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## **A comparison study of Chain-die Forming and roll forming by forming a top hat section**

### **Abstract**

Chain-die Forming, a novel sheet metal forming method, has been proposed and developed recently to overcome the problems that arose in roll forming. As an extension to roll forming, Chain-die Forming has been proposed to elongate the deformation length by increasing the virtual roll radii, and employing discrete profiled die-blocks which move on a track board with the desired large radii to implement or simulate the rotation of the virtual large rolls. The roll radii are so large and the forming length is so long that all redundant strain components occurring in roll forming are significantly reduced or even eliminated.

### **Keywords**

chain, study, comparison, top, roll, forming, section, die, hat

### **Disciplines**

Engineering | Science and Technology Studies

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# A comparison study of Chain-die Forming and roll forming by forming a top hat section

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**Abstract** Chain-die Forming, a novel sheet metal forming method, has been proposed and developed recently to overcome the problems that arose in roll forming. As an extension to roll forming, Chain-die Forming has been proposed to elongate the deformation length by increasing the virtual roll radii, and employing discrete profiled die-blocks which move on a track board with the desired large radii to implement or simulate the rotation of the virtual large rolls. The roll radii are so large and the forming length is so long that all redundant strain components occurring in roll forming are significantly reduced or even eliminated.

This paper studies using the Chain-die Forming method to make a top hat profile by one forming pass. In order to truly understand the Chain-die Forming process, FEA is employed to simulate the roll-forming process with different roll radii from 200 mm to 50 m, and the 50 m's simulation results are compared with experimental studies of Chain-die Forming with a 50 m virtual roll radii. The shapes in the middle and at both ends are compared; the strain developing histories at different positions are also studied. It can be concluded that the differences of "forming resistance" can be reduced by increasing the roll radii, and Chain-die Forming can successfully form a top-hat section in one pass. Besides, the sample's shape formed by the Chain-die Forming prototype is very close to the shape simulated by FEA.

**Keywords:** Chain-die Forming, springback, longitudinal strain, sheet metal, finite element analysis, redundant strain component

## 1. INTRODUCTION

Although conventional roll forming has been a highly efficient forming technique for manufacturing long sheet metal products with constant cross-sections in industrial practice, engineers' and designers' experience still plays an important role in roll forming design and new product development. It still has some fundamental and practical limitations due to the complexity of deformation behaviours, including longitudinal stretching and bending, transverse bending and shearing. With the exception of the effective transverse bending along the bending line, other unexpected deformations like longitudinal stretching and bending and in-plane shearing occur during the roll forming process.

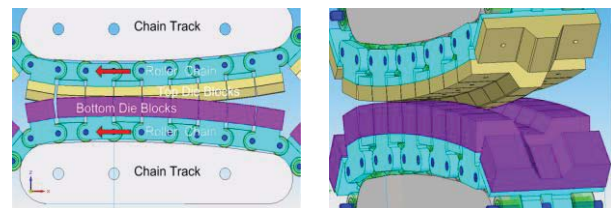
Earlier in the 1970s while studying the forming of circular sections, Suzuki *et al.* suggested a tri-axial surface deformation model and proposed that all other strains except transverse bending strains are the redundant strain components that should be minimized or eliminated in a forming process [1]. Bhattacharyya *et al.* developed a formula for the deformation length which was proved to be independent of the span space between adjacent roll stands [2]. Panton *et al.* pointed out that it is possible for there to be no longitudinal strain during roll forming (in which case there would be shear strain) or no shear strain (in which case there would be longitudinal strain). In reality, the strain will lie between these two extremes and will comprise of both shear and longitudinal strain [3, 4].

Ding proposed his first alternative design concept to minimize the strain path difference when forming wide panels [5], and introduced it publicly after a decade [6]. This approach is a theoretical one of "finding" or constructing an optimal transitional surface in terms of axial strains between the original strip and the final profile. The implementation method, Millipede Forming, was suggested [7].

Chain-die Forming, a novel sheet metal forming method, was proposed originally to extend the deformation

zone in virtual roll forming [8]. The basic idea of Chain-die Forming is to stretch the deformation length by increasing the virtual roll radii and employing the discrete profiled die-blocks moving on a track board to implement or simulate the rotation of the virtual large rolls. The roll radii are so large and the forming length is so long that all redundant strain components occurring in roll forming are significantly reduced or even eliminated [9].

The basic elements of a Chain-die Forming unit include a pair of tracks, roller chains and forming dies. The tracks, equivalent to the rolls in roll forming without rotating, have very large radii and roller chain running on it. The rotation of the rolls which sends the strip forward is carried out by a pair of roller chains running on the tracks and the profiles of rolls are manipulated by the forming die-blocks mounted on the chains, as shown in Figure 1. When a strip is fed into the Chain-die, the gap or the forming space, between the opposite die-blocks is gradually reduced, and the strip in the forming space is gradually pressed and bent to shape through a much longer forming distance than in roll forming [9].



**Figure 1.** The basic elements of Chain-die Forming

## 2. FEA MODELLING AND SIMULATION

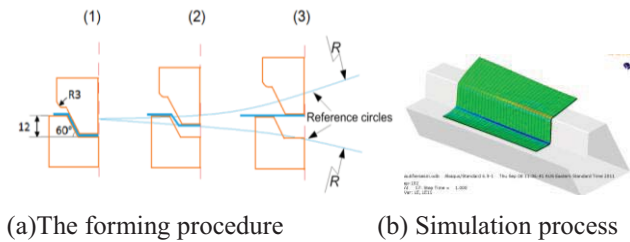
### 2.1. FEA modelling set-up and simulation process

The finite element model was established to simulate the roll forming process with different roll radii from 200 mm to 50 m in order to obtain true understanding of Chain-die Forming. The strip has an initial thickness of 0.5 mm, a width of 80 mm and a length of 300 mm. The sheet material used in the experiment is high strength steel

with an initial yield stress of 600 MPa. Young’s modulus and Poisson’s ratio are respectively  $E = 206 \text{ GPa}$  and  $\gamma = 0.3$ .

The symmetrical channel cross-section allows the modelling of a half-width sheet. An analytical rigid surface is employed to describe the rolls due to its less computational cost than a discrete rigid part, and the contact condition is frictionless. The die profiles and parameters can be shown in Figure 2. The strip mesh consists of 12000 ( $30 \times 80 \times 5$ ) elements. The rolls move towards the strip along the forming direction and the strip is set as the perpendicular direction motion only for simplification and accuracy. The simulation procedure is summarized as follows:

- First, locate the top and bottom rolls perpendicularly adjacent, 0.5 mm away (the strip thickness), and the strip is initially placed between them, in a good position according to the forming direction, ready to contact the rolls.
- Second, set the rolls with small displacement along the longitudinal direction towards the strip until they contact each other, at position (1) in Figure 2.
- Third, give the rolls a forward motion of 1500 mm, while the strip with only vertical freedom is gradually bent to the final top-hat profile, (position (2) in Figure 2) until the top and bottom rolls are fully engaged as shown in position (3) in Figure 2(a), and the simulation process can be seen in Figure 2(b).



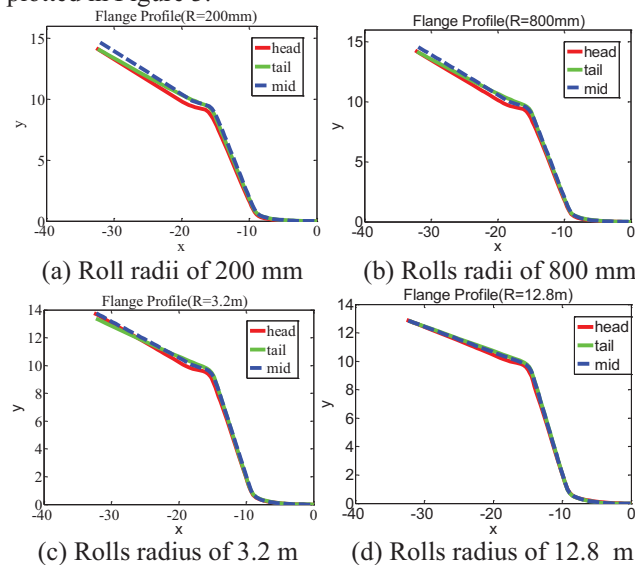
(a)The forming procedure

(b) Simulation process

**Figure 2.** Forming process

**2.2. Flange profile comparison results and discussion**

The roll radii increase from 200 mm to 50 m in a few steps, they are 200 mm, 800 mm, 3.2 m, 12.8 m and 50 m. The final profiles at middle and both ends are recorded and plotted in Figure 3.

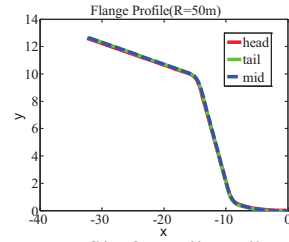


(a) Roll radii of 200 mm

(b) Rolls radii of 800 mm

(c) Rolls radius of 3.2 m

(d) Rolls radius of 12.8 m

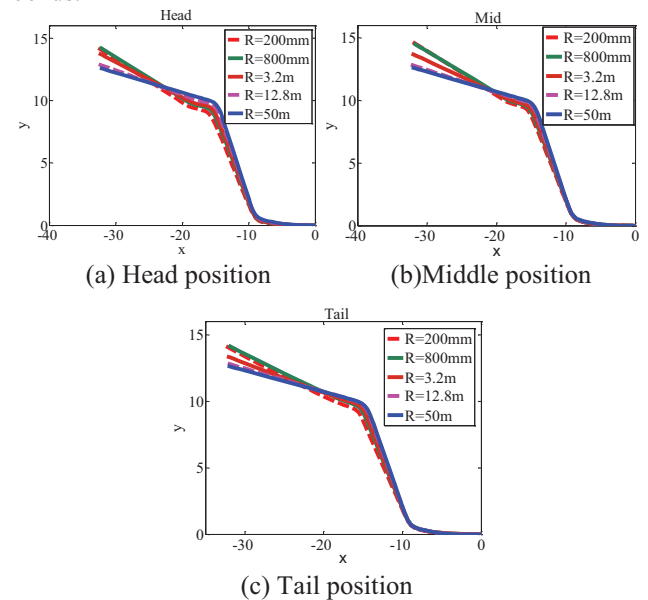


(e) Flange profile for rolls radius of 50 m

**Figure 3.** Flange profile for different rolls radius at middle and both ends

In Figure 3(a) the shape variation among mid-position and both ends is obvious and this is due to the differences of “forming resistance” at different positions during roll forming. In the beginning to form the head of sample, the material is behind the position to be formed and the rigidity of the coming material applies a sort of “resistance” to form the angles. At the end to form the tail, there is no coming material to constrain the shape, and the flange is more like a flat one as compared to the head. With the increasing roll radii, the differences are gradually reduced. If the roll radii are large enough, as shown in Figure 3(e), the differences between the middle position and both ends can be reduced to a negligible level and the shape variation is hard to be observed. The shape at both ends and the middle can be nearly the same but the difference by the plane-strain state and plane-stress state is still there. In this case, the forming process is nearly an air-brake bending.

The shapes in the middle and at both ends are also compared as shown in Figure 4. It can be clearly seen that as the roll’s radius increases, the sheet springback is reduced to become closer to the theoretical prediction at the bends.



(a) Head position

(b) Middle position

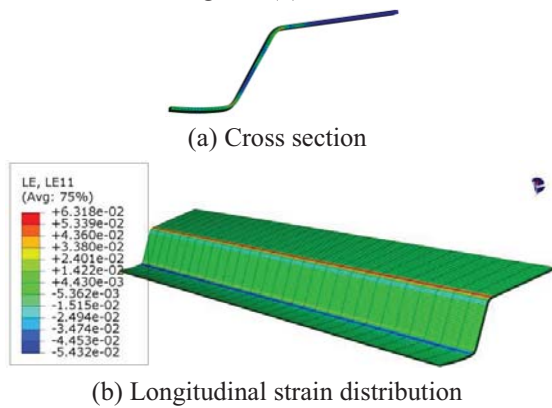
(c) Tail position

**Figure 4.** Flange profile at middle and both ends for different rolls

**2.3. Simulation results and discussion**

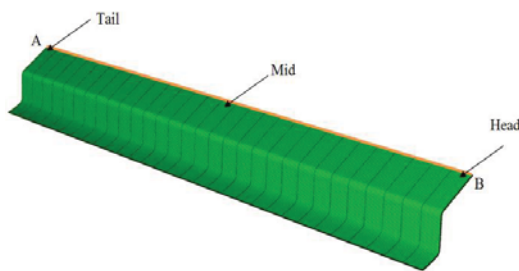
The final profile for the rolls radius of 50 m is plotted for the sake of comparison, and the cross section can be seen from Figure 5(b). Although the flange profile is not perfectly angled due to springback caused by its high yield strength mechanical behaviour, the final profile proves to

be right angled and within a small longitudinal strain range. The longitudinal strain distribution on the deformed sheet can be seen in Figure 5(b):



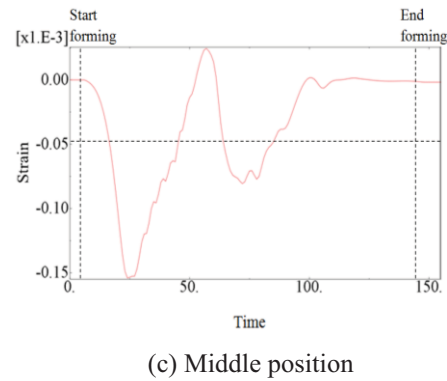
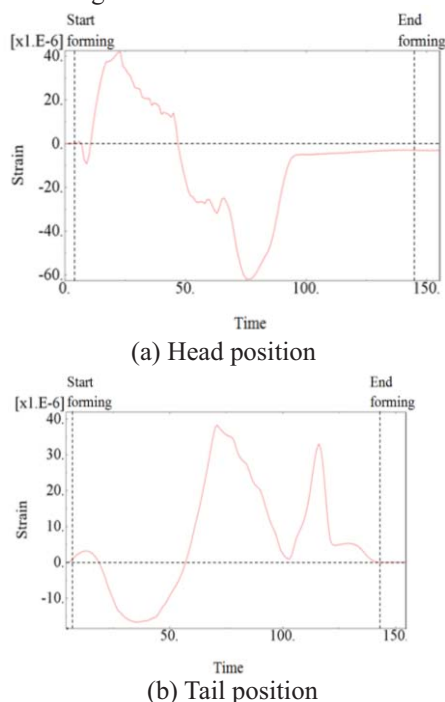
**Figure 5.** Final profile and longitudinal strain distribution

Since there are five layers divided along the thickness, the third layer (the middle layer) element at three different positions is selected to record the longitudinal strains as an average result. The three positions are 1.5 mm from the strip edge AB: head (where the deformation starts), tail (where the deformation ends) and middle (the middle of the strip along longitudinal direction) in Figure 7:



**Figure 6.** Locations of positions for longitudinal strain measurement

The longitudinal strains measured at the mentioned three positions above are recorded for the sake of comparison as shown in Figure 7:

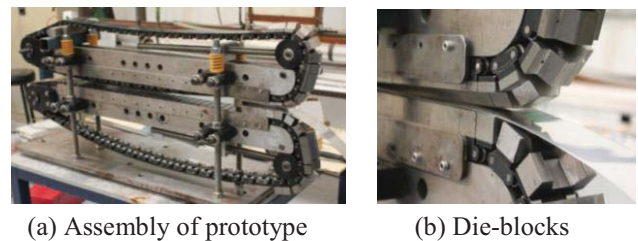


**Figure 7.** Development of longitudinal strain at three positions of the strip edge

From the figure, it can be seen that the maximum longitudinal strain is 0.015%, and the distribution gives a vibration within a small range.

### 3. EXPERIMENTAL WORK AND RESULTS ANALYSIS

The experimental work was processed on the prototype machine built to demonstrate the working principle of Chain-die forming. The assembly of the prototype is shown in Figure 8(a). It has a pair of gear-motors to drive the top and bottom chains individually. In this work, both motors were running with the same speed. After manual filing, the die-blocks are assembled on the chain links and the sample is located properly, as shown in Figure 8(b).



**Figure 8.** Assembly of prototype and die-blocks

The experiment samples were first cut to size 200 mm × 50 mm × 0.5 mm. Three positions are to be measured: middle and two ends. The surface coating was carefully removed and polished before being stuck to the strain gauge. In order to minimize the error caused by strain gauges, the strain gauges used in this study are ECH-120-2AA-11-RL30 from BCM. The strain gauge is 120 ohm and 2x2 mm in size with long legs. The legs are glued and insulated on a tape stuck onto the top and bottom surfaces of the sample and then soldered to the wires out of the sample. The data acquisition system used for the strain gauge measurement in the experiment is the National Instruments NI cDAQ-9172, and the module used to complete the data acquisition system is a NI 9237 simultaneous bridge module, as shown in Figure 9. The devices are connected to the computer and the sample via wires. As the prototype operates, the strain gauge devices start measuring. An oscillograph can be observed from the screen, and relevant data is collected and recorded correspondingly.





Figure 9. Strain gauge measurement devices

A few samples were produced and the deformed samples are shown in Figure 11(a) from different perspectives. It can be observed that the samples produced are perfectly straight and do not have any product defects such as end flares, edge waves, longitudinal curvature and twisting and the surface is smooth and shiny. The sample was then cut by wire half way in transverse direction and a few cuts in longitudinal direction, as shown in Figure 10(b). There is not any bending curvature and obvious shape variation on the cut and strip, and that is again evidence that the residual stresses inside the sample produced are close to zero and the residual stresses are related to the redundant strains during forming.

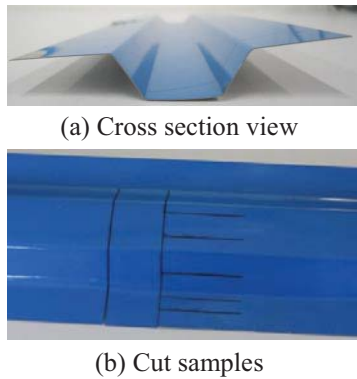


Figure 10. Deformed samples

The strain gauge measurement results at the middle position of the sheet with both the top and bottom positions before and after smoothing is recorded and plotted in Figure 11. The mean of the recorded longitudinal surface strains on the two surfaces gives the longitudinal membrane strain (shown with solid line). As shown in the diagram, the maximum axial strain is about 0.04%. It shows that the results obtained from FEA are within 30% of the experimental measurement. The experiment and FEA both prove the axial strain developed during Chain-die Forming is very small in an elastic regime.

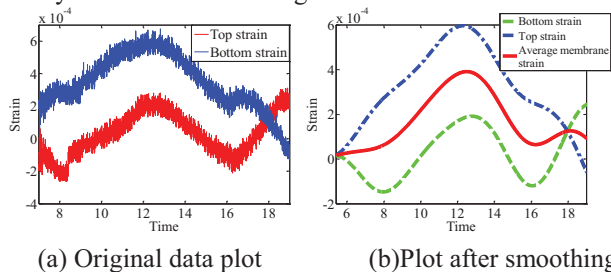


Figure 11. Development of longitudinal strain from strain gauge measurement

#### 4. CONCLUDING REMARKS

Chain-die Forming is further studied in this paper, particularly on using the Chain-die Forming method to make a top hat profile by one forming pass. Finite element analysis is employed to simulate the roll forming process

with different roll radii and the 50 m's simulation results are compared with experimental results. The shapes at middle and both ends are compared; the strain developing histories at different positions are also studied. Some conclusions can be made from this study:

- Using Chain-die Forming can achieve much more bending without product defects than in roll forming in a single pass. This is especially important with the high strength materials which are difficult to be roll formed;
- The end-flare of a roll formed product is related to the residual stresses developed during roll forming. The larger the roll the less the residual stresses. In Chain-die Forming, due to the large radius curvature, the redundant strains are almost in a negligible level and fully springback after forming, there is no observable end-flare;
- The sample's shape formed by the Chain-die Forming prototype is close to the shape predicted by FEA and that also shows the FEA modelling can be successfully used to simulate the Chain-die Forming process;
- Chain-die Forming can successfully form a top-hat section in one pass, but in practice it still requires a few passes to form the shape correctly. The advantages of using the new forming method are 1) fewer passes needed; 2) shorter forming mill; 3) more predictable when developing a new product and 4) higher product quality.

The productivity of Chain Forming in the earlier stage study has shown that it is superior to roll forming in redundant strain elimination, product shape accuracy and occurrence of product defects, footprint of forming line and process flexibility. Further study and industrial support are necessary to push the new technology to success.

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