical parameter
Necking
Tearing

ABSTRACT

Geometrical parameters of the flange were analyzed in the conventional hole-flanging process on thin sheet metal of 0.8 mm by varying both the initial hole diameter and the clearance-thickness ratio. An elastic-plastic finite element (FE) model with normal anisotropy assumption was performed together with experiments and analytical solutions. The excessive thinning generated by ironing was distinguished and the occurrence of a non regular geometry was identified by the exam of the final shape. The influence of the initial hole diameter on the state of the flange was also investigated. Therefore, the occurrence of defects such as necking and tearing were predicted by considering the uniform strain and the thickness of crack initiation under the simple tensile test, respectively. Practical diagrams were proposed to exploit the geometrical and forming parameters as well as the state of the flange. Good agreement was shown between numerical simulations and experiments.

1. Introduction

Hole-flanging process consists of forming an integral collar around the periphery of an initial hole in a sheet metal part. While different techniques are used to perform this process, the conventional hole-flanging remains the most frequently applied sheet forming technique in the manufacturing industrial parts. In this technique, a blank-holding force is set to clamp the sheet firmly between the blank-holder and the die, and then a punch forces the blank into the die to form a hollow flanged component.

For the majority of industrial applications, the flange must be produced free from defects. In addition, such specifications are often required for the final shape of the flange. The main requirements are focused on the height and the thickness of the flange. For example, a long flange is needed when an increase of bearing surface is required. In addition, a more substantial flange thickness is needed in the case of internal thread cutting that will be manufactured after the hole flanging process. To satisfy the requirements related to these geometrical parameters and the appearance of defects, several researchers have focused on studying the effect of the initial hole diameter $\Phi_{a.t}$ and/or the clearance j between the punch and the die.

The variation of the initial hole diameter $\Phi_{a.t}$ is considered among the technological solutions to control both the flange height and the flange thickness. By decreasing the initial hole diameter $\Phi_{a.t}$, the part of the workpiece subjected to the deflection increases. Therefore, the flange height increases while the flange thickness decreases and vice versa. This solution affects significantly the final shape of the flange in the case of thick sheet metal. In thin sheet metal, it also affects the magnitude of expansion that generates a tensile stress in the circumferential direction at the edge of the flange. According to the magnitude of expansion, different defects may occur. Necking and crack correspond to weak tensile stress magnitude. While for more pronounced tensile stress, tearing and fracture are the main observed defects.

Some research then have been devoted to limit the initial hole diameter below which material failure could take place. Huang and Chien (2001b) have studied both the flange thickness and the formability limitation of the hole-flanging process for various initial hole diameter $\Phi_{a.t}$. They have used a constant clearance j between the punch and the die greater than the thickness of thin steel sheet. They found that the fracture thickness of the sheet under the simple tensile test can be used to predict numerically the fracture which occurs at the extremity of the flange. They also defined a forming ratio $FR = \Phi_p/\Phi_{a.t}$, in which Φ_p was the punch diameter. By varying the initial hole diameter $\Phi_{a.t}$, they showed that the fracture occurs at the extremity of the flange when FR reaches a limiting forming ratio LFR. Huang and Chien (2001a) have found that the limiting forming ratio LFR is linked to the punch profile radius. Huang and

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http://dx.doi.org/10.1016/j.jmatprotec.2016.03.027
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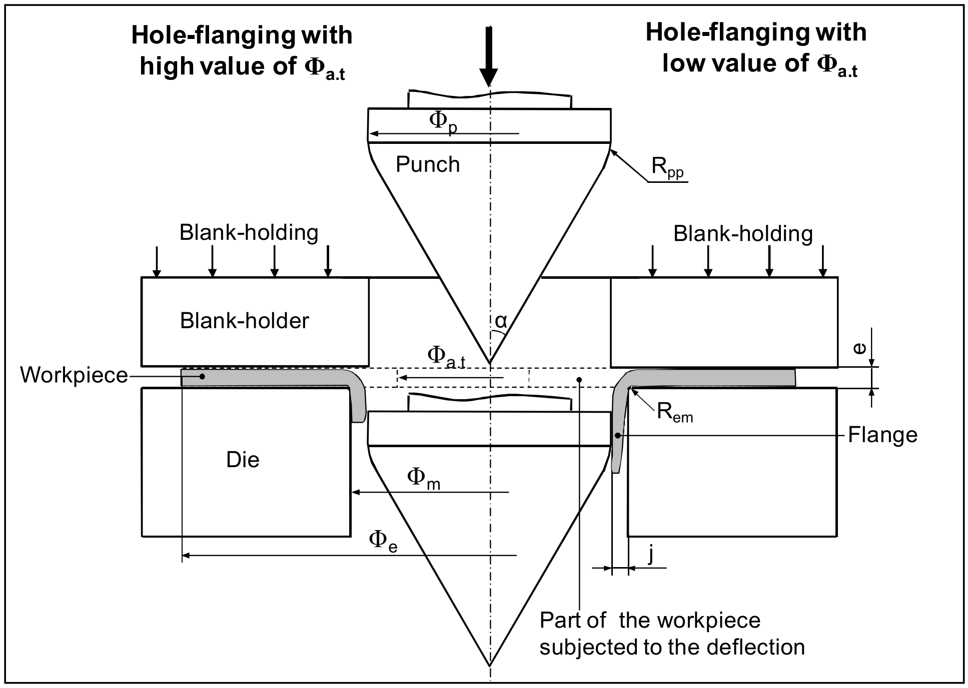

Fig. 1. Tool geometry parameters of the conventional hole-flanging process.

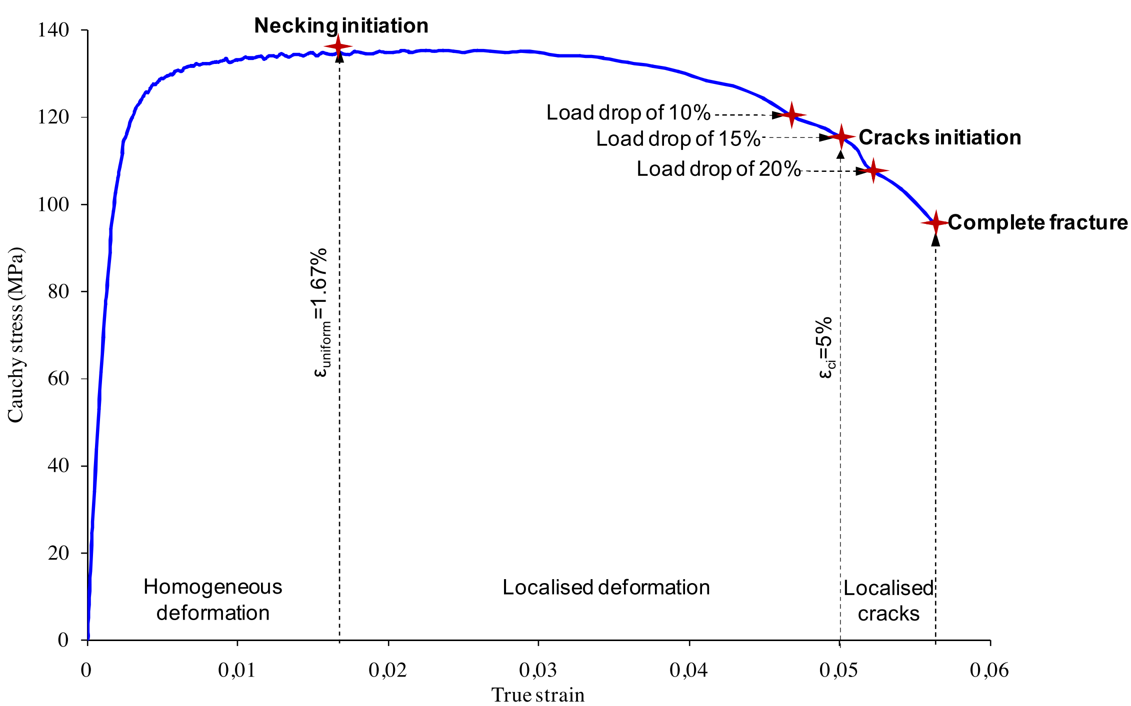

Fig. 2. Experimental stress–strain curve in the rolling direction of the 0.8 mm thin 1000 series aluminum alloy sheet.

Chien (2002) found that LFR is independent of the cone semi-angle of the truncated conical punch.

In addition to its effect on the final shape, the variation of the clearance j between the punch and the die is often used to distinguish between two hole-flanging conditions namely the hole-flanging with or without ironing. To control the occurrence of ironing, it is convenient to consider the clearance-thickness ratio Rc which is defined as the ratio of the clearance j to the workpiece thickness e. By setting a high value of Rc, the process is performed by edge stretching in which the flange thickness is reduced and an ordinary finished shape is obtained with a shorter flange. In contrast, by using a low value of Rc, the metal is squeezed between the punch and the die. So, ironing begins which results in a significant thinning of the flange leading to a long and vertical flange as well as a uniform thickness.

In the literature, the two hole flanging conditions with or without ironing are implicitly distinguished. Kumagai and Saiki (1998) have controlled the clearance-thickness ratio Rc to perform the hole-flanging process with ironing of thick sheet metal for a fixed initial hole diameter $\Phi_{a.t}$. They found that by increasing the part