1-1-2014

Geometrical and FEA study on Millipede Forming

Lingran Kong
University of Science and Technology Beijing

Di Tang
University of Science and Technology Beijing

Shichao Ding
University of Wollongong, sding@uow.edu.au

Yuankun Zhang
University of Wollongong, yz045@uowmail.edu.au

Geometrical and FEA study on Millipede Forming

Abstract

Millipede Forming is an innovative sheet metal forming approach that has been proposed and developed in Australia. U-channels, Z-channels or tubular products can be made by Millipede Forming. While a strip moves through an optimal transitional surface between the entry to exit of a forming stand, the redundant longitudinal membrane strain can be significantly reduced compared to the conventional roll forming, which is the essential principle to obtaining high quality products. The incremental forming process studied has demonstrated major advantages on space efficiency, power consumption and materials sensitivities. The purpose of this study is to investigate the effects of main geometrical parameters and their optimization, in order to minimize the redundant longitudinal strains into elastic to avoid the redundant plastic deformations at flange during forming. In this study, a mild-steel U-channel sample with 10 mm flange width, fabricated by Millipede Forming in a forming length of 200 mm has been studied. Theoretical longitudinal membrane strains at profile's edge of different transitional surfaces and downhill pass are also analyzed. The results showed that obtaining an optimal transitional surface is essential and necessary in controlling the peak longitudinal strain to an acceptable amount and that by increasing downhill pass, longitudinal strain can be significantly reduced. The optimized transitional surface and downhill pass flow were simulated by Abaqus, and the peak longitudinal strain was finally less than 0.2% through a very short forming length of 200 mm. The results prove that Millipede Forming can achieve a better product quality in a much shorter forming distance than conventional roll forming.

Keywords

geometrical, forming, fea, millipede, study

Disciplines

Engineering | Science and Technology Studies

Publication Details

Kong, L., Tang, D., Ding, S. & Zhang, Y. (2014). Geometrical and FEA study on Millipede Forming. AIP Conference Proceedings (1567): The 9th International Conference and Workshop on Numerical Simulation of 3D Sheet Metal Forming Processes (pp. 860-863). Australia: AIP.

Geometrical and FEA Study on Millipede Forming

Lingran Kong[a,b], Di Tang[a], Shichao Ding[b] and Yuankun Zhang[b]

[a]*University of Science and Technology Beijing, Beijing 100083, China*
[b]*University of Wollongong, Wollongong, NSW 2522, Australia*

Abstract. Millipede Forming is an innovative sheet metal forming approach that has been proposed and developed in Australia. U-channels, Z-channels or tubular products can be made by Millipede Forming. While a strip moves through an optimal transitional surface between the entry to exit of a forming stand, the redundant longitudinal membrane strain can be significantly reduced compared to the conventional roll forming, which is the essential principle to obtaining high quality products. The incremental forming process studied has demonstrated major advantages on space efficiency, power consumption and materials sensitivities. The purpose of this study is to investigate the effects of main geometrical parameters and their optimization, in order to minimize the redundant longitudinal strains into elastic to avoid the redundant plastic deformations at flange during forming. In this study, a mild-steel U-channel sample with 10 mm flange width, fabricated by Millipede Forming in a forming length of 200 mm has been studied. Theoretical longitudinal membrane strains at profile's edge of different transitional surfaces and downhill pass are also analyzed. The results showed that obtaining an optimal transitional surface is essential and necessary in controlling the peak longitudinal strain to an acceptable amount and that by increasing downhill pass, longitudinal strain can be significantly reduced. The optimized transitional surface and downhill pass flow were simulated by Abaqus, and the peak longitudinal strain was finally less than 0.2% through a very short forming length of 200 mm. The results prove that Millipede Forming can achieve a better product quality in a much shorter forming distance than conventional roll forming.

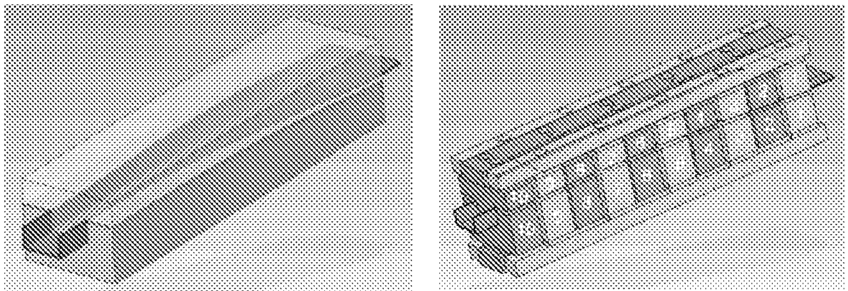
Keywords: Millipede Forming; Transitional Surfaces; Downhill Pass; FEA Modeling
PACS: 81.20.Hy

INTRODUCTION

Millipede forming is an alternative sheet forming method to roll forming. It was first invented to overcome product defects that are difficult to be solved by roll forming[1]. The concept of Millipede Forming is to manipulate a strip pass through an optimal strip's surface defined as a transitional surface. The transitional surface is defined as the mid-surface of the strip form entry to exit positions of a forming stand. In Millipede Forming, a flat strip is bent into a final profiled product through the specifically designed transitional passes by continuous forming steps. The strip is gradually deformed by passing the optimized transitional surface leading to minimized longitudinal strains[2], which is the main cause of product defects in roll forming like the edge wave, end flare, sweep or camber.

Figure 1 (a) and (b) are the sketches of using Millipede Forming to bend a flat sheet to a U-channel product. The transitional surface showed in the Fig. 1 (a) is a schematic optimal transitional surface from entry to exit. The change of shape occurs continuously over the whole area of forming distance, and such a surface can be generated by a pair of dies as shown. Such an optimal surface is unlike in roll forming where the main shape of change is concentrated on a small area approaching the rolls. With the characteristics of smooth shape variation, Millipede formed products have the advantages of low or near zero redundant plastic deformation and nearly zero residual stresses. Therefore, it is able to produce high quality products without residual stresses more easily than roll forming. Fig. 1 (b) shows the way a U-channel has been gradually fabricated through die-arrays of Millipede Forming. The details about the movement of die-arrays and the working mechanism of Millipede Forming were introduced in [1].

NUMISHEET 2014
AIP Conf. Proc. 1567, 860-863 (2013); doi: 10.1063/1.4850106



(a) Optimal transitional surface (b) Millipede Forming die-arrays

FIGURE 1. Concept of Millipede Forming method.

GEOMETRICAL PARAMETERS OF MILLIPEDE FORMING

The first step regarding the Millipede Forming application is how to construct an optimal transitional surface and analyze the developed transitional surface. In this study, as an example, a U-channel profile with 10 mm flange width is introduced to establish the analytical and numerical model of Millipede Forming. Although in principle many transitional surfaces can be employed to make the U-Channel, S. Ding[1] suggested that the transitional surface of Millipede Forming can be streamlined based on a point's locus and that the change of rate of bending angle at start and end positions should be zero in order to obtain smooth shape change at both ends. According to the previous studies, the transitional surface based on modified cosine curve similar to Kiuchi's shape function[3] approach has relatively good performance. The differentiable of a streamline anywhere is critical to avoid the peak longitudinal bending strain and can be befit to minimize the redundant strains which lead to the most product defects[4]. In this research, while the U-channel is formed along the designed transitional surface, the total bending angle is 90°, the bending angle, α , in longitudinal direction can be expressed as:

$$\alpha = \frac{\pi}{2} \times \frac{\cos^{n}\left(\frac{z\pi}{l} + \pi\right) + 1}{2} \tag{1}$$

Where z is the position along the forming direction, l is the specific forming length and n is the modification coefficient.

In this study, 3 different transitional surfaces with different modification coefficient n (n = 0.8, 1.0 and 1.2) are discussed and the relationship between bending angles and forming distance is as shown in Fig. 2.

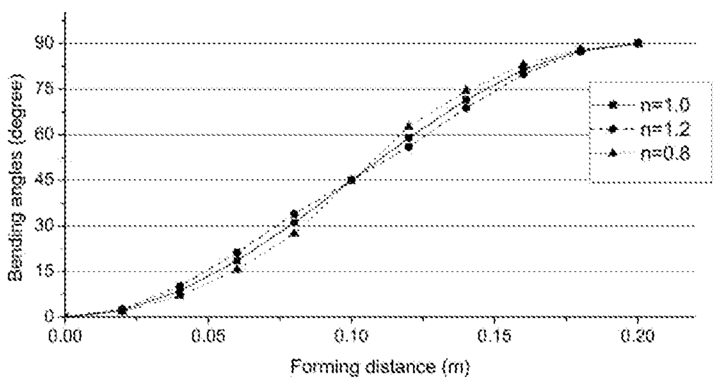


FIGURE 2. Working sequences of Millipede Forming

J. Paralikas *et al*[5]. studied the relationship between the longitudinal strain at flange edge and the bending angle along the forming distance. In current studies, 3 different transitional surfaces (n = 0.8, 1.0 and 1.2) were calculated by Matlab. The 200 mm forming length was divided into 200 grids and each interval is 1mm. Assumptions of that perpendicular planes to forming direction remain in plain, and the bending deformation only occur along the hinge but other part remain straight are made to analyze a point's locus during forming. The strains are then calculated based on definite divided differences. The results showed that at a peak strain of 0.8% for n = 0.8 which exceeded a critical value of 0.2%, an elastic limit strain for most mild steels. For n = 1.0 and 1.2, the peak strains of 0.195% and

0.203% for the two transitional surfaces are much smaller than n = 0.8. However, comparing the curves n = 1.0 and 1.2, the longitudinal strain distribution of n = 1.0 is more uniform than n = 1.2. Therefore, it is concluded that the transitional surface with modification factor of n = 1.0 has the best performance and it is employed in this model.

Although optimizing transitional surface is employed to reduce the longitudinal strain, further deduction is still necessary to manipulate the longitudinal strains in an elastic level. Downhill pass arrangement of roll forming centre position is considered as an effective way in this study. In order to determine the downhill value which is the offset value from the horizontal forming direction, 4 values of 1, 2, 3 and 4 mm were used in the analysis. The theoretical peak longitudinal strains at the edge of flange are shown in Fig. 3.

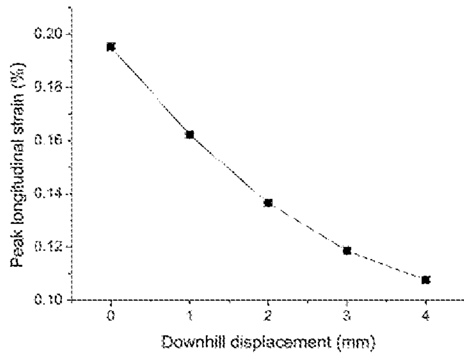


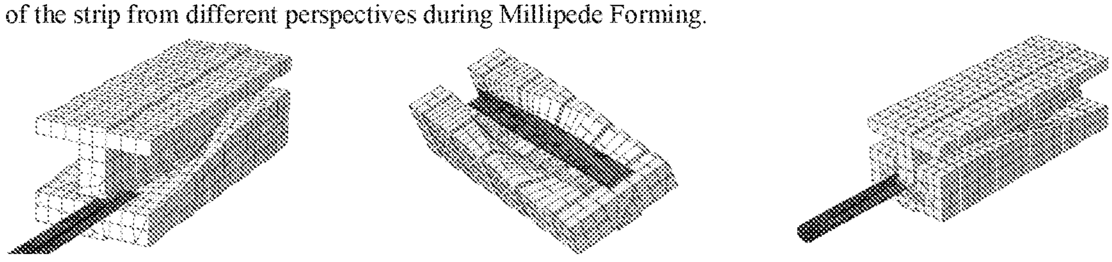
FIGURE 3. Effect of Downhill Displacement on Longitudinal Strain Reduction

It can be observed from Fig.3 that the peak longitudinal strains at the edge of flange decreases with downhill offset increasing. It was dropped to 0.108% while 4 mm downhill displacement is selected. However, it has to be addressed that large downhill will cause the curvature of centre streamline increase making the bending of formed shape no longer negligible. Thus in this study the downhill value of 4 is only to be used in our modeling work.

FEA MODELING AND DISCUSSION

Abaqus/Explicit package is employed to establish the Millipede Forming FEA modeling. In the modeling, the dies are treated as rigid bodies which were originally created by Pro/E and imported into Abaqus. The die-arrays' geometrical parameters were introduced in above context, the transitional surface of die-arrays is a cosine curve with a modification factor n of 1.0 and the downhill displacement is 4 mm with a 200 mm forming length.

The sample blank length is 200 mm, and the finished product is a right-angled channel section with 20 mm web width and 10 mm flange width. The thickness of the strip is 0.5 mm and the material's yield stress is 250 MPa, Hooke's law is adopted as material model with E=208 GPa. As the product is symmetrical, only half of the U-channel is used in the simulation. In consideration of the nonlinear effect of forming, the sheet is meshed by quadrangular shell element S4R and the mesh consists of 2884 (103×28×1) elements. Mesh refinement are imposed at the bending area and the edge of flange to get more accurate analysis results. The Fig. 4 shows the deformation process of the strip from different perspectives during Millipede Forming.



(a) Entry of the strip (b) Middle stage (top dies hidden) (c) Exit of the strip

FIGURE 4. Millipede Forming process of U-channel

Fig.5 shows the longitudinal membrane strains developed during the forming process of a middle point at the edge of the flange. It can be observed that the longitudinal strain quickly rises after entering the forming area and reaches the peak of 0.196% after passing a quarter of the forming length at a position of about 62 mm on the forming axis. Then the strain goes down and waves as the forming process continues as the strip moves forward. It finally drops to 0.058% while the measured point leaves the die-arrays. The FE analysis results are generally in good agreement with the theoretical work on the trend of strain changing along the forming direction, though the peak strain of simulation is slightly higher than the theoretical value. It can be noticed that the simulation result has some variation and extra swing compared with the theoretical result. The reason for this phenomenon can be understood, as the theoretical analysis is based an optimal transitional surface without any physical implementation, however, during the FEA forming process, the strip has vertical oscillation caused by the strip's springback and die-arrays alternative engagement that result in impact on the strip. These unexpected impacts make the strain oscillation, and are superposed on the strain curve. It should be pointed out that the peak strain of simulation is still under 0.2% and at most of the time the strain is below the elastic limit. The plastic deformation along the forming direction mostly would not occur at flange edges, which means the chance of observing product defects will be significantly reduced. Considering the total forming length is only 200 mm and the bending angle is 90° of the example, Millipede Forming has shown its potential to obtain high quality products compared with traditional methods.

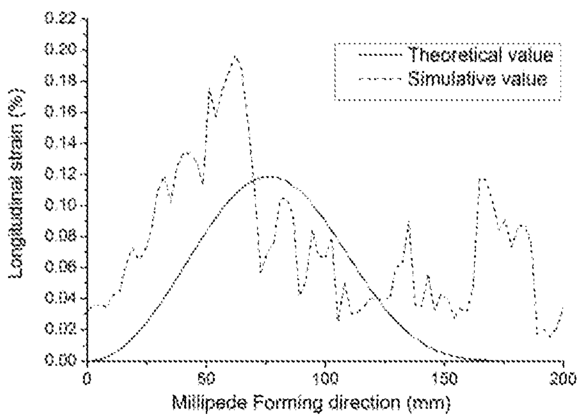


FIGURE 5. Axial longitudinal strains of the flange edge

CONCLUDING REMARKS

The geometrical and FEA modelling of Millipede Forming are introduced. Some concluding remarks can be summarised:

1) Geometrical parameters such as transitional surface shape and downhill displacement play a critical role in Millipede Forming, the optimal parameters can be optimized to reduce redundant longitudinal strains in order to achieve high product quality.
2) FEA results showed that the sample with 10 mm flange can be formed in only 200 mm forming length, and its maximum longitudinal strain is below 0.2% during the whole forming process and that is not beyond the elastic limit of strain.
3) There is still a lot of work that needs to be done to fully develop the new method for industrial application and for it to be recognized by industries. However, the theoretical work and FE simulation have shown that the advantages of Millipede Forming exceed those of conventional roll forming.

ACKNOWLEDGMENTS

The authors would like to give special thanks to the Faculty of Engineering and Information Science of the University of Wollongong for its financial support to the collaboration with USTB, and the support from Millipede Forming Pty Ltd and UniQuest are gratefully acknowledged. They also thank the colleagues at UOW and USTB for their support and encouragement.

REFERENCES

1. S. C. Ding, P. A. Meehan and W. J. T. Daniel, *J. Mater. Proc Tech.* **211**, 376-381 (2011).
2. S. M. Zhu, S. M. Panton and J. L. Duncan, *Proc. Instn. Mech. Engrs.* **210 (B)**, 127-134 (1996).
3. M. Kiuchi et al, *J of JSTP*. **306**, 874-881 (1986).
4. M. Lindgren, *J. Mater. Proc. Tech.* **186**, 77-81 (2007).
5. J. Paralikas and K. Salonitis, *Int. J. Adv. Manuf. Technol.* **56**, 475-491 (2011).