University of Wollongong

Research Online

Faculty of Engineering and Information
Sciences - Papers: Part A

Faculty of Engineering and Information
Sciences

1-1-2013

Parametric study on chain-die forming for advanced high strength steels

Yuankun Zhang

University of Wollongong, yz045@uowmail.edu.au

Shichao Ding

University of Wollongong, sding@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/eispapers>

Part of the [Engineering Commons](#), and the [Science and Technology Studies Commons](#)

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Parametric study on chain-die forming for advanced high strength steels

Abstract

As the applications of AHSS for the automotive industry are increasing significantly within the last decade, it becomes more and more important to develop a new forming technology as an alternative or even a replacement to roll forming to overcome the difficulties and problems of manufacturing the AHSS parts. The springback of the material with higher strength and thinner thickness becomes more difficult to predict, which directly affects the application of roll forming in AHSS. Chain-die forming, as an alternative to roll forming proposed and developed recently in Australia, is expected to be a solution to the problems addressed. It has been proved that chain-die forming has the advantages of low redundant strain components during forming and nearly zero residual stresses in products. In this paper, a case study of forming an AHSS U-channel with pre-made holes is studied in order to explore the limitations of chain-die forming and exhibit the advantages of the new method over roll forming. FEA is employed to simulate the forming process and the results are compared with the experimental results.

Keywords

steels, high, forming, die, advanced, parametric, chain, strength, study

Disciplines

Engineering | Science and Technology Studies

Publication Details

Zhang, Y. & Ding, S. (2013). Parametric study on chain-die forming for advanced high strength steels. *International Journal of Materials and Product Technology*, 47 (1-4), 138-149.

Parametric study on chain-die forming for advanced high strength steels

Yuankun Zhang* and Shichao Ding

Faculty of Engineering,
University of Wollongong,
Northfields, Wollongong, NSW 2500, Australia
E-mail: yz045@uowmail.edu.au
E-mail: sding@uow.edu.au

*Corresponding author

Abstract: As the applications of AHSS for the automotive industry are increasing significantly within the last decade, it becomes more and more important to develop a new forming technology as an alternative or even a replacement to roll forming to overcome the difficulties and problems of manufacturing the AHSS parts. The springback of the material with higher strength and thinner thickness becomes more difficult to predict, which directly affects the application of roll forming in AHSS. Chain-die forming, as an alternative to roll forming proposed and developed recently in Australia, is expected to be a solution to the problems addressed. It has been proved that chain-die forming has the advantages of low redundant strain components during forming and nearly zero residual stresses in products. In this paper, a case study of forming an AHSS U-channel with pre-made holes is studied in order to explore the limitations of chain-die forming and exhibit the advantages of the new method over roll forming. FEA is employed to simulate the forming process and the results are compared with the experimental results.

Keywords: chain-die forming; advanced high strength steels; AHSS; residual stress; longitudinal strain; finite element analysis.

Reference to this paper should be made as follows: Zhang, Y. and Ding, S. (2013) 'Parametric study on chain-die forming for advanced high strength steels', *Int. J. Materials and Product Technology*, Vol. 47, Nos. 1/2/3/4, pp.138–149.

Biographical notes: Yuankun Zhang is a PhD student at the School of Mechanical, Materials & Mechatronic, Faculty of Engineering and Information Sciences, University of Wollongong, Australia. Her research interest is Chain-die Forming. She received her BSc in Mechanical Engineering and Automation from Jilin University, China.

Shichao Ding is a Lecturer at the School of Mechanical, Materials & Mechatronic, Faculty of Engineering and Information Sciences, University of Wollongong, Australia. His major research interest is sheet metal forming. He received his PhD and MSc from the University of Auckland.

This paper is a revised and expanded version of a paper entitled 'Experimental study on chain-die forming for ultrahigh strength steel (UHSS)' presented at 15th International Conference on Advances in Materials & Processing Technologies, Wollongong, Australia, 23–26 September 2013.

1 Introduction

Advanced high strength steels (AHSS) is being widely introduced to the automotive industry in order to reduce the emission of CO₂ via reducing the costs of manufacturing and the weight of a motor vehicle. In manufacturing, reducing the CO₂ emission means the reduction of the total manufacturing costs of a vehicle includes the steel used in a vehicle without scarifying the passengers' safety. On road reducing CO₂ emission means that driving a lighter vehicle consumes less fuel. AHSS is a favourite to automotive industry as its overall indexes are much higher than other materials. In the approach of roll forming AHSS, Troive and Ingvarsson (2008) concluded that roll forming AHSS has the advantages of reduced distortion compared to mild steels, smaller bend radius than air-brake bending and low capital cost. Lindgren (2007) also concluded that as the strength of deformable material increases, the deformation length increases and the peak value of longitudinal strains and residual strains decrease. However, in the current stage this type of material has the required strength, but also has very limited ductility. When the material's strength is over 800 MPa, most of the AHSS have an elongation of less than 15%, which is much lower than that of interstitial free (IF) steels and bake hardening (BH) steels, leading to difficulties in applying those materials in manufacturing.

Roll forming has been widely appreciated by industries for mass manufacturing long and straight sheet metal products. However, the complexity of the deformation process has caused many fundamental and practical problems. The in-plane shearing leads to high transverse tension as the strip crosses the rolls, and the combination of bending, transverse tension and the doming of the strip can result in over-tension and splitting of the strip as it comes into contact with the bend corner of rolls. Even in cases where the splitting does not occur, it is still very difficult to predict and control the transverse tension, and the springback and residual stresses dominate the quality of the products (Ding et al., 2011). Although many studies were conducted to use 'bending' to replace 'stamping', and 'flexible roll forming' is also proposed to employ a computer system to control the positions and rotational angles of the forming rolls, the technology still has some fundamental difficulties, low efficiency and high cost (Gülçeken et al., 2007). All these make it imperative to replace the conventional roll forming with a new forming approach.

Chain-die forming, an alternative to roll forming, was proposed and developed recently to overcome the problems addressed above. It was originally proposed to stretch the deformation length by increasing the virtual roll radii and employing discrete profiled die-blocks moving on a profiled track board to simulate the virtual large rolls (Ding et al., 2011). It is possible to achieve the goal of keeping the longitudinal strain and shear strain remaining within an acceptable level by controlling the deformation length, so that the causes of product defects in roll forming can be thoroughly removed theoretically. The schematic structure of a chain-die former shown in Figure 1 has a pair of track boards which have very large radii with roller chains running on them, and also forming dies attached on the chains. The profiles of rolls are manipulated by the forming die-blocks mounted on the chains, and when a strip is fed into the forming space among die-blocks, the space between the opposite die blocks is gradually reduced and the strip in the forming space is gradually bent to shape through a much longer forming distance than in roll forming.

Figure 1 The basic elements of chain-die forming (see online version for colours)

Preliminary studies have proved that chain-die forming has the advantages of low redundant deformation during forming and nearly zero residual stresses in products. In this paper, this newly developed technology is further studied. As a case study of exploring the limitations of chain-die forming and exhibiting the advantages of the new method over roll forming, forming an AHSS U-channel with holes is studied. Experimental studies and FE simulation are conducted and discussed.

2 FEA modelling and simulation of chain-die forming

The chain-die forming process starts at the first contact between strip and dies as shown in Figure 2(c) to fully complete the forming through the forming length, as shown in Figure 2(a). The tooling is similar as air-brake bending, and the top dies are designed similar to a punch die and the bottom dies have a large radii corner to allow the flanges gradually bent up to a channel through the whole forming length.

Figure 2 The process of forming a 90° channel by chain-die forming (see online version for colours)

The blank's thickness is 0.5 mm and the width is 50 mm, and the deformed sample's shape is close to a shape shown in Figure 3(a), where the web is 20 mm wide and the flange is about 16 mm. The geometries of the forming dies are shown in Figure 3(b).

Figure 3 Shape of final deformed sheet and corresponding tooling, (a) samples to be formed (b) corresponding tooling (see online version for colours)

The mechanical behaviour of the sheet material used in the simulation and experiment has an initial yield strength of 906.6 MPa and can be described by Swift's isotropic strain hardening law (Heislitz et al., 1996):

$$\sigma_v = K (\varepsilon_0 + \varepsilon_p)^n$$

where σ_v is the flow stress; ε_p is the plastic strain. The simulation parameters are summarised in Table 1.

Table 1 Summary of simulation parameters

Material model	Isotropic, elastic-plastic, strain hardening
Young's modulus E	208 GPa
Poisson's ratio ν	0.3
Strength coefficient K	1,415 MPa
Offset strain	0.015
Strain-hardening exponent n	0.106
Sheet thickness t	0.5 mm
Sheet length L	300 mm
Friction coefficient μ	0.0
Roll property	Rigid

Due to the geometrical structural symmetry, only half of the geometry was modelled and Figure 4 is a symmetrical observation of result for better understanding. The strip is illustrated with three interested positions following the sequence being formed of the starting, middle and final positions along the forming direction, named head, middle and

tail. The mesh consists of $100 \times 300 \times 5$ elements. The die rolls are assigned perfectly rigid and the working areas are treated as whole bodies without segmentation. The contact condition is set as frictionless for simplification.

Figure 4 Modelling of chain-die forming a U-profile channel (see online version for colours)

In this simulation, a relative motion between the strip and the rolls is applied to simulate the chain-die forming process for simplification and accuracy reasons. The two rolls are assembled as shown in Figure 2(a), a cross sectional view of the rolls perpendicularly adjacent, 0.5 mm away (the strip thickness) and both set with longitudinal displacement for their forward motion. When the simulation starts, the two rolls move towards the strip simultaneously and the strip is gradually press-bent to the final profile when the top and bottom rolls are fully engaged. The friction between the rolls and deformed strip is neglected as in real situation the rolls and strip's relative speed in longitudinal direction is nearly zero. Figure 5 shows the final deformed shape obtained from ABAQUS FE simulation.

Figure 5 Deformed shape from simulation (see online version for colours)

The cross sections are plotted in Figure 6 for comparing the shape variation of the three positions. Close observation of the simulated shape shows that it is quite flat in the middle of the web, but the errors at close positions to the bend corner are increasing from tail to head. This trend of error matches with the flange's error. Indeed, the springback differences between head, middle and tail positions of the strip are very small, the errors

from the head to tail are mainly due to the shape errors on the web, and that matches with the produced samples in the experiment. The differences of the web are due to the forming sequence difference between the head and tail. While the head of the strip is being formed, the following material constrains the deformation of the head and as the tail of the strip is going to be deformed, there is no constrain behind and therefore, the variation between the head and tail still exists. But it can be reduced by increasing the deformation length or reducing the forming angle.

Figure 6 Shape variation at different positions and bend corner (see online version for colours)

3 FEM parametric studies

The development of longitudinal strains in which most roll forming engineers are interested is respectively measured at head, middle and tail positions of 1.5 mm away from the strip edge. In the roll forming process, the width of the deformed flange is an important factor which affects the longitudinal strain distribution. Similarly, in chain-die forming, the longitudinal strain is also a key parameter which needs to be studied. Three flange widths (marked as 'a' in figures), 15, 20 and 30 mm are analysed and the longitudinal strain developments during chain-die forming are plotted in Figure 7. As shown in the figure, the longitudinal strains at the middle position are generally varying between -0.02% and 0.07% . The strains at head and tail are even much smaller than at middle position within a range of $\pm 0.02\%$, as less constrains in axial direction at both ends, and the strip is nearly in a plain stress state. However, it should be pointed out that all the longitudinal strains are in elastic, after forming those strains are fully springback as pre-claimed advantages of the new method, and if the longitudinal strain is in plastic, we can always either break down the forming from one to two passes or increase the forming length via increasing the roll radii.

In particular, Figure 7(a) shows the longitudinal strains almost remain zero at head position during forming process, and tail position has similar trend except a little fluctuation before contact due to the turbulence and interactions of the forming material, as shown in Figure 7(c). At middle position in Figure 7(b), the strains reach a peak value when the material comes into the contact area and then decrease gradually till it ends contact. But the values of all strains remain in a very small range of $\pm 0.04\%$.

Figure 7 Strain comparisons for different flange widths, (a) head position (b) middle position (c) tail position (see online version for colours)

Another key parameter roll forming engineers may be interested in is the relationship between longitudinal strain and strip thickness. Three values of thickness, 0.5 mm, 2 mm and 3 mm, were considered for comparison, as shown in Figure 8. It can be seen that the strains increase with the increase of the material thicknesses, and for head and tail positions, the strains remain very small value within the range of 0.02%. For the middle position, the peak longitudinal strains occurred before the contact starts. The thicker the strip is, the higher the peak value will be. Those results indicate that the deformation area is larger than the contact area, which is similar to roll forming. The strains increase with the increase of the thickness.

Figure 8 Strain comparisons for different forming angles, (a) head position (b) middle position (c) tail position (see online version for colours)

4 Experimental studies

The experimental work was processed on the prototype chain-die former built to demonstrate the working principle, as shown in Figure 9(a). The shapes of the dies are also shown in Figure 9(b). It should be addressed that the dies used in these tests were designed to form a right angled channel section in one pass, an un-achievable target to roll forming, to reveal the potential advantages over roll forming. Also, it needs to be mentioned that even the original design had a gearbox to drive the top and bottom dies individually, but in this group of tests there was only a 90 W single phase AC motor with a speed controller used to drive the prototype from the bottom.

Figure 9 Prototype machine and its tooling, (a) prototype machine (b) assembly of die-blocks (see online version for colours)

The samples used in this experiment were 0.425 mm thickness base metal of G550 steel, and were first blanked to a size of 45 mm in width and 200 mm long. The G550 has a yield stress of about 630 MPa and tensile strength of about 700 MPa. In roll formed product design, there are some restrictions like avoiding design the holes too close to the edge or bend, or cross the bending line. In those samples, however, holes are drilled at different positions, which are close to the edge or bend (1 mm), across the bend and multiple positions. Samples produced are shown in Figure 10(a). Figure 10(b) shows a blank with different punched holes on the flange and the channel after forming. From observation and manually checking, the deformed sample is nearly right angled, and there is no visible surface damage on the sample and the surface is smooth. There is no product defects found in the formed products such as end flares, edge waves, longitudinal curvature and twisting, which shows that the residual stresses are well eliminated and controlled. Besides, there is no imperfection around the pre-drilled holes, and that is another evidence that the redundant deformation is well controlled and the residual stresses are thoroughly eliminated.

Figure 10 Deformed pre-drilled samples in the experiments, (a) deformed samples in experiments (b) sample profile comparison before and after deformation (see online version for colours)

In the strain gauge measurement, the data acquisition system employed is the NI cDAQ-9172 with a NI 9237 simultaneous bridge module. The strain gauges used in this study is ECH-120-2AA-11-RL30 from BCM. The strain gauge is $120\ \Omega$ and $2 \times 2\ \text{mm}^2$ in size with long legs. The strain gauges were bonded onto both top and bottom surfaces of the strips at head, middle and tail positions respectively. The average of the recorded longitudinal surface strains on the two surfaces were calculated and plotted as the longitudinal membrane strains as shown in Figure 11. From Figure 11, the longitudinal strains at the three various positions were vibrating at a lower level of 0.03%, which is similar with the FEA simulation results.

Figure 11 Experimental longitudinal strain measured at different positions (see online version for colours)

A U-profile channel section without pre-made holes was also produced to compare with FEA results. Figure 6 shows the shape predicted by FEA simulation and it well represented the actual shape of the sample produced on prototype, as shown in Figure 12. The longitudinal strains are also compared and are shown in Figure 13. From the figure, the strain developments were both within a very small range of $\pm 0.04\%$, which proves both FEA simulation and strain gauge measurement show that redundant strains are very small and results in the residual stresses of zero after forming.

Figure 12 Actual sample produced by chain-die forming

Figure 13 Comparison of experimental and FEA results (see online version for colours)

It should be pointed out that because both of the FEA simulation and strain gauge measurement show the longitudinal strains are in a very low level, the comparison with those two results to find some common characteristics does not make any sense as during the strain gauge measurement any machine's vibration from chain and die's motion will cause the strip's shape variation during forming and that will affect the accuracy of the measurement. Also, the strains investigated from both simulation and experiments are much smaller than the strains on the bend corner, which is also a cause of errors from simulation and experiment, but both results are in a small range within elastic regime.

5 Concluding remarks

As a newly developed forming technology, chain-die forming shows the advantages of lower redundant strains during forming and nearly zero residual stresses in products. Also, through analysing the forming process and forming the samples that are difficult to be roll formed, the results prove that due to the low redundant deformation, some unachievable targets can be completed by the new forming method. This paper has presented a bright future of the new technology for the sheet metal forming industry and has been especially important to AHSS. The low redundant deformation means even a low formability AHSS can still be used to form a complex shape product. Some concluding remarks from the studies introduced can be summarised:

- 1 It is possible to use chain-die forming to form a AHSS right-angled U-channel section in one pass. As there is very low longitudinal strain on the flange and web, the forming process does not stretch the pre-drilled holes on the flanges and web even the holes are very close to the edges or bends and across the bends. Some limitations in roll formed product design are no longer exist. Also, as the AHSS U-channel formed does not have any strain-hardening on the flanges, the channel can be used to further process such as bending and that is more significant for thicker AHSS products.

- 2 To chain-die forming a channel section, the maximum longitudinal strain occurs at the edge of flange on the middle position. There is shape variation between the head and tail due to forming sequence, but can be reduced by increasing the deformation length or reducing the forming angle.
- 3 The achievement of forming right-angled U-channel in one pass by chain-die forming proves that chain-die forming has great capability and productivity in AHSS forming as the springback is a negligible factor in AHSS forming tooling design. A much shorter production line than a roll forming line is expected as there is no need of correction stands.
- 4 Both FEA simulation and strain gauge measurement show that redundant strains are very small and the residual stresses are zero after forming.
- 5 Even the final profile is still not perfectly right-angled after springback, further studies need to be carried out to predict the shape accurately to minimise the tolerance. In industrial application, after a target angle was achieved by chain-die forming, a computer controlled roll forming pass is necessary to correct the forming angle and that needs to be further studied.

There is still a lot of work to be done before the first real part is produced for industry. The acceleration of this process requires lots of people's efforts and also supports from governments and industry.

References

- Ding, S., Daniel, W.J.T., Yuan, J. and Zhang, Y. (2011) 'Making roll forming flexible-introduction to chain-die forming', *Osaka 2012: Yokohama Tube & Pipe Conference, International Joint Symposium*, Osaka, Japan, pp.341–346.
- Gülçeken, E., Abee, A., Sedlmaier, A. and Livatyali, H. (2007) 'Finite element simulation of flexible roll forming: a case study on variable width U channel', *Cesme 2007: 4th International Conference and Exhibition on Design and Production of MACHINES and DIES/MOLDS*, 21–23 June.
- Heislitz, F., Livatyali, H., Ahmetoglu, A., Kinzel, G.A. and Altan, T. (1996) 'Simulation of roll forming process with the 3-D FEM code PAM-STAMP', *Journal of Materials Processing Technology*, Vol. 59, Nos. 1–2, pp.59–67.
- Lindgren, M. (2007) 'Cold roll forming of a U-channel made of high strength steel', *Journal of Materials Processing Technology*, Vol. 186, Nos. 1–3, pp.77–81.
- Troive, L. and Ingvarsson, L. (2008) 'Roll forming and the benefits of ultra-high strength steel', *Ironmaking Steelmaking*, Vol. 35, No. 4, pp.251–253.