Journal of Constructional Steel Research 118 (2016) 243–253

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental and numerical study of bowing defects in cold roll-formed, U-channel sections

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 20 October 2015
Accepted 8 November 2015
Available online 14 November 2015

Keywords:
Cold roll-forming
Symmetrical U-channel section
Bowing defect
Linear regression
Finite element simulation

ABSTRACT

Because the cold roll forming process has been developed such that it is now widely used in profile production, the importance of improved product quality is felt more keenly now than in the past. In order to improve the quality of cold-roll-formed products, it is necessary to investigate how defects that may occur during production can be reduced. This paper experimentally and numerically studies profile bowing, because such bowing is one of the most common defects caused by the cold roll formation of symmetrical U-channel sections. To this end, the influence of various factors associated with profile geometry and the cold roll-forming line is investigated and discussed. These parameters include strip thickness, radius of bend, flange width, bend angle increment at each stand, and inter-distance between two successive stands. Then, a curve fitting based on the linear regression method is used to compare the effects of the different input parameters on product bowing, which is used as the output parameter. Results show that the most important parameters to profile bowing are the bending angle increment at each stand, the flange width, and the strip thickness. Conversely, the effects of the inter-distance between successive stands and the radius of bend on the bowing defect are negligible.

1. Introduction

The cold roll forming process is a highly efficient and high-speed manufacturing process that fabricates products with desired lengths and constant cross sections. Due to these characteristics, this method is often used for mass production [1]. During the cold roll forming process, a strip with a specified width passes a number of forming stands. Moreover, bends are formed in the strip by the forming rollers at each stand until the strip reaches the end of the forming line, at which point the strip's final shape has been achieved. In this way, strip formation takes place uniformly over the entire length of the roll forming line. However, some defects result from this process; these have multiple causes and can be reduced by controlling individual factors throughout the cold roll forming process [2].

Fig. 1 shows a strip that has been formed into a U-channel section. The bowing defect deflects the product from its longitudinal axis as the product deviates from its straight line and bends toward the web of cross sections with the specific radius shown in the figure.

Thus, the greater the radius of the tangential arc, the less longitudinal axis deviation of the product; in this way, the severity of the defect is reduced.

Some research has already investigated the bowing and longitudinal strain on strip edges during the cold roll forming process. Through experimental tests, Ona and Jimma [3] studied bowing and warping defects in asymmetrical channel section products that were produced in an eight-stand cold roll forming line; their proposed solutions include transversely displacing the stands, using straighteners, and using a pair of rollers to adjust the pressure applied during strip formation to prevent over-bending. Bhattacharyya, Smith, Thadakamalla and Collins [4] examined the forming strip's required length upon entering the forming rollers at each stand using both experimental (using a one-forming stand to form U-channel sections) and analytical methods; they determined that the length of deformation depends on the strip thickness, the forming angle in the stand, and the channel's flange width. Moreover, Bhattacharyya and Smith [5] studied how to design flower patterns, taking into consideration the longitudinal strain on the channel edge as a determining factor. As a result, they proposed a logical flow chart for flower pattern design. They also concluded that the effects of forming angles in the initial and final forming stands are greater than the effects of forming angles in other stands. Panton, Duncan and Zhu [6] used analytical and experimental methods to study the production of hat- and U-shaped sections through four cold roll forming stands. They observed that, in these sections, there are

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http://dx.doi.org/10.1016/j.jcsr.2015.11.007
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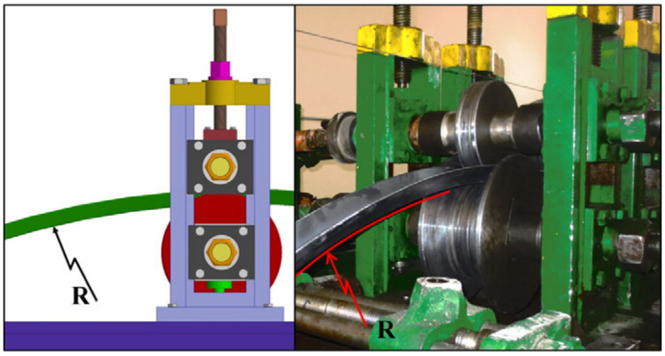

Fig. 1. Bowing defect in the roll-formed product.

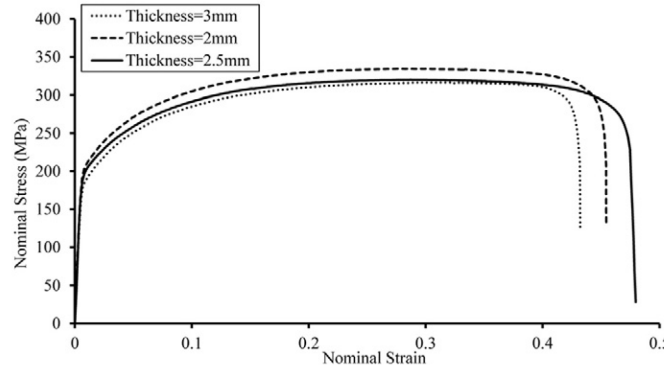

Fig. 3. Stress–strain diagrams obtained from tensile tests of samples with different thicknesses.

some areas without longitudinal, transverse, and shear strains. Han, Liu, Lu and Ren [7] used the B-spline finite strip method to study the effects of internal distances between forming stands, the yield strength of the strip, the bend angle increment at each stand, the web width, and the outer edge on longitudinal strain in channel sections; they showed that the maximum longitudinal strain will increase if the yield strength and strip thickness increase and the distance between stands, outer edge width, and web decrease. Sheu [8] by producing symmetrical channel sections in five forming stands, experimentally investigated the effects of the bend angle increment at each stand, the speed line, the friction coefficient, and the radius of the roller's corners on the difference between the angles and lengths of flanges in each product. He showed that the bend angle increment in each stand and the line speed have more effect on the angles and flange lengths in each product than do any of the other factors studied. Lindgren [9] studied the production of symmetrical channel sections of high-strength steel using the cold roll forming process and showed that increased deformation length results in decreased edge longitudinal strain in the flanges as well as decreased bowing and edge buckling. Using a combination of regression analysis and back-propagation artificial neural network (BPANN), Poursina, Salmani Tehrani and Poursina [10] predicted the maximum bowing that would occur in symmetrical channel sections; they obtained the same results using both methods. Jeong, Lee, Kim, Seo and Kim [11] used Shape-RF software to simulate the roll forming of asymmetrical U-channel sections for under-rails; they used two different flower patterns in order to compare the amount of longitudinal strain obtained by each in the flanges and bowing. Bui and Ponthot [12] used METAFOR code to simulate the cold roll forming of symmetrical channel sections and investigated the effect of distance between forming stands, forming speed, mechanical properties of the strip, and the friction coefficient on longitudinal strain. They found that longitudinal strain increased on the strip edge when the inter-distance between two successive stands decreased and the friction coefficient increased. Lindgren [13] used experimental design with the factorial method to investigate longitudinal strain and deformation length with the aim of achieving the number of stands required for roll forming; he indicated that flange size, the bend angle increment at each stand, and yield strength have augmentative roles and that strip thickness has a diminutive role on deformation length. He also indicated that the maximum longitudinal strain increased due to increased strip thickness and bend angle increment and decreased flange size, roller radius, and yield strength. Paralikas, Salonitis and Chryssolouris [14] discussed the parameters affecting the maximum longitudinal strain, the longitudinal residual strain in the strip edge, the geometrical accuracy of the product, and the transverse strain in the bend zone; they showed that longitudinal strain occurring in the flange zone plays an important role in product accuracy. In further studies, Paralikas, Salonitis and Chryssolouris [15] simulated the cold roll forming of a symmetrical channel section and investigated the effect of distance between forming stands, forming rate, gap between roller pairs in each stand, and roller diameter on the shear and longitudinal strains that occur on the flanges of products; they showed that, among these factors, the inter-distance between two successive stands and the gap between roller pairs in each stand have the most effect on shear and longitudinal strain. Using experimental design (response surface methodology), Zeng, Li, Yu and Lai [16] studied how flower pattern design profiles and optimal forming roller diameters reduce springback and longitudinal strain of the strip edge; they obtained the optimal diameter and angle for each stand in order to reduce springback and longitudinal strain of the strip edge. Punin, Kokhan and Morozov [17] studied the strip bowing that occurs between forming stands during the cold roll forming process and used Euler's method to reduce shortening defects on products; they showed that this defect is related to the number of

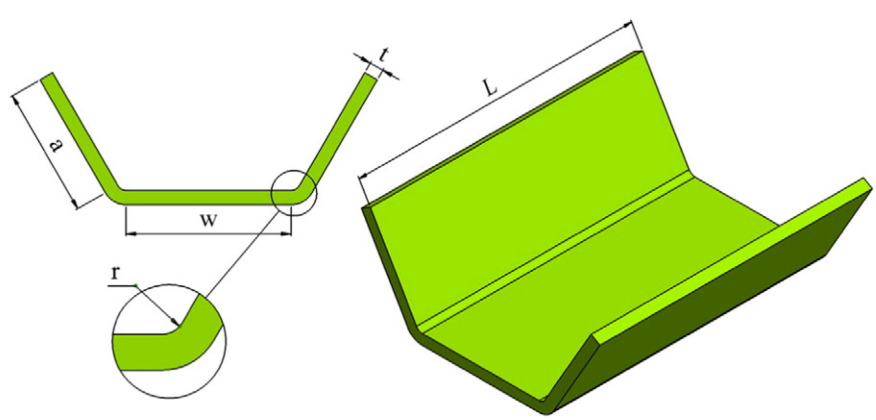

Fig. 2. Geometrical characteristics of a symmetrical channel section.