

Research Article

# Roll Form Process Analysis Using the Explicit Solution Method

Özgür YALÇIN<sup>1\*</sup>, Dr. Enes KURTULUŞ<sup>2</sup>

<sup>1</sup> Coşkunöz Metal Form 1, Orcid ID: 0009-0008-8106-6349 e-mail: oyalcin@coskunoiz.com.tr

<sup>2</sup> Coşkunöz Metal Form 2, Orcid ID: 0000-0003-4271-8566 e-mail: ekurtulus@coskunoiz.com.tr

\* Correspondence: oyalcin@coskunoiz.com.tr

Received 21 September 2024

Received in revised form 14 December 2024

In final form 25 December 2024

**Reference:** Yalçın, Ö., & Kurtuluş, E. (2024). Roll form process analysis using the explicit solution method. *The European Journal of Research and Development*, 4(4), 283-297.

## Abstract

*In the contemporary automotive industry, the focus on sustainability has driven the need for lighter, more energy-efficient, and environmentally friendly vehicles. High-strength materials play a pivotal role in this effort, enabling the production of lightweight yet durable components that reduce energy consumption and emissions. With the growing adoption of electric vehicles, lightweight design has become even more critical to balance battery weight and extend driving range while maintaining structural integrity.*

*In this context, the roll forming process offers an optimal manufacturing method for producing high-strength materials with complex cross-sectional profiles. However, the use of ultra-high-strength materials introduces additional challenges due to their higher yield strength, such as increased springback, tool wear, and greater sensitivity to thinning and cracking. These challenges not only complicate production but also require precise simulation to predict and mitigate defects. Additionally, calculation time plays a critical role in industrial applications, where fast and accurate simulations are essential to reduce development cycles and meet production deadlines.*

*This study analyzes the roll forming process using the explicit solution method in LS-DYNA.*

*The study focuses on modeling material deformation, elastic recovery, and contact interactions. The results demonstrate that the explicit solution method effectively captures the deformation characteristics of the roll forming process while offering computational efficiency, providing valuable insights for process optimization and predictions.*

**Keywords:** *Ultra-high-strength materials, Roll forming, Metal forming, Ls- Dyna, FEA, Explicit method*

## 1. Introduction

Roll forming is a continuous metal-forming process in which a strip or sheet of material is incrementally shaped into a desired profile using a series of precisely positioned roller stations. It is widely used in manufacturing industries due to its efficiency, versatility, and ability to produce parts with complex cross-sectional geometries. The process is particularly advantageous for high-volume production of lightweight and durable components, making it essential in automotive, construction, and appliance industries, among others.

The roll forming machine consists of several roller stations, including a first bending system and several straightening systems. The first bending system consists of a fixed bending housing pair and two side-bending housing pairs, each of which is pivotably connected with the fixed bending housing by means of a bending shaft. The first fixed roller and the first and second side-bending rollers, which are supported by the fixed bending and the side-bending housing, respectively, are arranged in opposed relation to the first bending housing. The pair of the first fixed rollers with the first and second side-bending rollers forms a channel through which sheet metal is fed.

The roll configuration of each roller station is too complicated to obtain an analytical solution. With advances in computer power, it is possible to perform full numerical simulations to provide valuable information on the mechanical behaviour of the roll forming process. The explicit solution method, particularly through FEA, has emerged as a powerful tool for analysing the roll forming process, enabling engineers to predict the mechanical behaviour of materials under different forming conditions [1].



Figure 1: Example of A Roll Forming Machine [7]

The technique is highly adaptable, accommodating a range of materials such as ultra-high strength steels (UHSS), aluminium, and other alloys. This adaptability is crucial for applications that demand materials with high strength-to-weight ratios, such as automotive structural components designed to enhance crash performance and fuel efficiency. Roll forming also offers precise dimensional tolerances, reduced waste, and the ability to form intricate profiles without interrupting production, making it a preferred alternative to traditional stamping or extrusion methods.

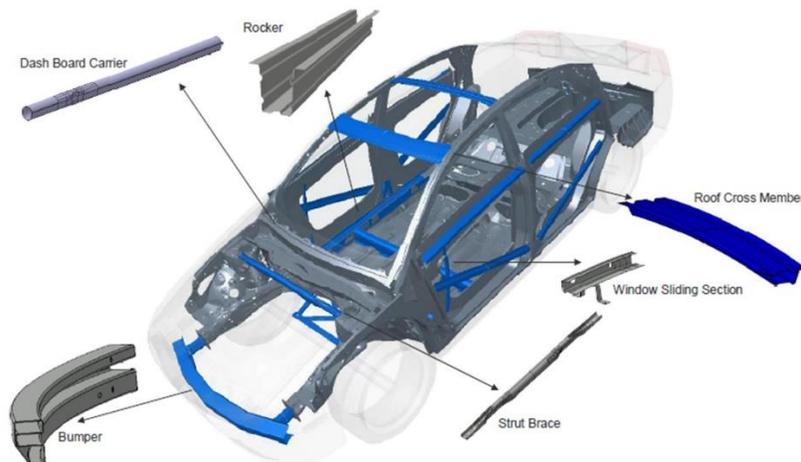


Figure 2: Example Automotive Parts Suited For Roll Form Process

Explicit solution method is one of the most used FEA methods for roll form process simulations. One of the primary advantages of using the explicit solution method in roll forming analysis is its ability to handle large deformations and complex material behaviours. For instance, studies have shown that the explicit FEA can effectively model the springback phenomenon, which is a common issue in roll forming where the material tends to return to its original shape after deformation. This capability is essential for optimizing the design of roll forming processes, as it allows for adjustments to be made to the roll geometry and process parameters to minimize defects and improve product quality [2].

Moreover, the explicit solution method facilitates the investigation of various factors influencing the roll forming process, such as material properties, roller configurations, and process parameters. For example, Mahajan et al. highlighted the importance of steady-state properties in the finite element simulation of roll forming, emphasizing that the design process is heavily reliant on the experience of designers and the iterative nature of the process [3].

This iterative design approach is further supported by the findings of Oh et al., who utilized response surface methodology to optimize roll forming parameters, demonstrating the potential for enhanced process efficiency and product quality [4].

Furthermore, the explicit solution method has been applied to study the effects of varying process parameters on the roll forming outcomes. For instance, studies have shown that altering the roll spacing and velocity can significantly impact the forming quality and the mechanical properties of the final product [5].

This article focuses on the application of the explicit solution method for roll form process analysis. By leveraging advanced simulation tools, engineers can optimize design parameters, reduce trial-and-error iterations, and ensure consistent product quality. This approach is particularly beneficial for industries that require complex profiles and utilize advanced materials, where precise control of the forming process is imperative.

## 2. Materials and Methods

Roll forming processes often encounter common defects, many of which originate from the incoming coil rather than issues inherent to the process itself. One major issue involves shape imperfections in the coil, as depicted in Figure 3. These imperfections, such as concave or convex deformations, can lead to defects in the final roll-formed product, including camber, longitudinal bow, twist, flare, center wave, and edge wave. These resulting faults, which significantly affect the quality and dimensional accuracy of the product, are illustrated in Figure 4.

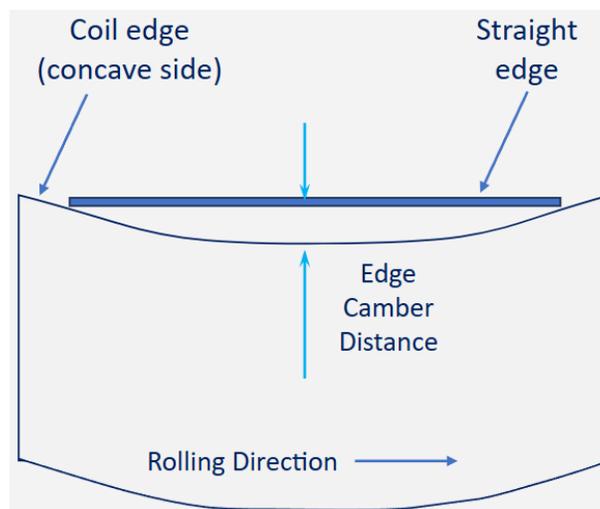


Figure 3. Coil Shape Imperfection [6]

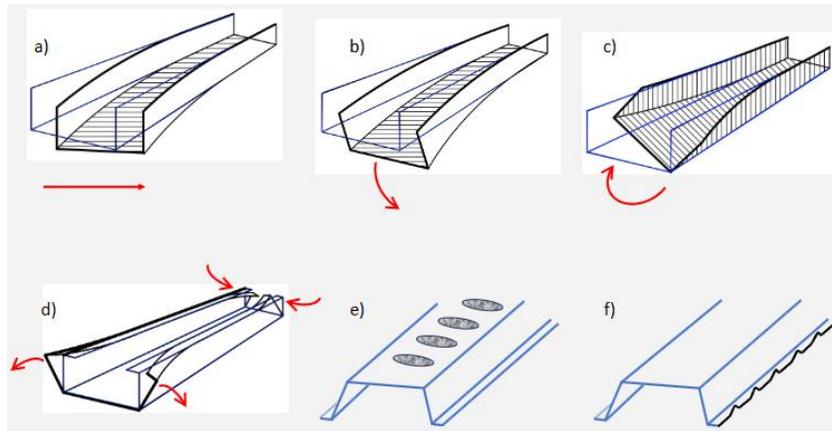


Figure 4. Shape deviations in roll formed components initiating from incoming coil shape issues:

a) camber b) longitudinal bow c) twist d) flare e) center wave (center buckle) f) edge wave. [6]

In addition to process-related issues, the inherent characteristics of high-strength materials can exacerbate these defects. Due to their limited formability and high yield strength, materials such as ultra high-strength steels (UHSS) are more prone to errors like springback, cracking, thinning, and torsional waviness during the roll forming process. These challenges arise from the material's resistance to deformation and its tendency to store elastic energy, which leads to dimensional inaccuracies in the final product. To mitigate these issues, the roll forming process must be carefully adapted to the behaviour of high-strength materials. Adjustments such as optimizing the number of roll stands, modifying forming angles, applying precise lubrication, and utilizing advanced simulation tools are essential to minimize defects and ensure consistent product quality. The influence of these material-specific factors and the resulting defects are depicted in Figure 5.

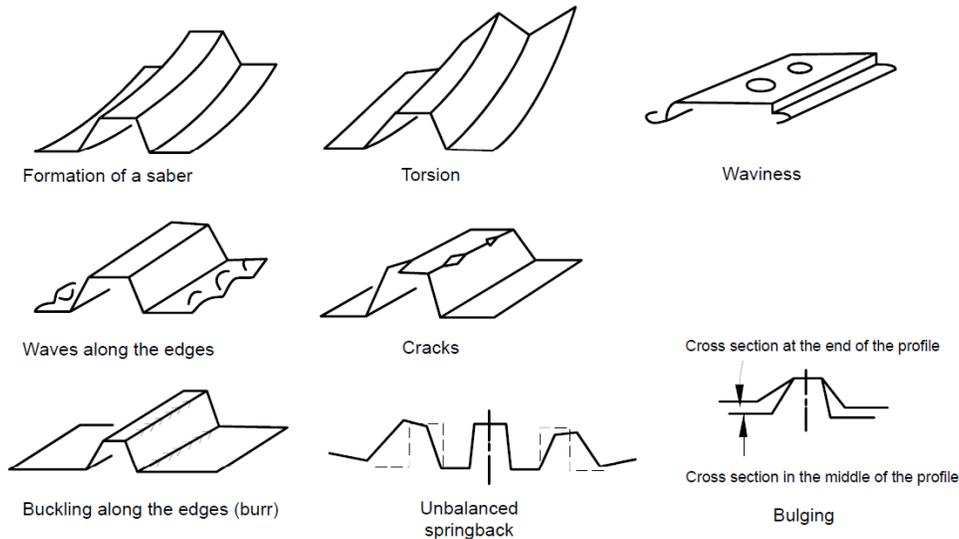


Figure 5. Most Common Process Faults of Roll Forming [7]

This study focuses on investigating defects arising from the roll forming process and the material behaviour, with particular emphasis on the thinning problem, one of the most prevalent and critical issues. Defects caused by coil shape imperfections, while relevant, are excluded from the scope of this analysis to maintain a concentrated approach on process- and material-induced faults.

## 2.1. Generating Sheet Part and Roll Design

COPRA RF software is used for generating flower pattern and check of the pre-feasibility of the part with analytical and empirical formulas by creating special term in roll form which is called “Flower Pattern”.

The COPRA RF software was used to generate the flower pattern, a critical step in roll forming design that visualizes the progressive deformation of the strip through successive roll stands. This stage involves assessing the pre-feasibility of the part by utilizing analytical and empirical formulas to ensure the process viability. Once the pre-feasibility was verified and the required number of roll stands determined, the roll designs were created as 2D sketches using COPRA RF, providing a precise foundation for subsequent roll forming operations.

After the process design is completed in COPRA RF, both the rolls and the strip are exported to CATIA V5, where a 3D model is created. This 3D model is essential for generating mesh of the parts, which is a crucial step in finite element analysis (FEA). The

mesh allows for the detailed simulation of material behaviour and deformation during the roll forming process, ensuring that the design can be tested virtually before physical production. The mesh creation process enables the accurate representation of complex geometries, ensuring that stress, strain, and other critical parameters can be effectively analysed during simulations.

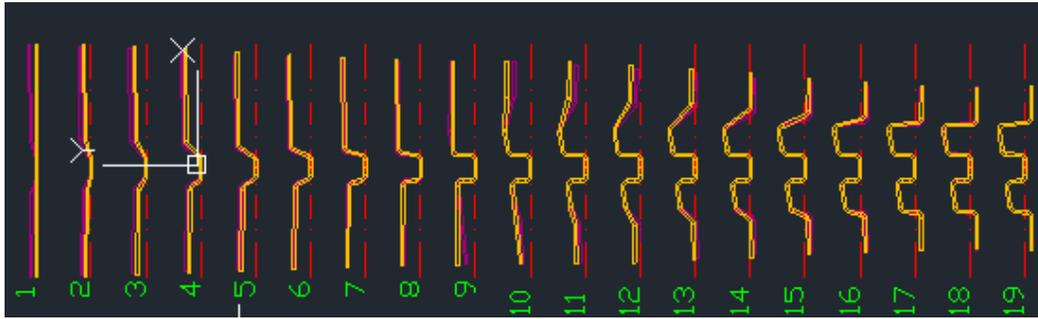


Figure 6. Flower Pattern Of the Part Created In Copra RF

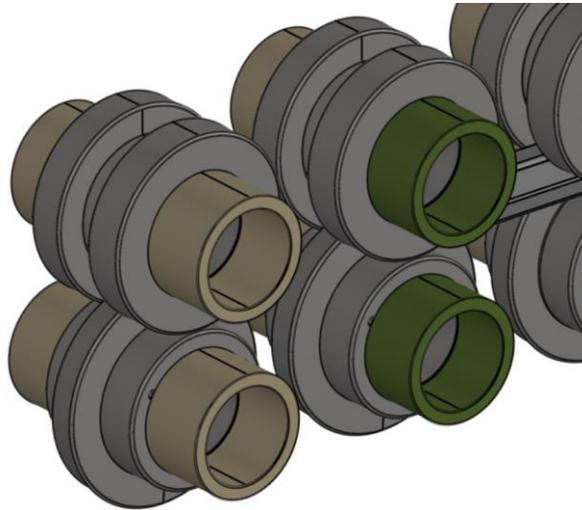


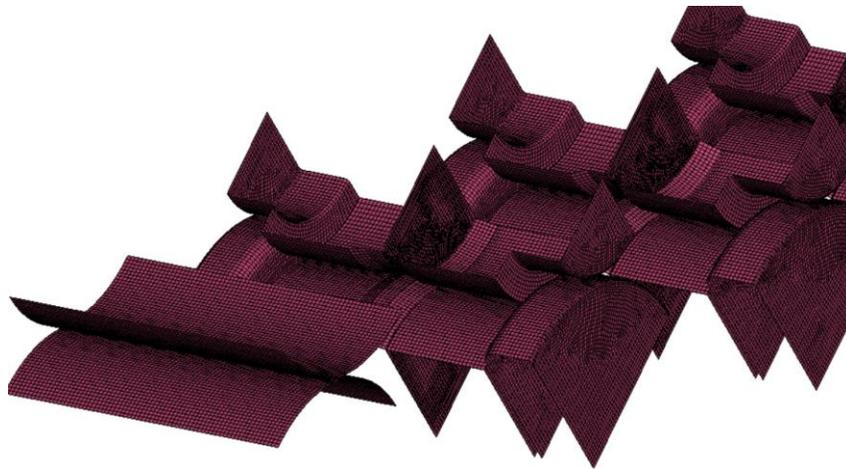
Figure 7. 3D Design of The Rolls

## 2.2. FE Modelling of Rolls And The Strip

The 3D models generated in CATIA V5 are utilized for creating the mesh, a critical step in finite element analysis (FEA). Given that the roll-formed parts are thin sheet metal component with 1.5 mm thickness, a shell modeling methodology was chosen for both the rolls and the strip to ensure computational efficiency and accuracy.

Particular attention was given to the mesh size, especially around the bending radius where a fine mesh was applied. The use of finer mesh sizes in these regions is crucial to accurately capture the bending shape and the resulting plastic strain as the material exits the rolls. This approach ensures a more precise representation of the deformation process, providing reliable results for evaluating the roll forming performance.

The rolls are stationary and constrained in six degrees of freedom (6 DOF). Due to this boundary condition, it is unnecessary to mesh the entire geometry of the rolls. Instead, only the contacting surfaces between the rolls and the strip are modeled, which sufficiently represents the interaction during the roll forming process. To further optimize computational efficiency, only a quarter of the rolls are modeled, taking advantage of the geometric symmetry to reduce simulation complexity without compromising accuracy. Ansys workbench and Ls Dyna is used for creating mesh.



*Figure 8. Mesh Model of The Rolls*

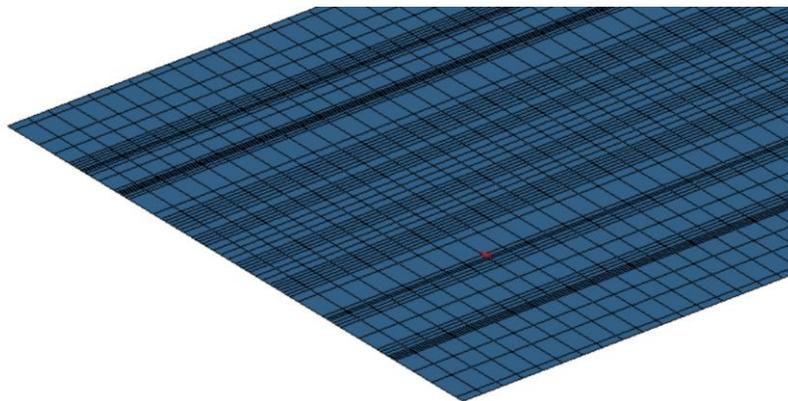
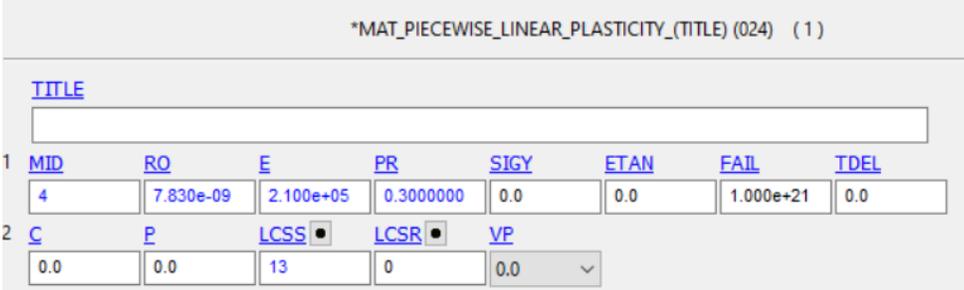


Figure 9. Mesh Model of sheet metal strip

### 2.3. Boundary Conditions and Modelling

Material behaviour is one of the most important things for roll form process simulation. In this article MAT 24\_ PIECEWISE\_LINEAR\_PLASTICITY card has been used for modeling non-linear behaviour of the strip. Steel material properties has been defined as shown in Figure 10. Hardening curve of the material has been shared by material supplier for forming simulations as effective plastic stress/ effective plastic strain and this curve is defined in Ls Dyna material card directly. The deformation of the rolls is negligible compared to that of the strip during the roll forming process. As a result, the rolls were modeled as rigid bodies to simplify the simulation and enhance computational efficiency. This approach significantly reduces computational time while maintaining sufficient accuracy for analysing the deformation of the strip.



*MAT_PIECEWISE_LINEAR_PLASTICITY_(TITLE) (024) (1)								
TITLE								
1	MID	RO	E	PR	SIGY	ETAN	FAIL	TDEL
	4	7.830e-09	2.100e+05	0.3000000	0.0	0.0	1.000e+21	0.0
2	C	P	LCSS	LCSR	VP			
	0.0	0.0	13	0	0.0			

Figure 10. Material Card Linear Properties

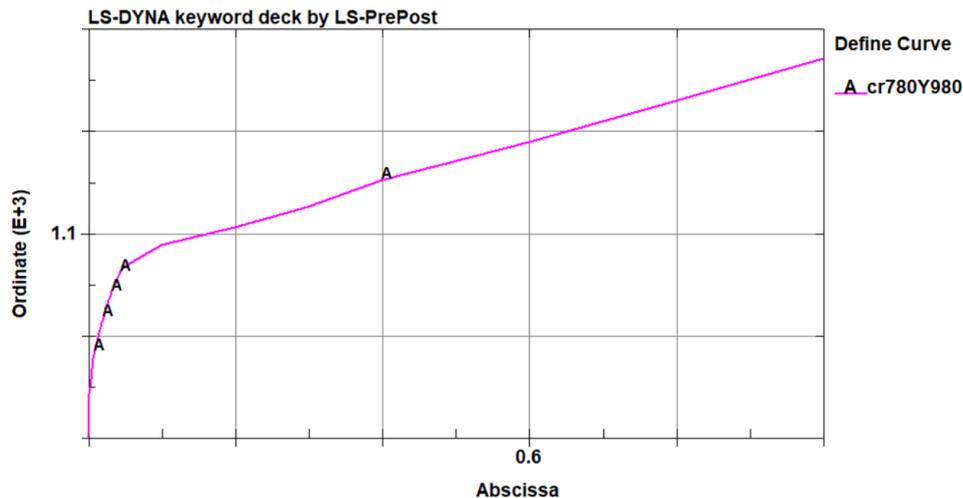


Figure 11. Hardening Curve of The Material

The fully integrated shell formulation (SECTION\_SHELL, ELFORM=16) ensured accurate stress and strain predictions without hourglass energy creation, while maintaining computational efficiency. A fine mesh size was applied around critical bending radii to accurately capture plastic deformation and ensure a precise representation of the bending process.

The rolls are constrained in all six degrees of freedom (6 DOF) to ensure their stationary position during the roll forming process. Motion is applied to the strip using the BOUNDARY\_PRESCRIBED\_MOTION\_SET keyword, with the velocity curve defined as shown in Figure 12. No additional constraints are imposed on the strip, allowing it to deform freely under the applied motion and contact interactions. The speed of the strip is higher than the real life to achieve effective computation time.

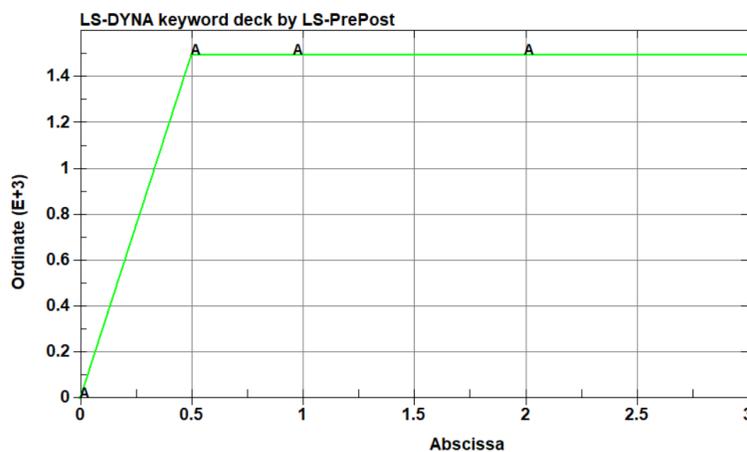


Figure 12. Motion Curve of The Strip

The AUTOMATIC\_SURFACE\_TO\_SURFACE contact card was employed to define the interaction between the rigid rolls and the strip. The SOFT=0 option, combined with the shell thickness offset setting, was used to accurately model the contact behaviour. As the rolls are fully constrained in all six degrees of freedom (6 DOF) and cannot rotate, the friction between the strip and the rolls was disregarded.

The simulation utilized an explicit time integration scheme, with a timestep factor of 0.9 (CONTROL\_TIMESTEP). Mass scaling was applied selectively to optimize computational efficiency while ensuring numerical stability. The simulation runtime was set to 3 seconds (CONTROL\_TERMINATION) to capture the entire roll forming process in efficient time.

### 3. Result

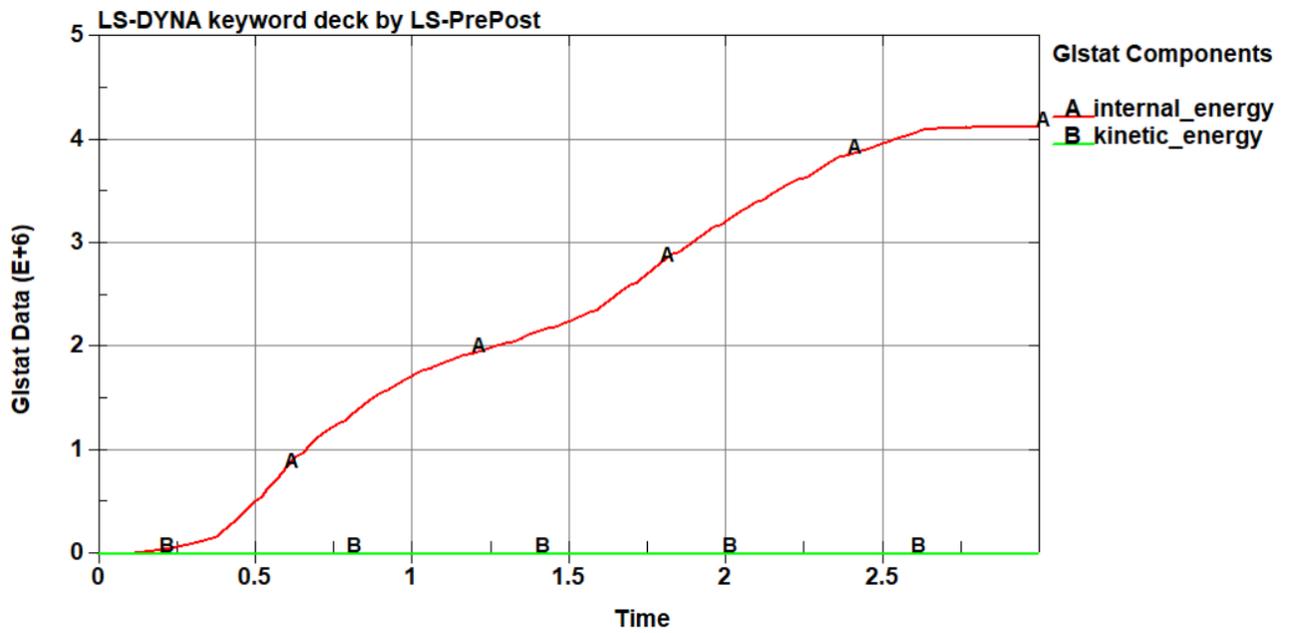


Figure 13. Internal Energy / Kinetic Energy

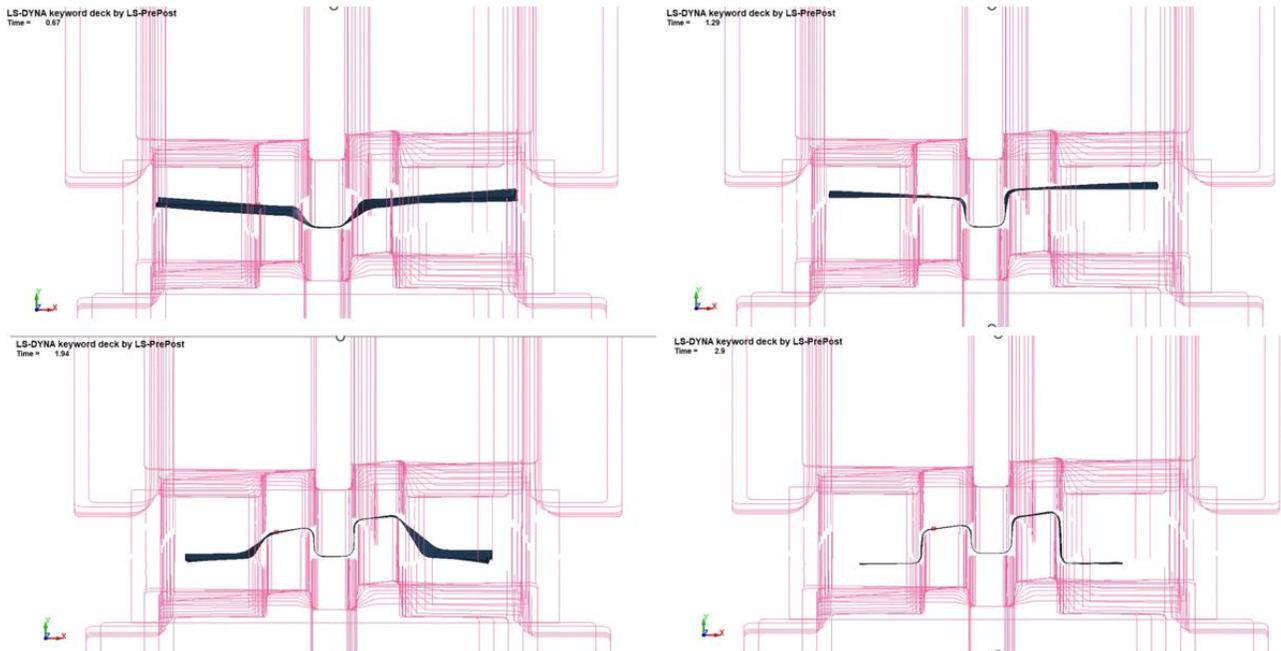


Figure 14. Front View of Strip Exiting From Different Rolls

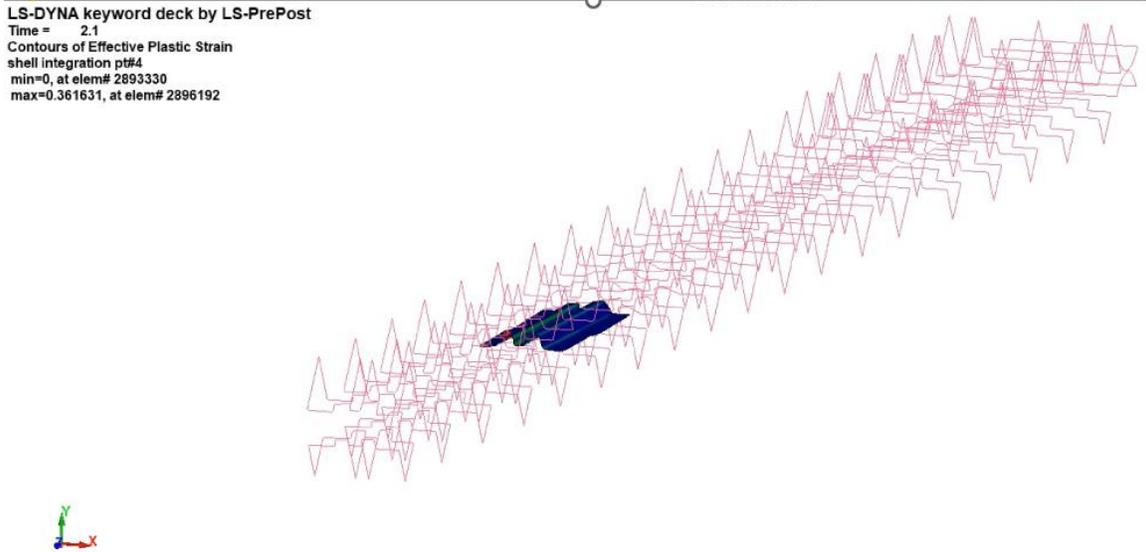


Figure 15. Isometric View of Strip Exiting From Different Rolls

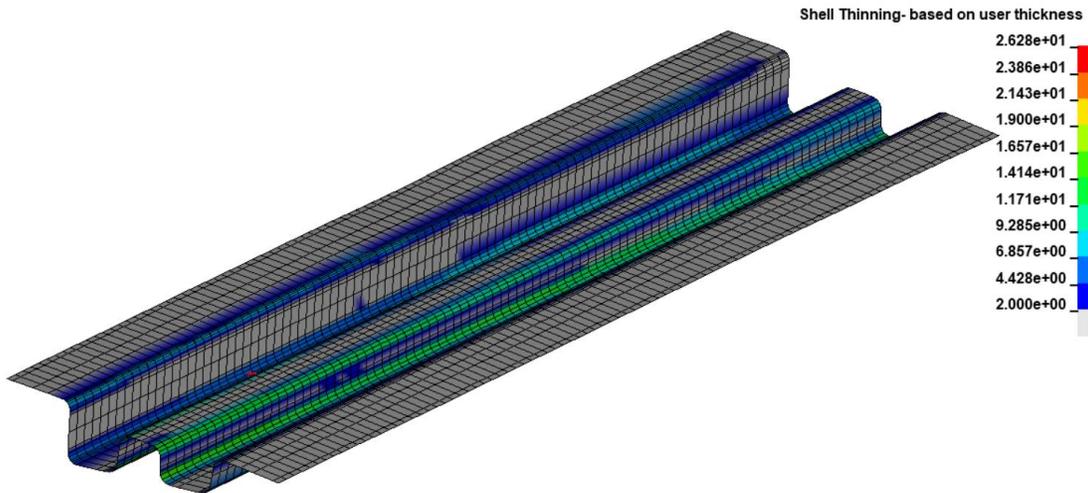


Figure 16. Percentage Thinning Fringe After Final Roll

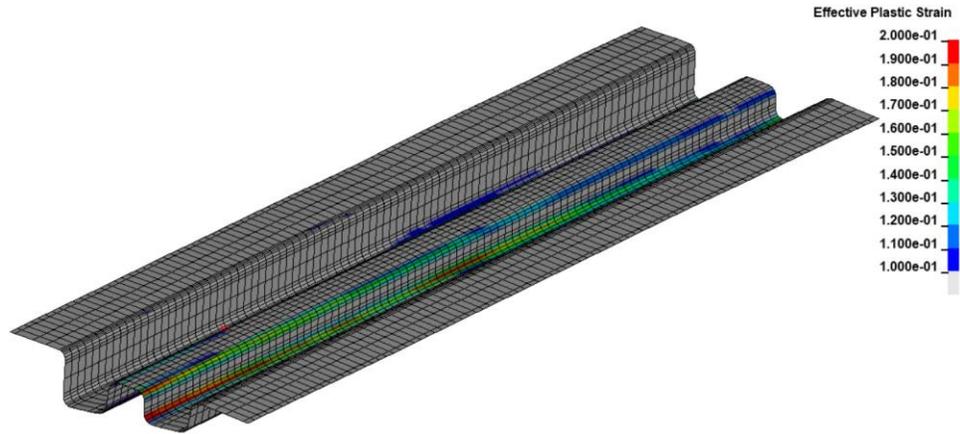


Figure 17. Effective Plastic Strain After Final Roll

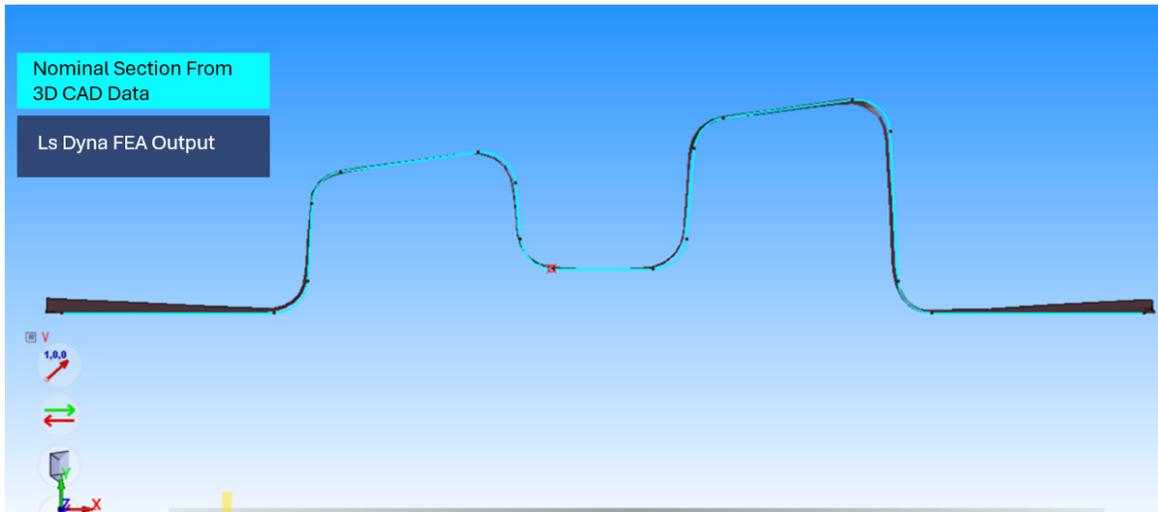


Figure 18. Section View Comparison of FEA Output And 3D CAD Data

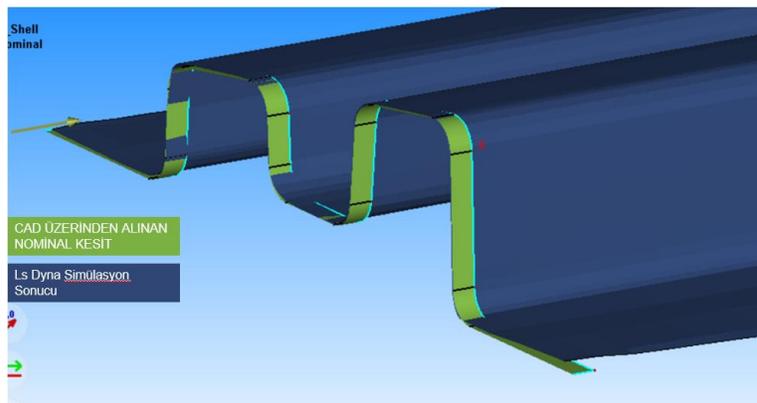


Figure 19. Isometric View Comparison of FEA Output And 3D CAD Data

#### 4. Discussion and Conclusion

The explicit simulation method is particularly suited for engineering problems involving short-duration events, such as blasts, crashes, drops, or other dynamic impact scenarios. However, its application extends to problems with highly nonlinear deformations, such as roll forming. Although roll forming is not a dynamic impact problem, it can be categorized as a quasi-static process. To ensure the validity of explicit simulations for quasi-static problems, careful attention must be paid to the ratio of internal energy to kinetic energy. The kinetic energy must remain sufficiently small to be considered negligible, thereby confirming that the problem remains within quasi-static limits. As illustrated in Figure 14, the kinetic energy in this study is significantly lower compared to the internal energy, validating the quasi-static nature of the simulation.

Figure 17 demonstrates that thinning values are higher along the bending radius, which aligns with expectations. Importantly, the thinning remains within acceptable tolerances. Similarly, as shown in Figure 18, plastic strain is also concentrated in the bending areas. Based on the observed strain values, no cracking is expected in the final product.

#### 5. Acknowledge

I would like to express my heartfelt gratitude to my manager, Serkan Alkan for the invaluable support, guidance, and encouragement throughout this project. I am also deeply thankful to my coworker, Enver Mutlu, for his collaboration and significant contributions, which greatly enhanced the quality of this work.

#### References

- [1] Peng, X., Han, J., Liu, J., & Yan, P. (2014). Technology of finite element analysis for roll forming process. *Advanced Materials Research*, 941–944, 1832–1835. <https://doi.org/10.4028/www.scientific.net/amr.941-944.1832>
- [2] Choi, H., Yoon, J., Lee, J., & Kim, G. (2019). A springback prediction of 1.5 GPA grade steel in roll forming process for automotive sill-side inner component. *Key Engineering Materials*, 794, 267–274. <https://doi.org/10.4028/www.scientific.net/kem.794.267>
- [3] Mahajan, P., Abrass, A., & Groche, P. (2018). FEA simulation of roll forming of a complex profile with the aid of steady state properties. *Steel Research International*, 89(5). <https://doi.org/10.1002/srin.201700350>
- [4] Oh, M., Lee, M., & Kim, N. (2010). Robust design of roll-formed slide rail using response surface method. *Journal of Mechanical Science and Technology*, 24(12), 2545–2553. <https://doi.org/10.1007/s12206-010-0914-2>

- [5] Zhen, J., Hu, Z., Feng, Z., & Cao, J. (2014). Analysis of flexible roller parameters influences on roll forming of three-dimensional parts. *Advanced Materials Research*, 875–877, 450–454. <https://doi.org/10.4028/www.scientific.net/amr.875-877.450>
- [6] AHSS Insights. (n.d.). Roll Forming. *ahssinsights.org*. Retrieved December 9, 2024, from <https://ahssinsights.org/forming/roll-forming/roll-forming/>
- [7] Vogel, P. (n.d.). Roll Forming with LS-DYNA. Retrieved December 9, 2024, from [http://1afb9901641b431ed16e-db18c087985512ddb23a000fc6f6ffd3.r27.cf2.rackcdn.com/marketing\\_archive/presentations/Rolforming\\_LSDYNA.pdf](http://1afb9901641b431ed16e-db18c087985512ddb23a000fc6f6ffd3.r27.cf2.rackcdn.com/marketing_archive/presentations/Rolforming_LSDYNA.pdf)