Journal of Materials Processing Technology 225 (2015) 213–220

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Experimental investigation of the ovality of holes on pre-notched channel products in the cold roll forming process

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ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 5 May 2015
Accepted 8 June 2015
Available online 12 June 2015

Key words:
Cold roll forming
Pre-notched channel section
Ovality
Regression

ABSTRACT

Owing to the increasing use and demand of pre-notched sections in automotive and construction industries, cold roll forming is a suitable production process because of its high efficiency. However, some defects such as ovality in the holes might reduce the quality of the products. In this study, the conversion of pre-notched strips into channel section products was investigated experimentally during a cold roll forming process. The effects of a number of features such as the flower pattern (the forming angle increment), uphill and downhill strategies, the horizontal distance between the stands, the lubrication condition, the longitudinal distance between the holes, the distance between the holes and the product edge, the hole diameter, the width of the channel web and flange, and the strip thickness on the ovality are discussed. The results showed that the forming angle increment has the most significant influence on the hole ovality, whereas the web width and lubrication condition are of the least importance. Furthermore, comparing the results of the forming of the pre-notched strips with those of strips without holes showed that piercing the holes intensifies hole ovality.

1. Introduction

The cold roll forming process is a cost-effective, mass production process used to fabricate constant cross-section parts with desirable lengths. In recent years, the demand for semifinal pre-notched components has increased significantly. Therefore, much effort has been expended to produce high quality products using the cold roll forming process.

Generally, there are two common methods for producing pre-notched products. In the first method, after forming the initial strip into a product without perforations, the holes are punched at the predetermined positions. This method is slow and prevents locating the holes in positions with poor accessibility. In the second method, the holes are made by two punch rollers in the first stand of a cold roll forming line after which the pre-notched strip undergoes the forming operations. In this method, different holes can be mass produced at the desired positions. High production speed and reliability are the characteristics of this second method (Halmos, 2006). However, the ovality of the holes is a major issue in the products fashioned using this method.

1.1. Ovality

As shown in Fig. 1, the holes' ovality results from a hole being stretched in one direction and compressed in the other. Therefore, the ovality percent (O) can be calculated using Eq. (1):

$$O = \frac{d_1 - d_2}{d} \times 100 \tag{1}$$

where d is the initial hole diameter before deformation and d_1 and d_2 are the largest and the smallest diameters after the deformation.

Many studies have been conducted to determine the parameters responsible for product quality in the cold roll forming process. Bhattacharyya et al. (1984) reported that the effect of the forming angle at the first and last stands is higher than that of the other stands to produce channel products with no buckled edges. They concluded that the deformation length depends on the geometry of the product section and the initial yield strength of the strip using an analytical and experimental study (Bhattacharyya and smith, 1984). McClure and Hanhui (1995) achieved consistent results with experimental samples by simulating the cold roll form-

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http://dx.doi.org/10.1016/j.jmatprotec.2015.06.008
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ing process of a channel section product using the commercial finite element software, ABAQUS. Heislitz et al. (1996) found an appropriate approximation for the longitudinal strain distribution using a finite element simulation of the roll forming process of a channel product employing PAM-STAMP software. Panton et al. (1996) studied the normal strains in the longitudinal and the transverse directions, as well as the shear strain and developed analytical relations to estimate them. Hong et al. (2001) simulated a cold roll forming process in COPRA software and concluded that the roll diameter, the strip thickness, mechanical properties of the strip and the speed of the production line have a significant effect on the deformation length. They also reported that the risk of edge buckling was increased when a longitudinal edge strain, was higher than the yield strain. Han et al. (2001) simulated a hat shaped section using a B-spline finite strip and concluded that the horizontal distance between the stands, the forming angle increment, the strip yield strength, the width of the product web and the width of the outside flange had significant effects on the longitudinal edge strain. Furthermore, they reported that the angle of the first stand should be lower than a specified amount to avoid edge buckling (Han et al., 2002). Tajdari and Farzin (2002) found that the shear stress plays an important role in the elastic-plastic behavior of the strip. Tehrani et al. (2006) used ABAQUS software to study the edge buckling of a channel section. According to their results, to avoid edge buckling, the first forming angle should not exceed a specified value. They also introduced a limit for the forming angle to prevent edge buckling of the circular sections (Salmani Tehrani et al., 2006). Lindgren (2007) studied the longitudinal edge strain and the deformation length of a channel product using finite element analysis of the cold roll forming of a channel product employing MARC/MENTAT software. He concluded that the strip strength increased the longitudinal edge strain and decreased the deformation length. He also presented relationship for the longitudinal edge strain and the deformation length. Bui and Ponthot (2008) used METAFOR finite element code to investigate the effects of the production line speed, the horizontal distance between the stands, the friction coefficient between the strips and the rolls and the mechanical properties of materials of the strip on the longitudinal strain, the strip geometry and the bend angle along the deformation length. They found that the work hardening coefficient of the strip increased the longitudinal edge strain. Paralikas et al. (2008) simulated the roll forming process using ANSYS/LS-Dayna software and found that the rate of forming, the horizontal distance between the stands, the coefficient of friction, the gap between the upper and lower rolls and the rolls diameter increased the maximum longitudinal edge strain. They also reported that the horizontal distance between the stands had the most effect on the longitudinal edge strain, but the roll diameter and the forming speed were the least effective (Paralikas et al., 2009). Paralikas et al. (2011) concluded that the downhill strategy can greatly reduce the longitudinal edge strain in roll forming of V-shape and U-shape section products. Zeng et al. (2008) analyzed the edge buckling and the distribution of the strip thickness by simulating the roll forming process using ABAQUS software. They concluded that a strip material with a low work hardening coefficient and a high yield and ultimate strength decreased the edge buckling and the thinning defects. Zeng et al. (2009) used a hybrid method experimental design and finite element analysis to optimize the roll diameter and the forming angle increment so that the springback and the longitudinal edge strain were minimized. Park and Anh (2011), using a combined method of finite element simulation, neural networks and genetic algorithms produced U-shape and V-shape section products with the lowest possible stand number and the least number of buckling and springback defects. Wiebenga et al. (2013) attempted to reduce the longitudinal bow and the springback by setting the gap between the upper and the lower rolls at each stand, the horizontal distance between the stands and the downhill strategy.

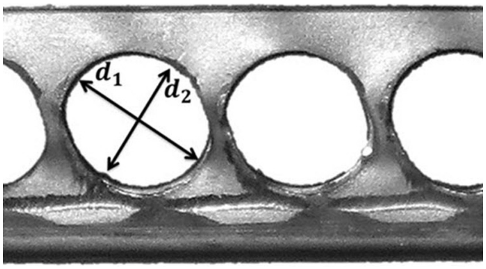

Fig. 1. Ovality defect in experimental tests.

There are a limited number of studies in the field of the cold roll forming process of pre-notched strips. Watari and Ona (1998) conducted experiments to investigate the influence of factors affecting the edge buckling, twist and the longitudinal bow of pre-notched channel and V-shaped products with square holes. They reported that the limited forming range of pre-notched strips depended on the hole size, the distance between the holes and the second moment of inertia of the cross section (Watari and Ona, 2001). Cavaguti and Ferreira (2010) analyzed the roll forming process of a channel product with rectangular holes in its web using SUPERFORM software. They reported that a small diameter of the lower roll together with application of a downhill strategy reduced the edge buckling of the web holes.

This review the literature showed that currently there is no research focused on the hole ovality defect in the pre-notched roll formed products. In the study reported in this paper, variables affecting the holes ovality in pre-notched channel section were studied. These factors included the flower pattern (the forming angle increment) of the profile, uphill and downhill strategies, the internal horizontal distance between the stands, the lubrication condition, the space longitudinal distance between the holes, the space distance between the holes and the product edge of the channel, the diameter of holes, the width of the channel web, flange size, and the strip thickness. Finally, the effects of each variable are discussed, and some recommendations for reducing the holes ovality defect are presented.

1.2. *Geometry of a pre-notched channel product*

The geometrical characteristics of a pre-notched symmetric channel section product are shown in Fig. 2.

As shown in Fig. 2, b is the distance between the holes and the product edge, a is the distance between the holes, d is the diameter of the holes, t is the strip thickness, h is the flange width, r is the inner radius of the corner, and w is the width of the web. These geometrical parameters can affect the holes ovality (Watari and Ona, 1998, 2001).

Groche et al. (2008) proposed using an inner corner radius that was equal to the strip thickness to reduce the springback phenomenon. On the other hand, if the inner corner radius is less than the strip thickness, crack occurrence will be unavoidable outside the bend (Suchy, 2006). Therefore, the inner radius was maintained equal to the strip thickness.

In the design process of a pre-notched channel product, some relationships between the flange width, the strip thickness, the holes diameter, the distance between the holes and the distance between the holes and the edge should be considered. Therefore, in order to generalize the results of this study to similar products with different sizes, three dimensionless variables were considered according to the results of some references (Watari and Ona, 1998, 2001) as given in Table 1. The levels of each parameter in the exper-