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Flange wrinkling in flexible roll forming process

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Abstract

Flexible roll forming is an advanced sheet metal forming process for producing variable cross section profiles. Flange wrinkling at the transition zone where the cross section changes is a major defect in the flexible roll forming process. In this paper, the flange wrinkling at the transition zone is studied using finite element analysis. The results showed that the strip deformation at the transition zone can be considered as a combination of two strip deformations observed in the conventional roll forming process and the flanging process. According to finite element analysis results, when the flange wrinkling occurs, compressive longitudinal strain is smaller than the necessary compressive longitudinal strain calculated by mathematical modeling to obtain the intended profile geometry in the compression zone. Therefore, comparison of compressive longitudinal strain obtained from the finite element analysis and the necessary compressive longitudinal strain is a good criterion to predict the flange wrinkling occurrence. A flexible roll forming setup was developed. Longitudinal strain history is obtained from the finite element simulation and is compared with the experimental data from the flexible roll forming setup. Results show a good agreement and confirm the finite element analysis.

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Keywords: Flexible roll forming; Variable cross section profiles; Wrinkling

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1. Introduction

Conventional roll forming process is one of the most common sheet metal forming processes where the strip is deformed by rotating rolls mounted on successive stands to produce a large variety of profiles continuously at high production rates. This process can only produce profiles with constant cross sections. However, a lot of components used in the automobile, railway cars, ship construction, and building industries have variable cross sections. Therefore, flexible roll forming has been developed recently to produce variable cross section profiles. Ortic (2001) developed a flexible roll forming machine for the production of 3D roof panels. Groche et al. (2003b) described a new tooling concept for flexible roll forming process. Ona (2005) proposed the intelligent roll forming machine for forming variable cross sections.

Contrary to conventional roll forming process, in flexible roll forming process the forming rolls are not fixed in their position but are moved along a path which describes the desired bend line of the profile. The forming rolls' positions must be such that they always are tangent to the deformed flange to avoid its additional deformation (Groche et al., 2008a). According to Fig. 1a, this is realized by superposition of a translational and rotational movement of the rolls. Typically these motions are controlled by computerized numerical controls. A flexible roll forming machine is able to produce profile families only by changing its control program (Fig. 1b).

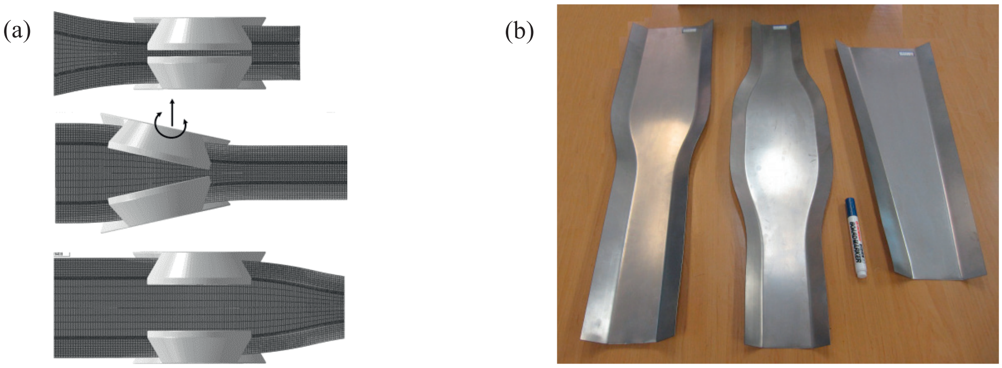


Fig. 1. (a) Flexible roll forming process and (b) channel profiles produced only by changing control program of flexible roll forming setup in the metal forming laboratory of Tarbiat Modares University, I. R. Iran.

In the flexible roll formed profiles, flange wrinkling and web warping are two major failure modes. Most of previous studies focused on understanding the causes of web warping and proposing solutions to overcome it and very few studies have been conducted on the analysis of the wrinkling in the flexible roll forming process. Groche et al., (2010c) developed a one-step-model to design flexible roll formed U-profiles free of wrinkle. They calculated critical stress by Euler formulation for buckling calculations of plates. A correction factor, k, was obtained from FEM simulation and was added to Euler formulation.

Generally, wrinkling is an unstable deformation due to excessive longitudinal compression at the strip edge (Kasaei et al., 2014). Wrinkling may be occurred at the constant cross section zone and also variable cross section zone in the flexible roll formed profiles. Reasons of the longitudinal compression at the constant cross section zone are similar to those in the conventional roll formed profile. Due to changing cross section, complex deformations create at the variable cross section zone so that some portion of flange is compressed in the longitudinal direction. The reason of the longitudinal compression is different from those at the constant cross section zone. Therefore, in this paper, the flange wrinkling at the variable cross section zone is investigated.

2. Finite element modeling and simulation

In order to study on the flange wrinkling, flexible roll forming process is modeled and simulated by Abaqus software. It had a forming stand where two stands with cylindrical rolls were employed before and after the forming stand in order to support strip (Fig. 2a). Target product is a channel whose cross section is variable along its length. Three distinct zones can be considered in the longitudinal direction: the slim zone, the transition zone, and the wide zone (Fig. 2b). In order to eliminate the effect of web warping on the flange wrinkling condition, web displacement is fixed in the perpendicular direction to strip (fixed web condition).

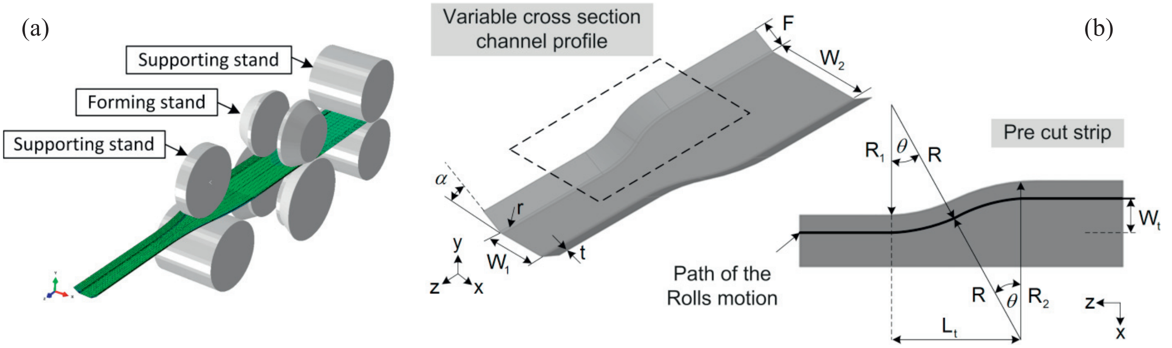


Fig. 2. (a) Simulated flexible roll forming and (b) geometrical characterizations of variable cross section channel profile and its pre cut strip.

In this paper, flexible roll forming process was simulated at two categories which are given in Table 1. The first category which was performed to study the flange wrinkling included three simulations by considering three different values for the flange length. The second category that consisted of one simulation was used in order to verify the finite element analysis by comparing the results with the data measured from the experiments.

Table 1. Simulation specifications.

Parameter	First category.	Second category.
Initial web, W_1 (mm)	20	70
Final web, W_2 (mm)	60	140
Thickness, t (mm)	1.2	0.5
Flange length, F (mm)	10, 20, 30	30
Forming angle, α (deg)	30	30
Radius of transition zone, R (mm)	400	400
Material [Elasticity modulus (GPa), Poisson’s ratio, Yield strength (MPa)]	Material 1[200,0.3,400]	Material 2[185,0.3,172]

3. Mathematical modeling

According to Fig. 2b, the transition zone can be divided into two zones: convex zone and concave zone. To obtain the intended profile geometry, the length of the strip edge should increase with increase of the forming angle at the concave zone while it decreases with increase of the forming angle at the convex region. Otherwise geometrical deviations from the target geometry can occur. Therefore, the concave region is always under tension while the convex region is always under compression. These two zones are similar to stretch and shrink flanges in the flanging process respectively (Fig. 3). The necessary circumferential strain that should occur at the flange edge can be calculated considering an ideal product at the flanging process. The necessary tensile and compression circumferential strains at edge are calculated using Eqs. (1) and (2), respectively.

$$\varepsilon_{\theta_s} = \ln\left(\frac{R_{\alpha 1}}{R_1}\right), \tag{1}$$

$$\varepsilon_{\theta_c} = \ln\left(\frac{R_{\alpha 2}}{R_2}\right), \tag{2}$$

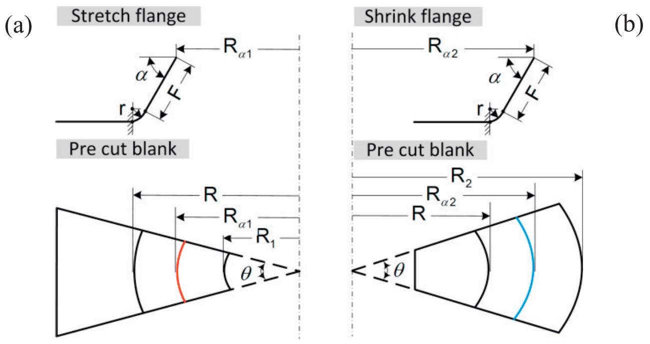


Fig. 3. (a) Stretch flanging and (b) shrink flanging.

4. Results and discussion

Study of the longitudinal strain distribution is a helpful method to a better understanding of flange wrinkling in flexible roll forming process. Therefore, the longitudinal strain was obtained from three finite element analysis on a path defined at the strip edge. The results were investigated at four different times: after finishing the deformation of the slim zone (t1), stretching zone (t2), compression zone (t3) and at the middle of the deformation of the wide zone (t4). Finite element analysis results and mathematical modeling results are shown in Figs. 4.

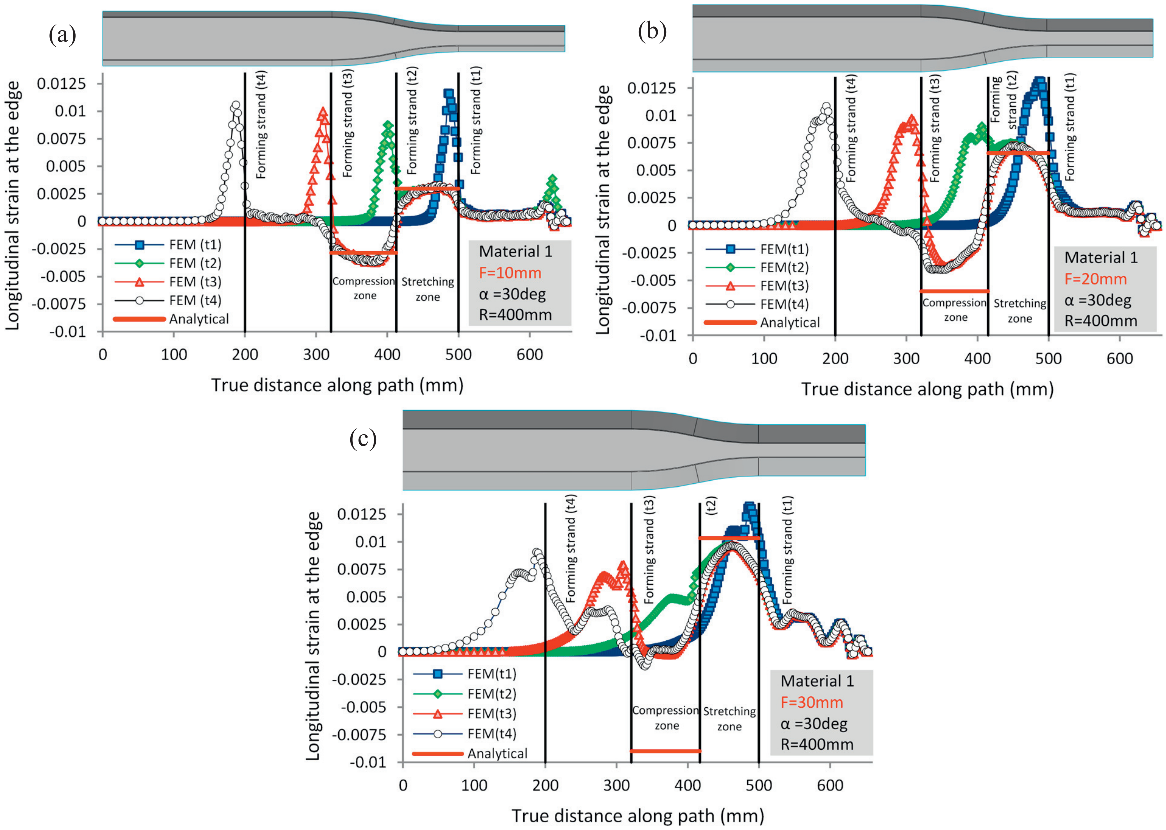


Fig. 4. Longitudinal strain at the flange edge at four different times of flexible roll forming for (a) F =10 mm, (b) F=20 mm and (c) F=30 mm.

According to Fig. 4, a peak longitudinal strain occurs at the deformed strip edge before the forming stand at all four studied times. Because the flange edge has to move along spatial paths before the forming stand which are longer than those for other portions of deformed strip. This is a specific deformation of the conventional roll forming process. As it was explained during mathematical modeling, at the transition zone, there is another type of deformation which according to the flange shape. During deformation of the stretching zone (t1-t2), the peak longitudinal strain before the forming stand helps the increase of the edge length. However, during deformation of the compression zone (t2-t3), this has negative effect on the decrease of the edge length. It is concluded that the deformation of the flexible roll forming process at the transition zone is a combination of the conventional roll forming process deformation and the flanging process deformation.

The results show that with increase of the flange length from 10 to 20 mm, the difference between the compressive strain at the compression zone obtained from the finite element analysis and the necessary compressive strain calculated by mathematical modeling increase. According to Eq. (2), the necessary compressive strain increases with increase of flange length. However, in the finite element analysis, this is correct before the onset of flange wrinkling. Therefore, based on difference between the compressive strain obtained from the finite element analysis and the necessary compressive strain calculated by the mathematical modeling, the flange wrinkling at the compression zone can be predicted. Fig. 5b shows the onset of flange wrinkling in the flange length 20 mm. Since the increase of the flange length from 20 to 30 mm decreases the compressive strain obtained from the finite element analysis and increases intensively the difference of that and the necessary compressive strain, flange length 30 mm is more talented for flange wrinkling. Fig. 5c shows view of the wavy edge in the flange length 30 mm. It is noticeable that, unlike the flange lengths of 10 and 20 mm, the edge strain of the flange length 30 mm has some fluctuations at slim and wide zones (Fig. 4c) that show the edge wrinkling in these zones (Fig. 5c).

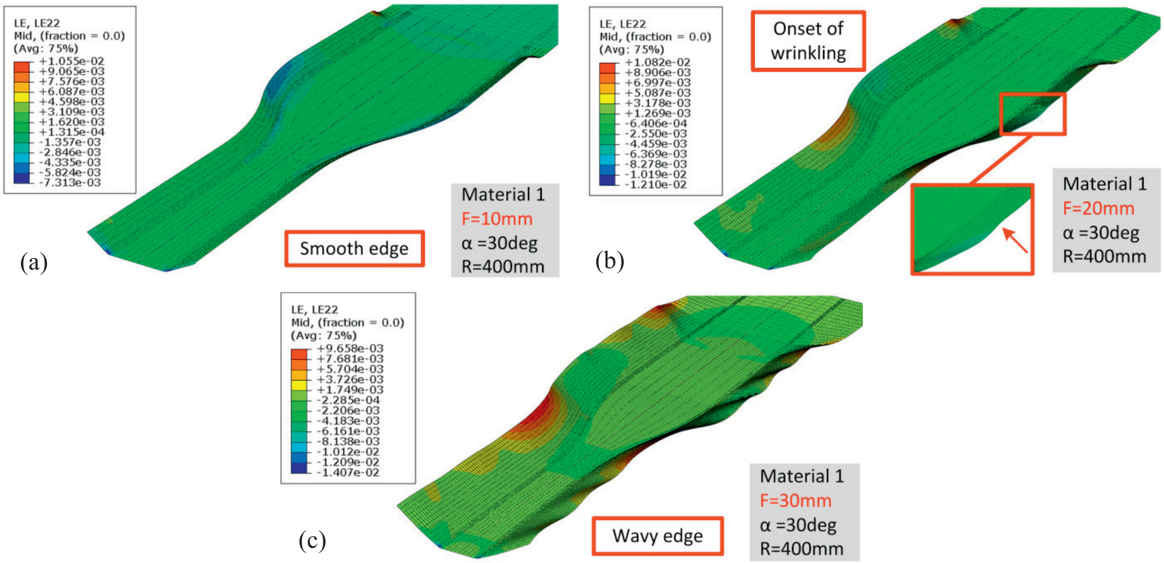
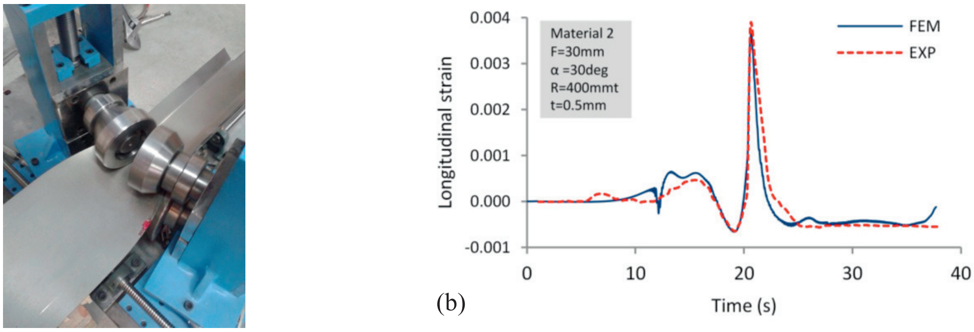


Fig. 5. Flange wrinkling in the flexible roll forming simulation for (a) F=10mm, (b) F=20mm and (c) F=30mm.

5. Verification of the simulation

A flexible roll forming setup was developed and experimental tests for verification of finite element simulation were conducted according to second category in Table 1. Longitudinal strain history at the flange edge was measured using resistance strain gauge. Strain gauge was mounted at the middle of the compression zone on the top surface of strip, with 3 mm lateral distance from flange edge (Fig 6a). Since a blank holder was not applied in the flexible roll forming setup, the fixed web condition is removed in the finite element simulation. Fig 6b shows comparison between experimental results and finite element simulation results. It is observed that experimental and simulation results are in a very good agreement. Therefore, the simulation results are reliable.

According to Fig. 6, peak longitudinal strain occurs before measuring point enters to the forming stand. But due to the absence of blank holder, web warping occurs and thus the compressive strain does not imply correctly to flange edge.



(a) (b)

Fig. 6. (a) Flexible roll forming setup and (b) comparison of the experimental and simulation longitudinal strain history at the meddle of compression zone on the top surface.

6. Conclusion

In this paper, in order to study on flange wrinkling in the flexible roll forming process, finite element analysis and mathematical modeling were employed. The results can be briefly expressed as:

(1) At the transition zone, the strip deformation is a combination of strip deformation in the conventional roll forming and flanging processes. Similar to the conventional roll forming process, the strip edge is stretched before the forming stand. Then, by entering to forming stand, strip is deformed to stretching zone or compression zone according to flange shape. Although the strip deformation is gradually in this step, it is similar to the strip deformation in the flanging process.

(2) Due to stretching the flange edge before the forming stand, the edge experiences a permanent plastic deformation which helps the increase of the edge length in the stretching zone and resists against the decrease of the edge length at the compression zone.

(3) At the compression zone, when the flange wrinkling initiates, the longitudinal edge strains obtained from the finite element analysis are smaller than the necessary compressive strain calculated by the mathematical modeling. Therefore, this strain difference can be a suitable criterion to predict the flange wrinkling at the compression zone

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