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An Investigation on Bend Curve in the Transition Zone on Web Warping of Channels with Variable Width in the Flexible Roll Forming Process

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ABSTRACT

Flexible roll forming is a modern process to produce products with variable cross section that can be used in construction and automotive industries. In this paper, effects of different bend curves on web warping has been studied in transition zone. Considering geometrical boundary conditions of the transition zone, five different curves including circular, quadratic, cubic, quartic, and quintic curves were studied numerically and experimentally. According to the finite element results, longitudinal strains on profile edge which are less than the desirable strain increase the web warping defect. Product with circular bend curve showed the maximum amount of web warping while the quartic bend curve led to the lowest. In order to verify the finite element analysis, the longitudinal edge strain and the web warping were measured experimentally. A good agreement between the experimental and finite element results confirmed the accuracy of the model.

KEYWORDS:

Flexible Roll Forming, Products with Variable Cross Section, Web Warping, Bend Curve.

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1- Introduction

Flexible roll forming which is able to produce variable cross section products is a new generation of the conventional roll forming process. In order to produce variable width products, forming rolls have a linear movement along their axis as well as two rotational motions around their axis and perpendicular to their axis. The rolls axis should always be perpendicular to the bend curve [1, 2].

In the previous studies found by the authors, bend curves were considered in the form of tangent circular arcs. In this study, considering geometrical boundary conditions of transition zone, effect of five different bend curves on the warping defect was investigated numerically and experimentally. These curves were circular, quadratic, cubic, quartic and quintic.

2- Product Geometry

In this study, final production is a U-cross section product with varying width along its length. Half of the initial pre-cut sheet is shown in Figure 1. The product dimensions are provided in Table 1.

According to the transition zone geometry, six boundary conditions were considered including coordinates and slopes of the first point, the last point, and the turning point (Eqs. 1 to 6). The bend curve equations of the transition zone were developed according to these boundary conditions.

$$x(0) = 0 \quad (1)$$

$$x'(0) = \left.\frac{dx}{dz}\right|_{z=0} = 0 \quad (2)$$

$$x(117.02) = 17.5 \quad (3)$$

$$x''(117.02) = \left.\frac{d^2x}{dz^2}\right|_{z=117.02} = 0 \quad (4)$$

$$x(234.04) = 35 \quad (5)$$

$$x'(234.04) = \left.\frac{dx}{dz}\right|_{z=234.04} = 0 \quad (6)$$

Eqs. (7) and (8) represent circular arcs.

$$(x(z) - 400)^2 + z^2 = 400^2 \quad (7)$$

$$(x(z) - 365)^2 + (z - 234.04)^2 = 400^2 \quad (8)$$

Quadratic equations are:

$$x(z) = 1.27796 \times 10^{-3} z^2 \quad (9)$$

$$x(z) = -1.27796 \times 10^{-3} z^2 + 0.59819\, z - 35 \quad (10)$$

Eq. (11) is cubic.

$$x(z) = -5.4604 \times 10^{-6} z^3 + 1.91694 \times 10^{-3} z^2 \quad (11)$$

Eq. (12) represents the quartic curve.

$$x(z) = 3.56426 \times 10^{-17} z^4 - 5.4604 \times 10^{-6} z^3 + 1.91694 \times 10^{-3} z^2 \quad (12)$$

The quintic curve is introduced by Eq. (13).

$$x(z) = 8.87447 \times 10^{-11} z^5 - 5.19245 \times 10^{-8} z^4 + 4.26149 \times 10^{-6} z^3 + 1.34811 \times 10^{-3} z^2 \quad (13)$$

The bend curves of the transition zone are drawn in Figure 2.

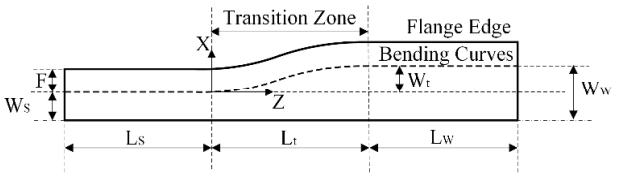

Figure 1. Geometry characteristics of precut sheet

Table 1. The quantities of Production Geometry

Parameters	Quantities (mm)
Length of the slim zone (*LS*)	250
Length of the wide zone (*LW*)	250
Length of the transition zone (*Lt*)	234.04
Width of the slim zone (*WS*)	70
Width of the wide zone (*WW*)	140
Flange width (*F*)	30
Thickness (*t*)	1

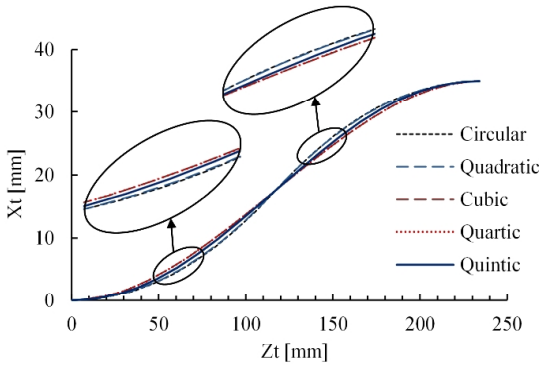

Figure 2. Bending Curves

3- Experimental Study

A flexible roll forming machine produced in metal forming laboratory of Tarbiat Modares University was used for experimental tests. This machine has one forming station. Web warping and longitudinal strain history on profile edge were measured for profiles with circular bend curve. A St12 steel strip with a thickness of 1 mm was used. Rolls motions were controlled by CNC.

4- Finite Element

Finite element simulations were performed by ABAQUS 6.13. In finite element model, four stations

were applied. One of them was forming station. Rolls were considered rigid and strip was modeled by elastic-plastic shell elements.

5- Results and Discussion

5-1- Verification

In order to verify the finite element model, the experimental and finite element results were compared for the edge strain history of a point on the transition zone middle and the web warping.

In profile with circular bend curve, 2.09 mm web warping was measured in the experimental test while the web warping of 1.93 mm was obtained from the in finite element analysis. The relative difference of 7.66% was small enough to verify the finite element model.

5-2- Web Warping

The web warping results obtained for the five studied bend curves are shown in Figure 3 where the circular bend curve resulted the maximum web warping and the quartic bend curve led to the minimum. An accurate look at Tables 2 and 3 and Figure 3 shows that there is a significant relationship between the web warping and change of flange edge length. An increasing difference of desirable length and edge length after forming increases the web warping. (Eq. 14).

$$\%Error = \frac{l_d - l_f}{l_d} \times 100 \quad (14)$$

%Error: Relative difference of desirable and formed edge length

l_d: Desirable length of flange edge

l_f: Formed length of flange edge

5-2- Conclusion

In this study, the effect of bend curve in the transition zone on the web warping is investigated numerically and experimentally for channels with variable width. Five different types of curves in the transition zone including circular, quadratic, cubic, quartic and quintic curves were studied. The brief results are:

1. If the length of the flange edge reaches to the desirable length, the web warping will decrease.
2. Web warping was maximum for profiles with circular bending curve.
3. Web warping of profiles with cubic and quartic bend curve was 15% less than that of profiles with circular bend curve.

Table 2. Compare with desirable and formed length in concave zone

Bending curves	Quantities (mm)		%E
	Desirable	Formed	
Circular	111.04	110.46	0.52
Quadratic	111.18	110.64	0.49
Cubic	112.51	112.51	0.29
Quartic	112.53	112.53	0.27
Quintic	112.14	112.14	0.32

Table 3. Compare with desirable and formed length in convex zone

Bending curves	Quantities (mm)		%E
	Desirable	Formed	
Circular	126.48	127.59	0.88
Quadratic	126.3	127.39	0.86
Cubic	124.31	125.21	0.72
Quartic	124.31	125.18	0.7
Quintic	124.79	125.76	0.78

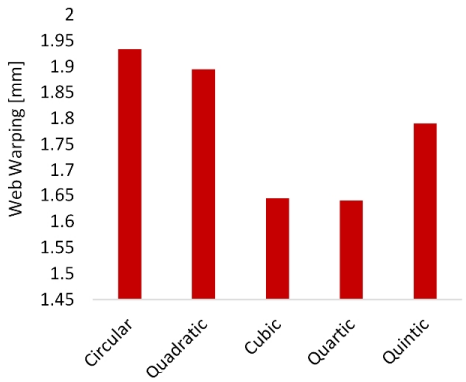

Figure 3. Bar graph of Web Warping

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