International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-07, Issue-05, AUG 2021

Numerical Investigation of Residual Stresses in Roll Forming of Metal Sheets

D. Yesane, Research Scholar, MIT College of Engineering, Pune, India,

dayanand.yesane@mmit.edu.in

R. Hingole, Professor, D.Y.Patil College of Engineering, Pune, India, rshingole35@gmail.com

Abstract: **Roll forming is a continuous bending. Metal sheet is passed between successive pairs of rolls to get required shape. Due to the high part quality and tolerance requirements of the automotive industry, Finite Element Analysis (FEA) is a tool used to find deformation in metal sheet during roll forming process. FEA helps designer to find exact steps to be required for roll forming for getting required shape. FEA also helps to improve quality and accuracy of final roll forming product with less cost. This paper tried to summarize all FEA study of roll forming for different design parameters and its results.**

Keywords — Roll forming, longitudinal strain, residual stress, FEA

I. Introduction

Roll forming is a metal forming process. It has so many applications in different fields like structures, domestic appliances, automobile sector, furniture, airplane parts. It is a extremely productive process. The use of this process is increasing day by day. Roll forming process has many advantages. One of them is no additional operation like welding, punching, clenching required after last bending. The product after final step is directly ready for use. **Figure 1** showing schematic diagram of 3 stage roll forming process.

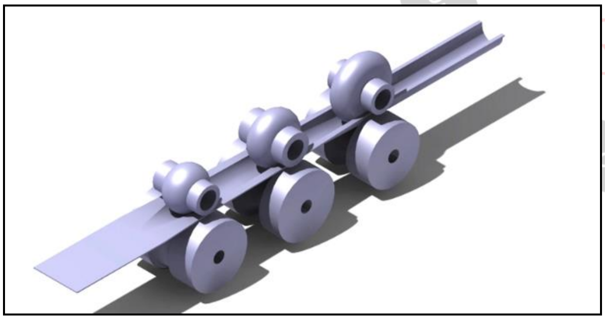

Figure 1. Roll forming process [21]

II. Method

Roll forming is continuous bending operation. For required quality and accuracy in roll forming product, Finite Element analysis is used widely by designer. Limited research has been done on roll forming simulation for different shapes and by taking different materials. **Figure 2** shows shape defects in roll forming product. These defects should be minimized in final roll forming product by using FEA tool.

A. Abvabi, J. Mendiguren, A. Kupke, B. Rolfe and M. Weiss [1] investigated effect of change in elastic modulus on springback by taking V-section profile for DP 780 material. They used COPRA-FEA and MSC-Marc softwares for their study. They concluded that if a material undergoes plastic deformation, it will result in decrease in elastic modulus of steel.

Boman et al. [2] used Arbitrary Lagrangian Eulerian (ALE) model for the simulation of 3D U-shaped roll forming process. He used linear isotropic hardening rule as a material model for his simulation.

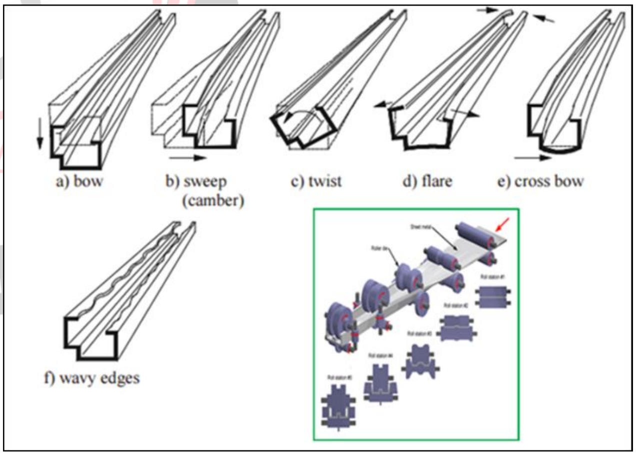

Figure 2. Shape defects in roll forming [22]

Q.V. Bui and J. P. Ponthot [3] simulated a cold roll forming process by using 3D finite element analysis. Material model used by them was Swift's isotropic strain hardening law. They observed more springback with high strength materials, reduction of longitudinal strain with increasing distance between stands, increment in waviness with high strength materials.

Farzin, Tehrani and Shameli, [4], introduced Buckling Limit of Strain (BLS), which is limiting factor in roll forming process. He used LUSAS 12.3 software for determining BLS. He selected quadrilateral thin shell

 DOI : 10.35291/2454-9150.2021.0442 © 2021, IJREAM All Rights Reserved.

element for his study. He concluded that BLS is independent on bend angle, but it depends on thickness-flange length ratio and mechanical properties. His results were closely agreed with Kiuchi's method. He validated his FEM results with theoretical results (Modified Levy-Mises Method and Prandtl-Reus Equation) and Experimental results (Fewtrell Method).

Kang et al. [5] studied roll forming parameters by taking MS980, martensitic steel material. They used ABAQUS software with Hollomon law plastic model. They proposed parabola, decline and equal distribution schemes in which equal distribution scheme got good square shape and uniform force on each pass.

Kim and Oh [6] Developed a 3-dimensional Finite Element Method (FEM) of deformation analysis for roll forming process. He used flow stress theory for his analysis. He presented longitudinal strain, through thickness stress variation by FEM and validated his results with experimentation.

Li et al. [7] did a numerical study on chain die forming. They considered AHSS material and U-channel for their study. ABAQUS/standard software was used by them for FEA simulation. They compared simulation results for both chain die forming with roll forming. They concluded that with increase in flange height, residual strain will also increase.

Livatyali, Duggal, Ahmetogelub and Altan [8] conducted investigation on roof panels. His aim was to eliminate crack formation at coated and painted roof panels. He used FEM for his analysis and tested various roll design by FEM and suggested optimal roll geometry which will not develop any crack in roof panels. He used Deform-2d software to lateral strain. He analyzed that by reducing overbend in sheet and by adding compression at fillet, the peak tensile strain can be reduced.

Y. J. Long, L.Ying-bing, L. Da-yong, P. Ying-hong [9] Simulated roll forming process by using dynamic explicit finite element method. Dynamic explicit FEM has better capability than implicit, it reduces CPU time for simulation. He selected U-channel for his study for bending 900 angle in four stand set up. He used Swift's isotropic strain hardening model and Hooke law for his simulation.

J. Paralikas, K. Salonitis, and G. Chryssolouris [10] investigated effect of roll forming process parameters on longitudinal strain and shear strain by taking symmetrical shape product of AHSS DP780 material by using Ls-dyna software.

J. Paralikas, K. Salonitis, and G. Chryssolouris [11] calculated optimum values of process parameters to minimize longitudinal and shear strain. They stated that distance between roll stands plays major role in roll forming process and final quality of product. He used LS-dyna software with SHELL163 element for their study. **Figure 3** and **Figure 4** show the effect of roll forming process parameters on longitudinal and shear strain.

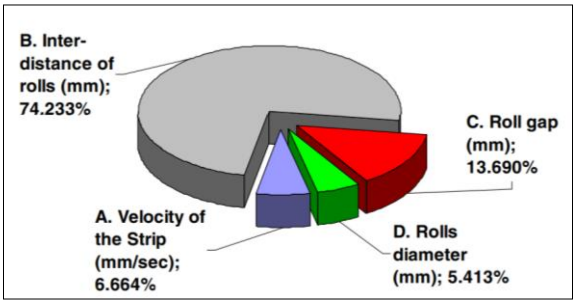

Figure 3. Effect of roll forming process parameters on longitudinal strain [11]

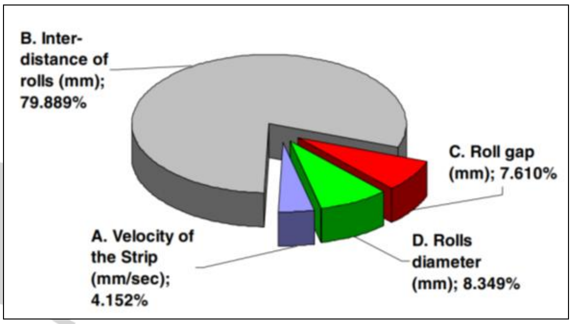

Figure 4. Effect of roll forming process parameters on shear strain [11]

J. Paralikas, K. Salonitis, and G. Chryssolouris [12] investigated effect of roll forming parameters on a quality of final product. He used AHSS material with V-section profile for his study. He considered roll forming parameters like velocity of roll forming line, gap between rollers, distance between roller stands, diameter of roller. **Table 1** shows effects of roll forming process parameters on longitudinal and residual strain.

Table 1. Effects of roll-forming parameters [12]

Effect on / Increase of	Long/nal strain peak @ strip edge	Long/nal residual strain @ strip edge	Dimensional accuracy	Transversal strain @ bending corner
Line velocity	😐	☹️	😐	☹️
Rolls inter-distance	🙂	🙂	😐	🙂
Friction coefficient	😐	☹️	😐	☹️
Rolls gap	🙂	☹️	☹️	☹️
Rolls diameter	😐	🙂	🙂	🙂

J. C. Park, D.Y.Yang, M. H. Cha, D.G.Kim, J.B. Nam [13] investigated a new incremental counter forming in flexible roll forming. For simulation of this process, they used ABAQUS implicit code by using Swift's isotropic strain hardening law and Hooke's law. This process reduces the shape error of final roll formed product. They validated

 DOI : 10.35291/2454-9150.2021.0442 © 2021, IJREAM All Rights Reserved.

their numerical results with experimentation.

Z. Qian, Y. Sun, P.A. Meehan, W. J. T. Daniel, and S. Ding [14] investigated effect of material strength, metal sheet thickness, gap between rollers and diameter of rollers on chain die formed AHSS U-channel sections. They validate FE simulation results with experimental work.

W.M. Quach, J.G. Teng, and K.F. Chung [15] developed analytical method for coiling and uncoiling of metal sheets which will be provided input for roll forming process. He compared analytical results with FEA results which are closely agree with analytical results. He used ABAQUAS software for his study. He took CPE4R 2-D plane strain 4-node element for simulation. He concluded that longitudinal and transverse residual stress are depend on coiling radius of metal sheet.

B. Rossi, H. Degee, and R. Boman [16] evaluated corner strength enhancement of thinwalled sections. They used METAFOR software for their study by taking high strength steels and stainless steel as a material.

K. Salonitis, J. Paralikas and G. Chryssolouris [17] investigated effect of velocity of roll forming line, distance between roller stands, gap between rollers and diameter of rollers by taking AHSS material.

Sheikh, and R. R. Palavilayil [18] assessed technical capability of SHAPE software for the simulation of roll forming process. He explained simulation method using SHAPE-RF algorithm. He compared FEM result using MARC 7.0 and SHAPE RF software and concluded that SHAPE-RF is best suitable software for Roll forming simulation with higher advantages.

H. Wang, Y. Yan, F. Jia and F. Han [19] studied fracture behaviour of DP980 steel during roll forming process. They used ABAQUS/Explicit with S4R shell element. They adopted Oyane fracture criteria for their study.

Y. Yan, H. Wang, Q. Li, B. Qian, K. Mpofu [20] used Swift hardening equation for simulation by ABAQUS softaware for flexible roll forming. They found that Hill 48 yield criteria will reflect material deformation with high capacity. They plotted longitudinal strain and shear strain developed in flexible roll forming and validated this data with experimentation.

III. Conclusion

Numerical simulation is widely used for predicting deformation in roll forming process. Different FEA softwares like ABAQUS, Ansys, Ls-Dyna, Copra-RF are used for the simulation of roll forming process. Most important step while designer to find out total steps required for final product in roll forming. Numerical solution helps a designer for this.

Finite Element method for roll forming is divided in three stages.

1. Pre-Processing: To simulate roll forming process required inputs are

   a) Number of passes

   b) Roll geometry (imported from CAD software

   c) Initial section geometry

   d) Velocity of rollers and friction between rollers

   e) Process conditions (cold forming/hot forming)

2. Solution Phase: Proper selection of solver is required among skyline solver and Sparse solver. Appropriate meshing must be defined. Material model is also needed for the simulation.

3. Post processing phase: This phase plots results of the analysis. Some of them are as follows

   a) Effective strain rate

   b) Longitudinal strain

   c) Strain rate

   d) Strain through thickness

   e) Equivalent plastic

Roll forming process parameters plays important role in roll forming design. Longitudinal strain, spring back and residual stress are the main important factors. These factors affect final quality of roll forming product. Most of researchers developed numerical solution for longitudinal strain, residual stress and spring effect and validated simulation results with experimentation. **Table 2** shows effect of different roll forming parameters on residual stress.

Table 2. Effect of increase in roll forming design parameters on Residual strain

Sr. No	Roll forming design parameters	Effect of increase in parameters on Residual strain
1	Material of sheet/Yield Strength	Decrease in residual strain
2	Distance between roll stand	Decrease in residual strain
3	Strip Thickness	Decrease in residual strain
4	Forming speed/Velocity	Insignificant influence
5	Friction	Insignificant influence
6	Roll Gap	Increase in residual strain
7	Bending Angle	Increase in residual strain

 DOI : 10.35291/2454-9150.2021.0442 © 2021, IJREAM All Rights Reserved.

References

[1] A. Abvabi, J. Mendiguren, A. Kupke, B. Rolfe, and M. Weiss, "Evolution of elastic modulus in roll forming", International Journal of Material Forming, 2017, vol. 10(3), pp. 463-471.

[2] R. Boman, L. Papeleux, B. Q. Viet, J. P.Ponthot, , P. Wouters, and R. Kergen, "An ALE Model for Numerical Simulation of Cold Roll Forming Process", American institute of physics, 2005, pp. 768-773.

[3] Q.V. Bui and J. P. Ponthot, "Numerical simulation of cold roll-forming processes", Journal of materials processing technology, 2008, vol. 202, pp. 275–282.

[4] M. Farzin, M.S.Tehrani, E.Shameli, "Determination of buckling limit of strain in cold roll forming by the finite element analysis", Journal of Materials Processing Technology, 2002, vol. 125–126, pp. 626–632.

[5] W.Kang, Y. Zhao, W.Yua, S. Wang, Y. Ma, and P. Yan, "Numerical simulation and parameters analysis for roll forming of martensitic steel MS980", Procedia Engineering, 2014, vol. 81, pp. 251–256.

[6] N. Kim, and S. I. Oh, "Analysis Tool for Roll Forming of Sheet Metal Strips by the Finite Element Method", Annals of the ClRP,1999, vol. 48(1) pp. 235-238.

[7] Y. Li, Y. Sun, H. Xiao, H. J. Bong, L.Shi, S. Li, D. Li, S. Ding, R.H.Wagoner, "A numerical study on chain-die forming of the AHSS U-channel and contrast with roll forming". International Journal of Mechanical Sciences, 2018, vol. 135, pp. 279–293.

[8] H. Livatyali, N. Duggal, A. Ahmetogelub, T. Altan, "Investigation of crack formation on the Galvalume coating of roll formed roof panels", Journal of Materials Processing Technology, 2000, vol. 98, pp. 53-61.

[9] Y. J. Long, L.Ying-bing, L. Da-yong, P. Ying-hong, "Simulation of Roll Forming With Dynamic Explicit Finite Element Method", American institute of physics, 2005, pp. 197-200.

[10] J. Paralikas, K. Salonitis, and G. Chryssolouris, "Investigation of the effect of roll forming pass design on main redundant deformations on profiles from AHSS," Int J Adv Manuf Technol., 2011, vol. 56, pp. 475–491.

[11] J. Paralikas, K. Salonitis, and G. Chryssolouris, "Optimization of roll forming process parameters-a semi-empirical approach". International Journal of Advanced Manufacturing Technology, 2010, vol. 47, pp. 1041–1052.

[12] J. Paralikas, K. Salonitis, and G. Chryssolouris, "Investigation of the effects of main roll-forming process parameters on quality for a V-section profile from AHSS", Int J Adv Manuf Technol, 2009, vol. 44, pp., 223–237.

[13] J. C. Park, D.Y.Yang, M. H. Cha, D.G.Kim, J.B. Nam, "Investigation of a new incremental counter forming in flexible roll forming to manufacture accurate profiles with variable cross-sections", International Journal of Machine Tools and Manufacture, 2014, vol. 86, pp. 68-80.

[14] Z. Qian, Y. Sun, P.A. Meehan, W. J. T. Daniel, and S. Ding, "Experimental and numerical investigation of flange angle in Chain-die formed AHSS U-channel sections", Int J Adv Manuf Technol, 2017, vol. 92(1-4), pp. 1-12

[15] W.M. Quach, J.G. Teng, and K.F. Chung, "Finite element predictions of residual stresses in press-braked thin-walled steel sections", Engineering Structures, 2006, vol. 28, pp.1609–1619.

[16] B. Rossi, H. Degee, and R. Boman, "Numerical simulation of the roll forming of thin-walled sections and evaluation of corner strength enhancement", Finite Elements in Analysis and Design, 2013, vol. 72, pp. 13-20.

[17] K. Salonitis, J. Paralikas and G. Chryssolouris, "Roll Forming of AHSS: Numerical Simulation and Investigation of Effects of Main Process Parameters on Quality", Engineering Against Fracture: Proceedings of the 1st Conferenc,2009, pp. 327-328.

[18] M. A. Sheikh, and R. R. Palavilayil, "An assessment of finite element software for application to the roll-forming process", Journal of Materials Processing Technology, 2006, vol. 180, pp. 221–232.

[19] H. Wang, Y. Yan, F. Jia and F. Han, "Investigations of fracture on DP980 steel sheet in roll forming process", Journal of Manufacturing Processes, 2016, vol. 22, pp. 177-184.

[20] Y. Yan, H. Wang, Q. Li, B. Qian, K. Mpofu, "Simulation and experimental verification of flexible roll forming of steel sheets", International Journal of Advance Manufacturing Technology, 2014, vol. 72, pp. 209–220.

[21] D. Yesane, R. S. Hingole, "Review article: Computational and Experimental Studies in Roll Forming Research", International Conference on Recent Advances in Mechanical Engineering 2015.

[22] D. Yesane, R. S. Hingole, "The Investigation of Effects of Roll Forming Parameters on Shape Defects of Channel Section", Int J Current Engi Tech, 2016, vol. 6, pp. 244-247.

 DOI : 10.35291/2454-9150.2021.0442 © 2021, IJREAM All Rights Reserved.