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Ovality and Bow Defect of Pre-punched Sheets in Roll Forming of Trapezoidal Sections

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ABSTRACT

Roll forming process is used for manufacturing sheet metal parts by successive bending and creating the final shape with gradual deformation. In this article, deformation of a pre-punched sheet due to the roll forming process was studied. Two main defects in the roll forming process are ovality of holes and bow defect. The ovality of the hole is influenced by the process parameters including sheet strength, thickness, initial hole diameter and distance of hole center to lateral edge. Due to the roll forming process, the sheet undesirably bent along longitudinal direction to a slight curved part which called bow defect. Also, the magnitude of product's curvature along longitudinal direction (bow defect) was measured. The experimental tests were conducted on ASTM 230, 275 and 340 galvanized steels. The results showed that increase in the yield strength elongates the hole along rolling direction and shortened the hole perpendicular to rolling dimension. Therefore, the ovality of hole increases by increasing the yield strength. Also, similar trends were observed by increasing the thickness and the distance between hole center and lateral edge. The results showed that the bow defect decreases by increasing the material yield strength, while with increase in the sheet thickness, initial hole diameter and hole distance from lateral edge the bow defect was increased.

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1. INTRODUCTION

Metal forming processes can be classified into two distinct groups; bulk metal forming and sheet metal forming. In sheet metal forming processes, external force is applied to a sheet for modify its geometry to the desired shape. The applied force causes the material to deform plastically. Different methods of sheet metal forming processes are developed as bending, deep drawing, stretching and rolling [1-3]. Roll forming process is one of the sheet metal manufacturing process. This process is also called contour-roll forming or cold-roll forming and is used for forming of sheet metals into desired shape continuously. The initial blank passes through a set of driven rolls and the metal strip is bent in consecutive stages. The formed strip is then sheared into specific lengths and stacked. The sheet thickness usually ranges from about 0.125 to 20 mm. Forming speed is usually below 1.5 m/s. Dimensional tolerances and springback are two main objects need special consideration in designing the rolls' shape and their sequence. The rolls generally are made of carbon steel or gray iron, and they may be chromium plated for a better surface finish and to reduce wear of the rolls. Lubricants may be used to reduce wear and improve surface finish [4]. Hong et al. [5] developed a finite element code for simulation of roll forming process. The investigation shows that work hardening exponent of plastic deformation zone has most significant effect on shape tolerances. Farzin et al. [6] introduced a new criterion called buckling limit of strain (BLS), limiting strain based on plastic local buckling of the rim. By calculating BLS, the design process of cold roll forming parts can be done more confidently. Supplementary study have been done by Salmani Tehrani et al. [7]. Alsamhan et al. [8] developed a real time re-meshing technique to model the roll forming process of trapezoid sections. Bui and Ponthot [9] simulated a cold roll-forming process by a non-commercial 3D finite element analysis code. The results show that material behavior (the yield strength and the work-hardening exponent) have significant impacts on the product quality, whereas

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forming speed and friction at roll-sheet interface appear to play a minor role. It should be noted that the roll forming speed is determined by the rotational speed of the rollers and it varies in a specified range, So the effect of roll forming speed is not so wide that the can affect on the product quality. Lindgren [10, 11] studied the roll forming of high strength steels. Lindgren studied the effect of yield strength increase due to the roll forming. The number of forming steps and the distance between them are influenced by this increase in the yield strength. The result showed that the required torque and force of roll forming process increased by increasing in the yield strength. Ona [12] used roll forming process to produce pipe from thin steel sheets. A stainless steel 304 with 0.1 mm thickness, 2100 MPa tensile strength and 1.5% elongation was successfully formed to pipe. Shirani Bidabadi et al. [13] studied the influence of geometrical variables of pre-notched channel products and the roll forming variables on the ovality of holes in the U-shaped sections. Main factors affecting on the final shape of the hole include of hole's diameter, the distance between the holes and the distance between the hole and the strip edge (or the bend line). Safdarian and Moslemi Naeini [14] investigated the effect of roll forming parameters of channel section (as bending angle increment, thickness, flange width, web width, friction, rotation speed and distance between the roll stand) on the edge longitudinal strain and bow defect of samples (the sample has an anticlastic curvature and is not flat). Experimental and numerical results showed that bow defect increased along with bending angle. Also, friction in the roll-strip contact and speed of roll stand did not affect on the edge longitudinal strain. Lee et al. [15] studied the roll forming of sheet to fabricate pipelines. The process modeled in FE software and the variation in flow stress and thickness was studied. The kinematic hardening model (Bauschinger effect) was included in study. Abvabi et al. [16] studied the roll forming process of a V-sections with 0.5, 1.5 and 2.5 percent thickness reduction. By increasing the amount of applied cold work, the springback and induced residual stresses increased. Cai et al. [17] focussed on fabricating sweep surfaces by continuous roll forming process. Despite of roll forming, pairs of small-diameter rollers placed perpendicular to feeding direction and form the blank to desired surface. Crutzen et al. [18] modeled the roll forming process using Arbitrary Lagrangian Eulerian (ALE) and classical Lagrangian formulation. The results showed that using ALE technique increase the efficiency and the solution converge more rapidly. Paralikas [19-21] studied the roll forming of advanced high strength steel (AHSS) Dual-Phase series (DP-780). The effect of the process parameters and flower pattern design on the deformation, elastic longitudinal strains and the final produced cross section was investigated. Elastic longitudinal strains were calculated based on the geometric constraints, and as proven the longitudinal strains are proportional to the flange width and to the bending angle increment. Therefore, springback can be predicted in roll forming of AHSS. Farahmand and Abrinia [22] proposed an upper bound solution for fabricating polygonal cross-section thick tubes by means of a roll forming rig with flat rolls. Zeng et al. [23] studied on the optimization of cold roll forming based on response surface methodology (RSM). A mathematical model was established to find springback angle and maximum edge strains as a function of forming angle increments and roll stand radii. Results showed that the desired profile can be manufactured without any troubles such as edge wave caused by excessive edge stretching, and consequently RSM can minimize the number of stands. Wiebenga et al. [24] used the robust optimization technique to determine the optimal process settings in order of reducing the geometrical tolerances of final product. In this way, the longitudinal bowing and springback in the final product was controlled despite of the variation of material properties during the operatio process. According to the literature survey it can be concluded that most of the researches focussed on the deformation of a complete sheet due to roll forming process and no investigation was found on deformation of a pre-punched sheet. In this article, the deformation of pre-punched holes was studied during the roll forming of galvanized steels. Effects of process parameters as yield strength, sheet thickness, hole diameter, distance from the external edges on variation of hole shape were considered experimentally.

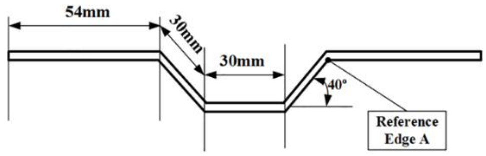
2. MATERIALS AND ROLL FORMING PROCESS

In this study, a trapezoidal cross section similar to Figure 1(a) was selected for investigation. The initial blank width is equals to 198 mm. The angle between the inclined edges is 100 degrees. The flower pattern of roll forming is shown in Figure 1(b). Three different thicknesses were included in the investigation (0.4, 0.5 and 0.6 mm). The final shape was fabricated by a roll forming machine which is showed in Figure 1(c). The holes were created on inclined section (Figure 1(c)). Reference edge **A** was selected as shown in Figure 1(a). The distance between the lateral edge and hole is measured from reference edge **A**. The roll forming machine had five rolling stages which gradually formed the final shape from a flat sheet to a trapezoidal cross section. Figure 2 shows the rollers which formed the sheet in 1st and 5th stage.

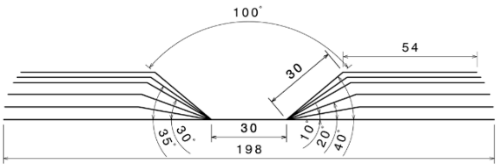
The experimental tests were implemented with ASTM 230, 275 and 340 galvanized steel materials with yield strengths of 230, 275 and 340 MPa, respectively.

Different set of experiments were carried out. The experimental tests can be listed as the following categories:

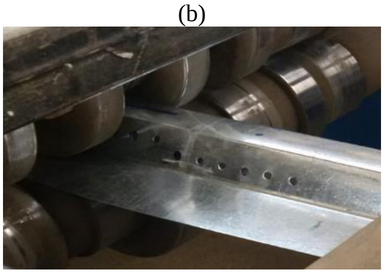
- Studying the effect of yield strength: in this case, holes with 5 mm diameter were created at 6 mm distance from edge **A**. The thickness of sheet was equals to 0.5 mm.
- Studying the effect of thickness: in this case, holes with 5 mm diameter were created at 6 mm distance from edge A. The yield strength of sheet was equals to 230 MPa.
- Studying the effect of hole diameter: in this case, holes with 5, 7.5 and 10 mm diameter were created at 14 mm distance from edge A. The yield strength and thickness of sheet were equal to 230 MPa and 0.5 mm, respectively.
- Studying the effect of distance from edge: in this case, holes with 5 mm diameter were created at 6, 14 and 22 mm distance from outer edge. The yield strength and thickness of sheet were equal 230 MPa and 0.5 mm, respectively.



(a)



(b)



(c)

Figure 1. a) Dimensions of final shape b) flower pattern of roll forming c) the sample of roll forming in 5th stage

(a)

(b)

Figure 2. a) 1st stage b) 5th stage of the roll forming machine

Table 1 shows the experimental tests planning for investigation of the effect of process parameters. Figure 3 shows the deformation of holes for 10 mm initial hole diameter after roll forming process. Also, Figure 4 depics the obtained samples with 6 and 14 mm distance from edge **A** (initial hole diameter 5 mm). The final diameter along the rolling direction and transverse direction after roll forming were measured. For better understanding of hole deformation, the ovality ratio was defined by Equation (1).

$$Ovality\ Ratio = \frac{Hole\ Diameter\ in\ Rolling\ Direction}{Hole\ Diameter\ in\ Transverse\ Direction} \quad (1)$$

The roll forming process caused the final part to have a slight anticlastic curvature which called bow defect. When a bowed part positioned at a flat surface, maximum distance from the flat surface can be measured and used as a criterion. In this article, this distance is called "bow height". Effect of process parameters on the bow height was investigated in experiments. Figure 5 shows a formed part and the definition of bow height.

3. RESULTS AND DISCUSSION

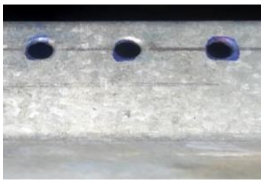
3. 1. Effect of Sheet Yield Strength

The effect of sheet yield strength on hole deformation and ovality ratio is shown in Figure 6.

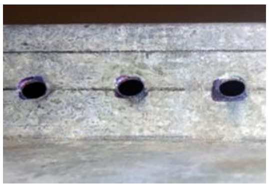
TABLE 1. Experimental tests planning.

Yield strength (MPa)	Hole diameter (mm)	Thickness (mm)	Distance from edge A (mm)
230, 275, 340	5	0.5	6
230	5	0.4, 0.5, 0.6	6
230	5, 7.5, 10	0.5	14
230	5	0.5	6, 14, 22

Figure 3. Deformation of 10 mm initial hole diameter



(a)



(b)

Figure 4. Deformation of 5 mm initial hole diameter for (a) 6 mm (b) 14 mm distance from outer edge

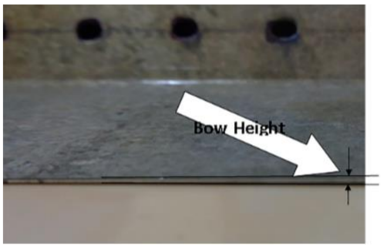


Figure 5. Bow defect in roll forming of pre-punched sheet

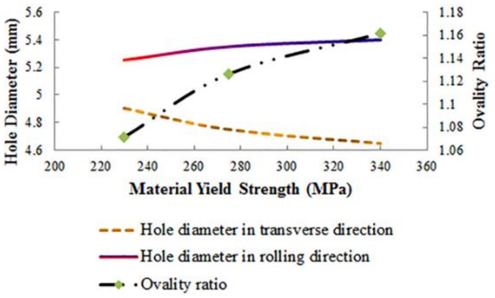


Figure 6. Effect of sheet yield strength on hole deformation and ovality ratio

As it is seen, with increase in the sheet strength the hole diameter in rolling direction has increased while in transverse direction decrease in the hole diameter occurred. Consequently, the ovality ratio has increased by increasing in sheet strength. Also, effect of sheet strength on bow defect is shown in Figure 7. The bow height has decreased by increasing the material strength. The investigation reported by other researchers [25] showed that the most influential parameters were the bending angle increments at each stand, the flange width, and the strip thickness. Conversely, the effects of the inter-distance between the successive stands and the radius of bend on the bowing defect were negligible.

3. 2. Effect of Sheet Thickness The effect of sheet thickness on hole deformation and ovality ratio is shown in Figure 8. This figure shows that with increase in the sheet thickness the hole diameter in transverse direction decreased while in rolling direction a slightly increased.

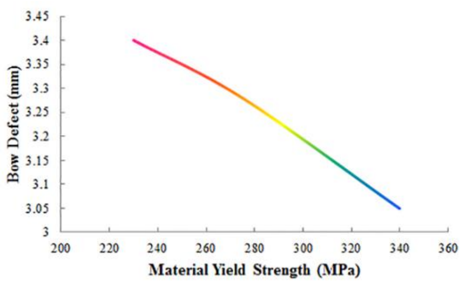


Figure 7. Effect of sheet strength on bow defect after roll forming process

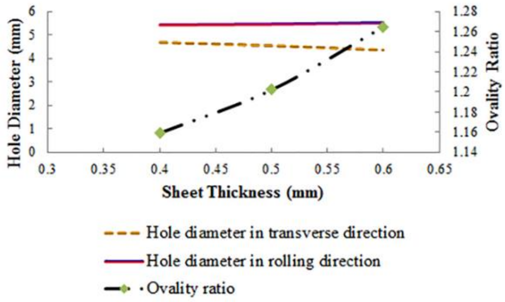


Figure 8. Effect of sheet thickness on hole deformation and ovality ratio

However, the ovality ratio slightly increased by an increase in sheet thickness. Also, the effect of sheet strength on bow defect is shown in Figure 9. By increasing the thickness of sheet, the bow height has increased. The bow defect and ovality both increases and depends on the thickness while in yield strength increase; which means they change conversely.

3. 3. Effect of Initial Hole Diameter Figure 10 shows the percentage of hole diameter change in rolling and transverse direction due to increase in initial hole diameter. As it is illustrated in Figure 10 by increasing the initial hole diameter, deformed diameter in rolling direction has increased while in transverse direction decrease in hole diameter occurred.

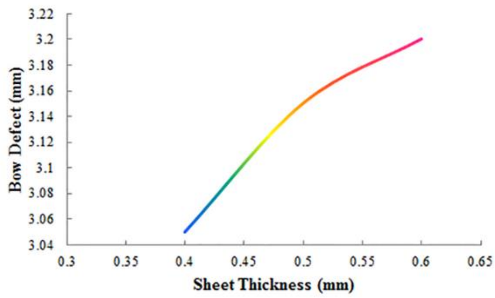


Figure 9. Effect of sheet thickness on bow defect after roll forming process

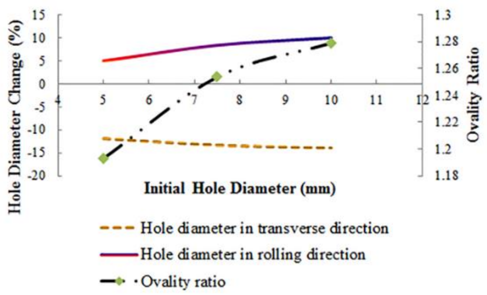


Figure 10. Effect of initial hole diameter on hole deformation and ovality ratio

It should be noted that the ovality ratio increases by an increase in initial hole diameter. Figure 11 shows the variation of bow height by the pre-punch hole diameter. According to Figure 11 the bow defect is increased by increasing in the hole diameter. Increasing in the pre-punch hole diameter leads to more ovality and more bowing.

3. 4. Effect of Distance of Hole Center to Lateral Edge The effect of hole distance from edge **A** on hole deformation and ovality ratio is depicted in Figure 12. This figure shows that with increase in the hole distance from edge **A** the hole diameter in transverse direction has slightly decreased while in rolling direction a slight increase was observed. However, the ovality ratio somewhat increases by an increase in sheet thickness. Also, the effect of hole distance from reference edge **A** on bow defect is shown in Figure 13.

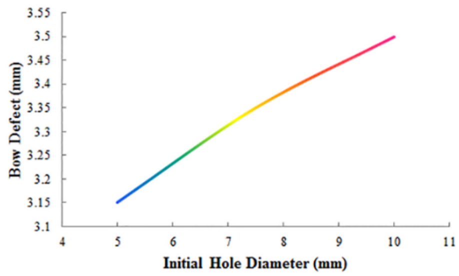


Figure 11. Effect of initial hole diameter on bow defect after roll forming process

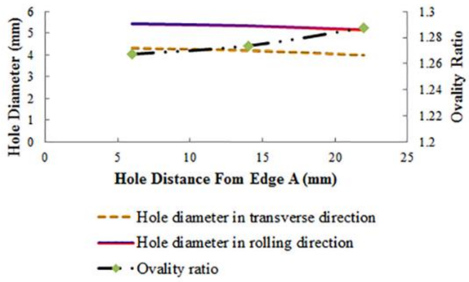


Figure 12. Effect of hole distance from edge A on hole deformation and ovality ratio

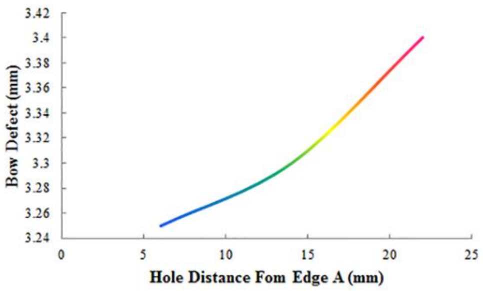


Figure 13. Effect of hole distance from edge A on bow defect after roll forming process

By increasing the distance from reference edge **A**, the bow height increases. The distance from edge does not have significant effect on ovality of the hole but bowing has increased.

4. CONCLUSIONS

In this article, the deformation of holes in pre-punched sheets in roll forming process were investigated. The results showed that by increase in the sheet strength and initial hole diameter, the hole diameter in rolling direction was increased while in transverse direction decrease in hole diameter was observed. Therefore, the ovality ratio was increased by increase in sheet strength. Also, by increase in the sheet thickness and increase in the hole distance from edge **A** the ovality ratio increased. In addition, bow defect was decreased with increasing in the sheet strength. While bow defect was increased with increasing in the sheet thickness and increasing in the hole diameter and increase in the hole distance from edge **A**.

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چکیده

فرآیند شکل‌دهی غلتکی یکی از فرآیندهای ساخت قطعات ورقی بوسیله خم کردن تدریجی ورق می باشد. در این مقاله به مطالعه تغییر شکل ورق با سوراخ‌های اولیه در فرآیند شکل‌دهی غلتکی پرداخته خواهد شد. دو عیب اصلی در فرآیند شکل‌دهی غلتکی، عدم دایروی بودن (بیضوی بودن) سوراخ‌ها و تاب برداشتن قطعه است. بیضوی شدن سوراخ‌ها وابسته به پارامترهای فرآیند شامل استحکام تسلیم ورق، ضخامت، قطر اولیه سوراخ، فاصله سوراخ ها از یکدیگر و فاصله مرکز سوراخ تا لبه جانبی است. در اثر فرآیند شکل دهی فلتکی، ورق به شکل ناخواسته در راستای طولی خود خم شده و قطعه ای غیرتخت و دارای انحنا را ایجاد می کند که این عیب را تاب برداشتن می گویند. در این مقاله میزان ارتفاع خمیدگی اندازه‌گیری شده است. آزمایش‌های تجربی بر روی ورق گالوانیزه ASTM 230، 275 و 340 انجام شده است. نتایج نشان می‌دهد که افزایش استحکام تسلیم باعث کشیدگی بیشتر سوراخ‌ها در راستای نورد غلتکی و کاهش قطر سوراخ‌ها در راستای عمود می‌شود. لذا میزان بیضوی بودن سوراخ ها، با افزایش استحکام تسلیم ورق افزایش می‌یابد. همچنین نتایج مشابهی با افزایش ضخامت و افزایش فاصله میان مرکز سوراخ و لبه جانبی نیز بدست می‌آید. همچنین با افزایش استحکام تسلیم ورق، ارتفاع خمیدگی کاهش می یابد در حالی که با افزایش ضخامت ورق، قطر اولیه سوراخ ها و فاصله مرکز سوراخ تا لبه جانبی، میزان ارتفاع تاب برداشتن افزایش می یابد.

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