International Journal of Machine Tools & Manufacture 86 (2014) 68–80

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

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

Investigation of a new incremental counter forming in flexible roll forming to manufacture accurate profiles with variable cross-sections

Jong-Cheol Park [a,1], Dong-Yol Yang [a,*], MyungHwan Cha [b,2], DonGun Kim [b,2], Jae-Bok Nam [b,2]

[a] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Guseong-dong 373-1, Yuseong-gu, Daejeon, Republic of Korea

[b] Metal Forming Research Group, Steel Solution Center, POSCO, Songdo-dong 180-1, Yeonsu-gu, Incheon, Republic of Korea

ARTICLE INFO

Article history:
Received 25 April 2014
Received in revised form
29 June 2014
Accepted 2 July 2014
Available online 14 July 2014

Keywords:
Flexible roll forming
Incremental counter forming
Roll formed 3D shape

ABSTRACT

A roll-formed profile with variable cross-sections fabricated by flexible roll forming has a shape error, such as warping, because of geometrical deviations in transitional zones of the profile between the initial metal strip and the roll-formed profile. To reduce the shape error, a new process called incremental counter forming (ICF) is proposed. Our investigation of the ICF process shows that the longitudinal strain distribution at the flange of the roll-formed profile can be controlled by combinations of forming parameters of the ICF process. As the forming parameters increase the longitudinal strain distribution in the concave zone, the shape error decreases. However, when the longitudinal strain distribution in the straight zone reaches a critical limit, the additional longitudinal strain works as an excessive longitudinal strain to worsen the shape error. An analytical model, which describes the longitudinal strain at the flange during roll forming, is adopted to reveal that the increase of the longitudinal strain is induced by increasing derivatives of a bending angle, which is controlled by the forming parameters of the ICF process. Finally, the FE simulation has been carried out to compare with the experimental results, which show that the ICF process is effective for reducing the shape error of the profile with variable cross-sections in flexible roll forming.

1. Introduction

Roll forming is a competitive sheet metal forming process for mass production of profiles. An array of forming rolls is aligned to form the profiles continuously. Initial metal strips can be bent incrementally at each forming roll to final shaped profiles. By employing various combinations of forming rolls, roll forming allows the profiles to be formed into profiles with complex shaped cross-sections which are constant along rolling direction. In addition, roll forming can be used in manufacturing light weight structures made of high strength steels with high accuracy. However, the shapes of the profiles manufactured by roll forming are limited to profiles with constant cross-sections along rolling direction.

Flexible roll forming is introduced to overcome the limitations of conventional roll forming. Flexible roll forming allows profiles to acquire variable cross-sections by controlling the roll stands with CNC. The process has the capability to manufacture profiles with variable cross-sections [1]. However, shape defects, such as warping and wrinkling over the profiles, occur because of the geometrical deviations in the transitional zones of the profile between the initial metal strip and the roll-formed profile, such as the concave zone and the convex zone, as shown in Fig. 1 [2].

Contrary to typical bending operations, when an initial metal strip is being formed during roll forming, not only bending deformation but also additional deformations occur unavoidably to cause shape errors, because of continuous changes of cross-sections of the profile along the longitudinal direction. In particular, longitudinal strain at a flange section is a main factor in managing shape errors [3]. A redundant longitudinal strain at the flange during roll forming induces shape defects, such as warping, twisting, bowing, etc. To minimize the shape defects, it is necessary to adjust the forming parameters of roll forming to reduce the longitudinal strain at the flange section.

As compared with the longitudinal strain at the flange section of a profile fabricated by conventional roll forming, the characteristics of the longitudinal strain at the flange of a profile with variable cross-sections fabricated by flexible roll forming are considerably different. The transitional zones of the profile with

* Corresponding author. Tel.: +82 42 350 3214; fax: +82 42 350 5214.
E-mail addresses: parkjc@kaist.ac.kr (J.-C. Park), dyyang@kaist.ac.kr (D.-Y. Yang), mhcha@posco.com (M. Cha), kimdongun@posco.com (D. Kim), jbnam@posco.com (J.-B. Nam).
[1] Tel.: +82 42 350 3254.
[2] Tel.: +82 32 200 1722.

http://dx.doi.org/10.1016/j.ijmachtools.2014.07.001
0890-6955/

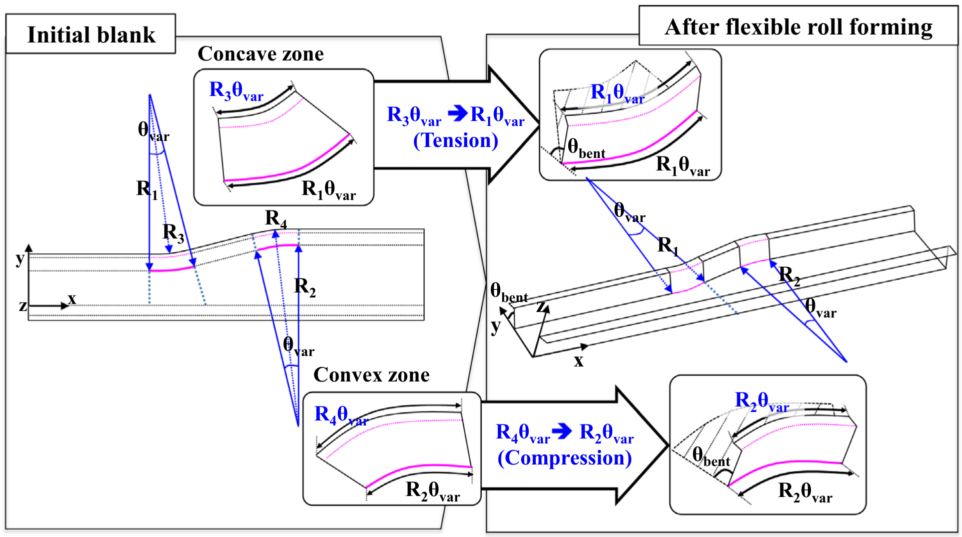

Fig. 1. Schematics of geometrical deviations in the transitional zones of a profile with variable cross-sections between the initial metal strip and a roll-formed profile.

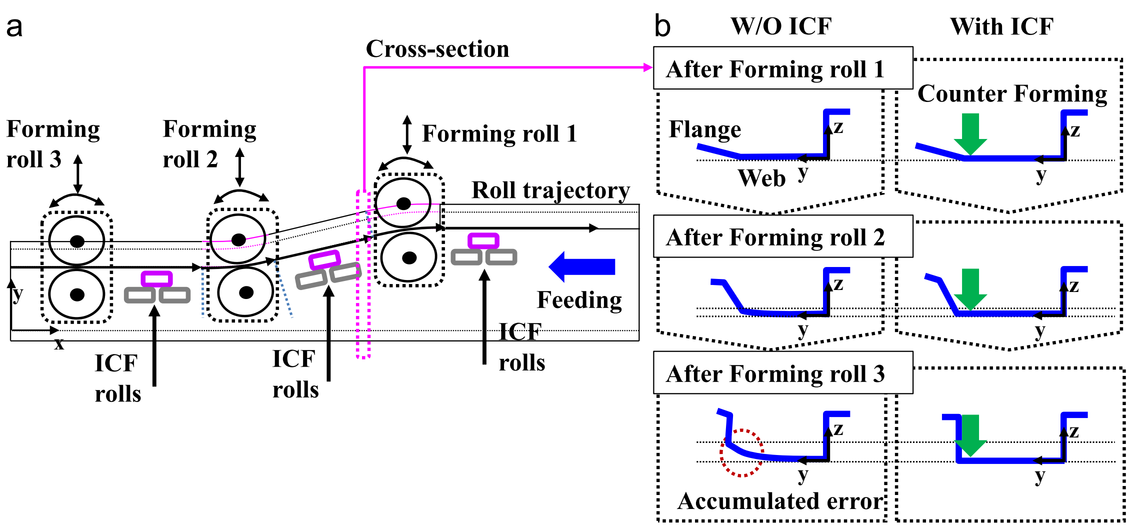

Fig. 2. Concepts of incremental counter forming (ICF) to improve the shape error. (a) Schematic of flexible roll forming with the ICF process and (b) change of cross-sections of the profile during flexible roll forming with the ICF process and without the ICF process.

variable cross-sections need to be stretched in the concave zone and to be compressed in the convex zone along the longitudinal direction to compensate for the geometrical deviations between the initial metal strip and the roll-formed profile [4]. Several processes have been further proposed to reduce the shape error.

Larrañaga et al. investigated the effects of local heating by laser in the transitional zones during flexible roll forming [5]. He investigated the effects of heating temperature and local heating areas at the transitional zones. The results showed that high temperature which was enough to increase ductility was effective and the flange section of the profile was an effective area to improve the shape error. Berner et al. investigated the effects of roll type blank holders that could follow a roll trajectory [4]. The roll type blank holders could effectively hold the transitional zones that the shape error mainly occurred during flexible roll forming. The set of roll type blank holders was designed with one upper roll and two lower support rolls. Rotatory and translatory movements of the roll type blank holders to follow contours of the transitional zones were controlled by self-adjusting forces, such as spring force, or oil pressure. Their investigation showed that the flange in the concave zone was stretched and the flange in the convex zone was compressed by the roll type blank holders to reduce the shape error.

In this paper, a new incremental counter forming process is proposed that is combined with flexible roll forming to improve the shape error. To analyze the longitudinal strain distribution at the flange, an analytical model of longitudinal strain is used as a reference case to eliminate the geometrical deviations. With FE simulations, the forming parameters of the new process are investigated regarding the shape error and the longitudinal strain distribution at the flange of the roll-formed profile. The procedure to control the distribution of additional longitudinal strain by the new process is also analyzed to improve the shape error. Then, the FE simulations are compared with the experimental results to confirm the validation of the FE simulations.

2. Experiments

2.1. *Concepts of the incremental counter forming (ICF) process*

As the initial metal strip is being bent incrementally during flexible roll forming, the geometrical deviations in each transitional