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Agile Tube Roll Forming, a New Process Architecture for Manufacturing of Longitudinally Welded Tubes

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Abstract. Thick-walled longitudinally arc-welded tubes are indispensable in modern infrastructure owing to their exceptional load-bearing capacity and structural integrity. Nevertheless, their fabrication remains highly challenging, as the conventional forming forces demand the use of large-scale industrial presses. To address this limitation, this research introduces a novel process architecture that integrates agile tube roll forming process for tube manufacturing, thereby enabling the production of such tubes using significantly smaller and more flexible manufacturing systems. To this end, three tube support configurations—namely, support-less, dynamic roller support, and static support—were systematically investigated in this study on 7, 9, 11, and 15 mm thick 304 stainless steel. While the supportless condition represents the most economical option, the incorporation of dynamic or static support significantly improves geometric accuracy, yielding near-net cross-sections combined with reductions in tube ovality of approximately 75 and 79 %, respectively, compared to support-less configuration. Considering the straightness of the weld line as a quality indice, the dynamic support provides the highest quality. Using the static/dynamic support strategies, the deformation forces arise between 2 and 3 times compared to support-less strategy.

Introduction

The longitudinally welded Tubes are indispensable components in modern engineering, serving two principal roles. Structurally, they are widely employed in construction, infrastructure, and automotive systems, where durability, high strength-to-weight ratio, precision, and cost efficiency are critical. In fluid transport, they ensure the continuous and reliable conveyance of oil, gas, and water. Stainless steel welded tubes, in particular, are vital in the food, chemical, pharmaceutical, and all other industries, where superior corrosion resistance and hygienic performance are required.

Longitudinally welded tubes are commonly manufactured using the processes: I) Continuous roll forming (tube mill), II) UOE forming (U-press, O-press, expansion), and III) JCOE forming (J-press, C-press, O-press, expansion). Fig. 1 illustrates approximate thickness–diameter applicability ranges according to the industrial catalogues from Japan, China, the UK, the USA, and Türkiye (Turkey).

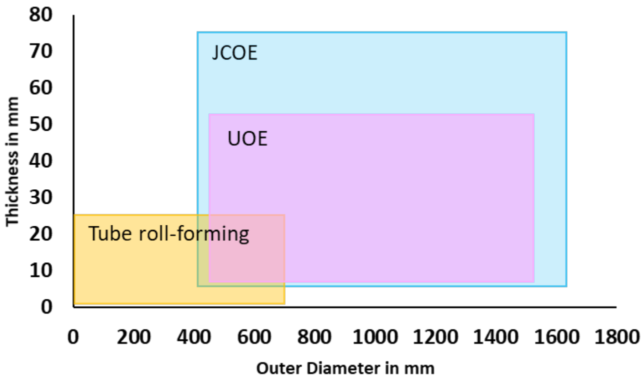

Fig. 1. Approximate thickness–diameter applicability ranges for tube roll forming, UOE forming, and JCOE forming processes.

Roll forming is a continuous process in which a (commonly coiled) metal strip passes through successive, precisely aligned roll stands that incrementally shape it into a constant open and closed cross-section [1], resulting in comparatively low forming forces. While the process is highly economical for large-scale production, it is generally uneconomical for small batches [2] due to the high initial expense of manufacturing the roll tools and providing the motors needed to drive the rollers.

To address this gap, agile roll forming process has been introduced. Agile roll forming process [3] is the new concept of roll forming processes in which a blank-holder constrains the blank while a (pair of) roller(s) move(s) both along and perpendicular to [4,5] the length of the profile and incrementally shape(s) the blank into the desired profile. This concept minimizes the number of the rollers, minimizing the initial manufacturing cost and time, resulting in agility. While this concept has been successfully fulfilled manufacturing of uniform [3,4] and non-uniform [5,6] open profiles, the manufacturing of closed profiles hasn't been investigated yet. To enable tube manufacturing using the agile roll forming machine, it is necessary to redesign the roller system and the blank-holder section based on the forming strategy.

This study introduces a novel process concept for the production of longitudinally welded tubes, roller design, and integration of various process configurations. The target geometry is a tube with an outer diameter of 200 mm and a length of 500 mm.

Design and Numerical Modeling of Agile Tube Roll Forming Process concepts.

Agile Tube Roll Forming configurations

Fig. 2 presents three configurations of the agile tube roll forming process: (a) support-less, (b) dynamic support-assisted, and (c) static support-assisted. The support-less configuration represents the simplest setup, aiming to minimize initial cost and system complexity, thereby achieving the highest level of process agility. The static support-assisted configuration provides internal surface referencing of the tube to enhance dimensional accuracy while maintaining a relatively simple dynamic process. This configuration is more suitable for shorter tubes, whereas the dynamic support-assisted configuration is preferable for longer tubes when higher dimensional accuracy is required.

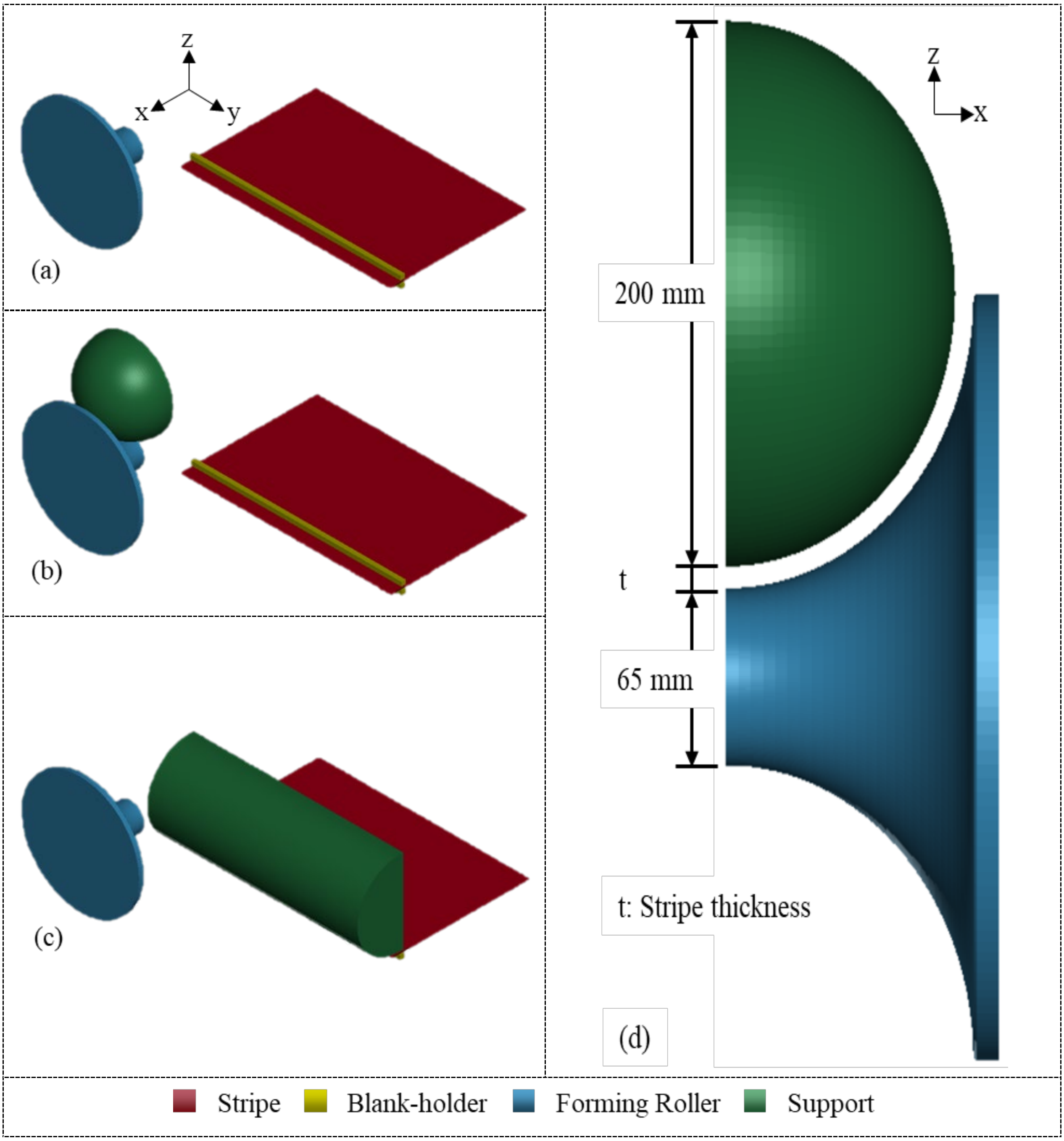

Fig. 2. Schematic of the agile tube roll forming process for production of longitudinal welded tubes; (a) Support-less, (b) Static support, and (c) Dynamic support. (d) Dimensions and lateral view of the Forming roller and support.

Forming strategy

Several forming strategies-namely the W (reverse) forming, Double Radius (DR) forming, Single Radius (SR), and edge forming strategies-are available in conventional tube roll forming technology [7,8]. Among these, the edge forming approach enables the use of one roller (set), making it particularly suitable for the proposed process. Accordingly, this strategy and its corresponding flower pattern are adopted in the present research.

Stripe feed and toolpath

To achieve the final tube shape, a coordinated combination of stripe feeding and repetitive roller movements is essential. Fig. 3 illustrates the toolpath and stripe feed in the agile tube roll forming process. During the forming stage, the roller(s) move along the y-direction (longitudinal axis of the tube), transferring the roller profile into the stripe. After completing each forming step, the stripe is fed along the x-direction. The repeated sequence of these motions ultimately results in the formation of the desired tube shape.

Schematic illustration of the coordinated roller and stripe feed motions in the agile tube roll forming process. The diagram depicts 18 representative forming steps. The red dashed line represents the roller position along the y-direction, and the blue dashed line denotes the stripe feed along the x-direction. The accompanying schematic shows the progressive formation of the half-tube profile in the x–z plane corresponding to each forming step.

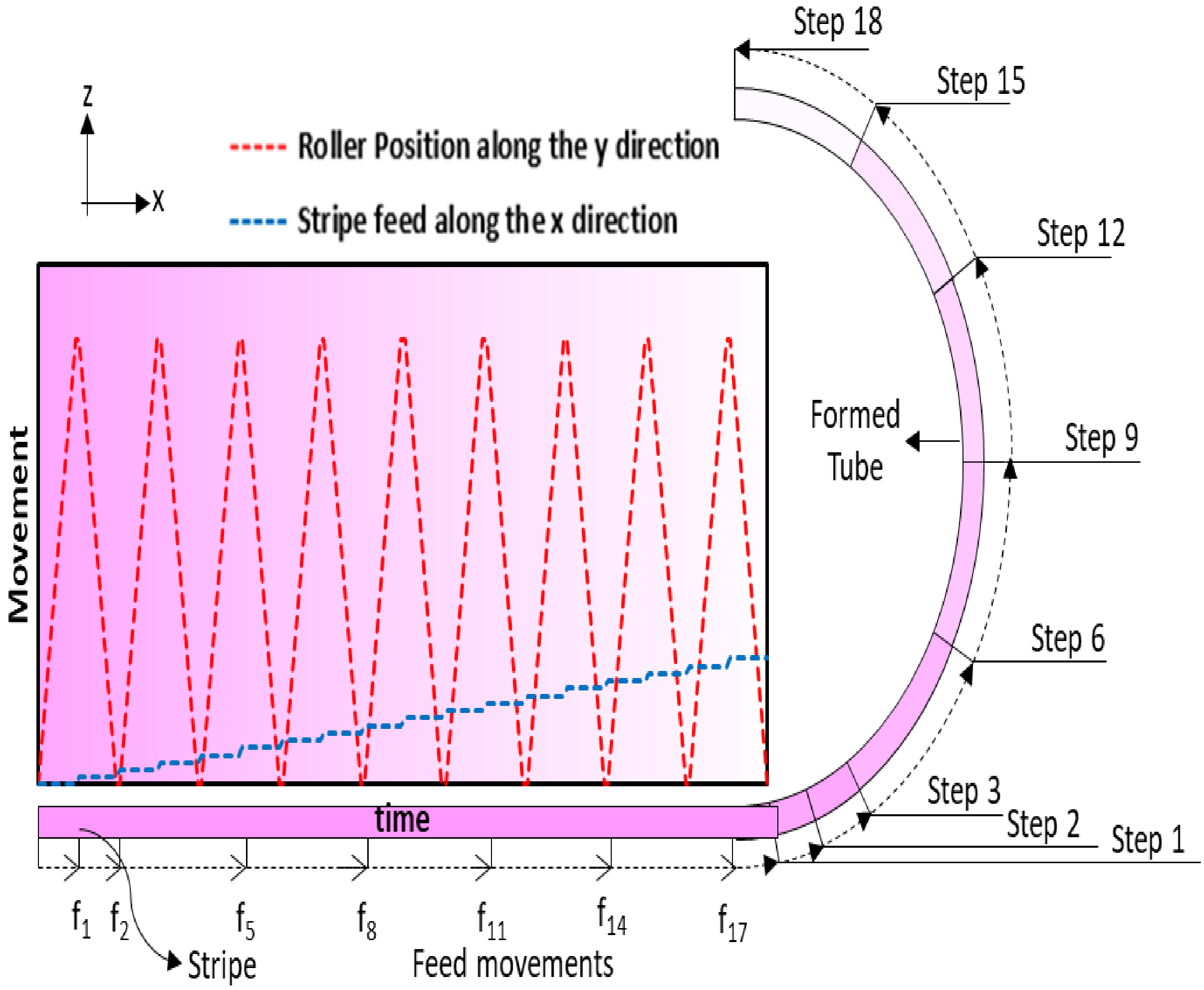

Fig. 3. Toolpath and feed movement in agile flexible roll forming process.

Material

In this study, AISI 304 steel was selected as the reference material. Test specimens were prepared from strips with an initial width of 200 mm. Using laser cutting, tensile samples were fabricated with a gauge length of 8mm and a gauge width of 3mm, as illustrated in Fig. 4-(a). The specimens were oriented at 0°, 45°, and 90° relative to the rolling direction. Tensile experiments were carried out at room temperature on an MTS 322™ hydraulic dynamometer equipped with a Zeiss Gom Aramis DIC system, which was employed to capture the true strain paths of the samples. All tests were performed at a strain rate of 0.1 s^{-1}, corresponding to the strain rates typically observed in roll forming operations. The resulting true stress–strain curves (Fig. 4-(b)) were subsequently incorporated into the numerical roll forming model.

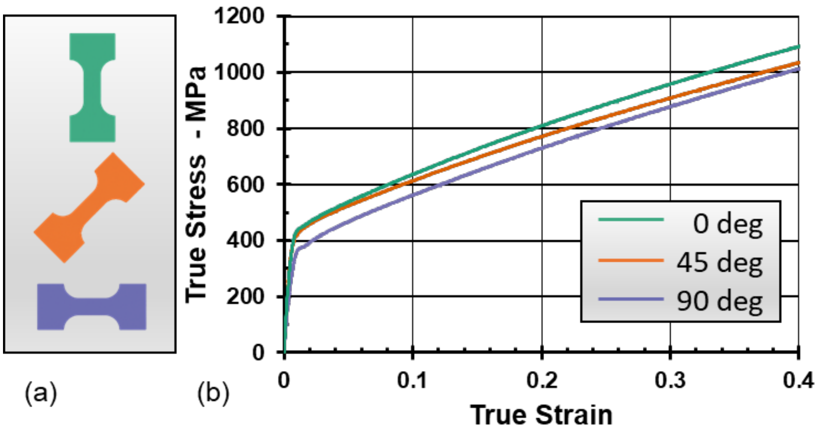

Fig. 4. Tensile test results of the reference material.

Modeling

The forming process was simulated using the LS-Dyna™ software environment and solved using an implicit solver for the tube roll forming process following by implicit calculation of the elastic recovery (springback). The 7, 9, 11, and 15mm thick stripes with a length of 325.1, 328.1, 331.3, and 337.6 mm, respectively, and a width of 500 mm were modeled as a deformable part discretized using rectangular meshes, using fully integrated shell elements, having an average size of 1 mm along x-direction and 5 mm along y-direction and 7 integration points through thickness (z-direction).

The interaction between rollers and strips was modeled using a Coulomb friction model with both static and dynamic friction coefficients set to 0.2. To achieve the desired geometry along the length of the tube, rollers move along the y-direction to copy the shape of the rollers' contact to the sheet. After the rollers pass completely along the tube length, the blank holder releases the strip, and the strip advances incrementally along the x-direction. This loop repeats multiple times till reaching the ideal geometry of the tube.

To determine the optimal setup design, the process was modeled under three different conditions (see Fig. 2): (a) support-less, (b) dynamic support-assisted, and (c) static support-assisted agile roll forming. The forming rollers and the dynamic/static supports were represented using fully integrated rigid shell elements, with mesh sizes ranging from 0.5 mm to 1 mm depending on geometric complexity. The interaction between rollers and strips was modeled using a Coulomb friction model with both static and dynamic friction coefficients set to 0.2. To achieve the desired geometry along the length of the tube, the toolpath method described in Fig. 3 has been implemented.

The blank holder was modeled using fully integrated rigid shell elements with a size of 2.5 mm. Similar to the roller/support-stripe interaction, static and dynamic friction coefficients set to 0.2 for the blank holder-stripe interaction. The cyclic load between the blank holders and stripe set to 200 MPa during the forming and 0 in the stripe feed stage.

Results and Discussion

Cross-sectional view

Fig. 5 illustrates the cross-sectional views of the tubes produced by agile roll forming, with the corresponding strain distribution along the circumference, obtained using a cutting plane normal to the y-axis at y = 250 mm. The results highlight the influence of thickness and support technology on both the geometry and strain localization. At smaller thicknesses, the sections deviate more significantly from the ideal circular shape, resulting in higher ovality. As the tube thickness increases, the proportion of the elastically deformed region relative to the plastically deformed region through the thickness of the tube decreases, resulting in a lower elastic recovery level. Generally, the results demonstrate that not only the ovality is minimized in thicker tubes, but also the strain distribution is more homogeneous, leading to improved geometric accuracy.

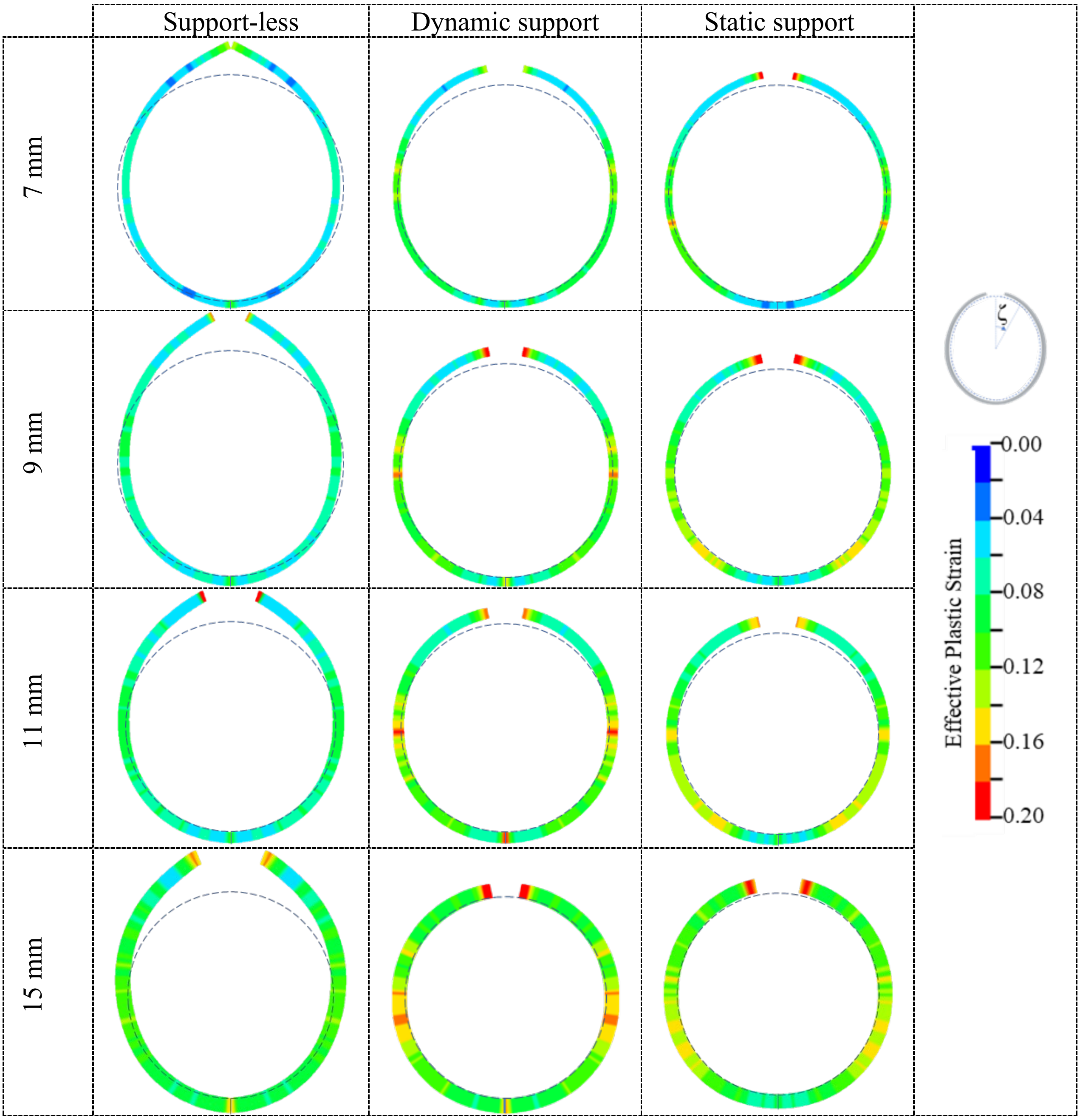

Fig. 5. Cross-sectional view of the tubes modelled using agile tube roll forming technology.

On the other hand, in the support-assisted agile tube roll forming setups, the dynamic/static support part acts as a reference for the inner surface of the tube, it leads to better cross-sectional accuracy by decreasing the ovality, showing the importance of using a support in agile tube roll forming. As the static support provides a more global support for inner surface of the tube, it improves the strain distribution in static support assisted agile roll forming compared to the dynamic-assisted condition.

The effective plastic strain maps reveal that deformation is concentrated at specific angular positions, particularly near the forming closure regions (ζ=0˚), where localized peaks in strain appear. On the other hand, around ζ=90˚, especially when using the dynamic support, there is strain non-homogeneity, referring to the Roller(s)-stripe separation point. Around ζ=180˚ which is the end of the stripe, there is not enough material flow because of the boundary condition applied and when the thickness is maximum, another peak is observed.

Ovality

As shown in Fig. 6, tube ovality is significantly influenced by both thickness and the applied support condition. The support-less case exhibited the highest ovality, ranging between 13.5% and

22.6%, which reflects considerable geometric distortion caused by springback and non-uniform deformation. With the application of dynamic support, ovality values were reduced to a lower level, starting at approximately 8.3% for the thinnest tube and steadily decreasing to 0.4% as thickness increased. The static support condition provided the most favorable results, maintaining ovality 4.9% for the thinnest tube and approaching below 2.5% in the 9, 11, and 15mm thick tubes.

Two clear trends can be identified from these results. First, increasing tube thickness enhances circularity, as the higher elastic-to-plastic ratio through the wall reduces distortion. Second, the introduction of support systems—especially static support—improves process stability by decreasing the sensitivity of the process to thickness change. From a manufacturing perspective, these findings demonstrate that support-assisted strategies are highly effective in reducing cross-sectional distortion and ensuring improved geometric accuracy in agile roll forming.

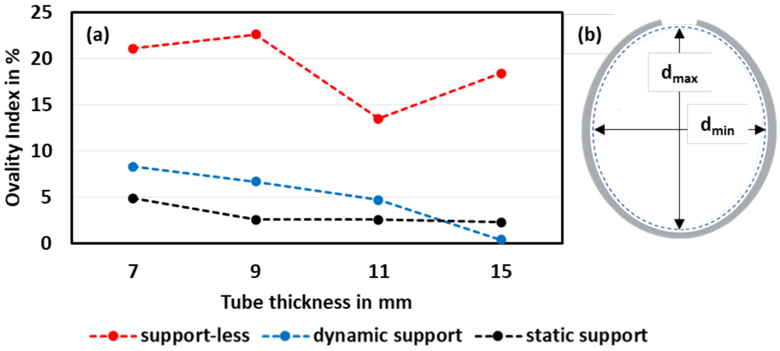

Fig. 6. (a) Ovality index results. (b) Schematic of tube cross-section showing the d_{min} and d_{max}.

Straightness of the weld line

Fig. 7 represents the straightness of the formed weld line as a factor to investigate the quality of the manufactured tube. Considering the thickness, the maximum deviation of the weld line—excluding the support condition effect—decreases from 22 to 12 mm, where the thickness increases from 7 to 15 mm. The dynamic assisted support condition shows its success in reaching the best weld line quality, by reaching to a deviation of around 2 mm in the case of the 9 mm thick tube. On average, the support-less configuration leads to higher deviations along the weld line, which shows the importance of support to avoid deviations. On the other hand, the use of dynamic support prevents unnecessary stripe-support contact, resulting in lower deviations along the weld line.

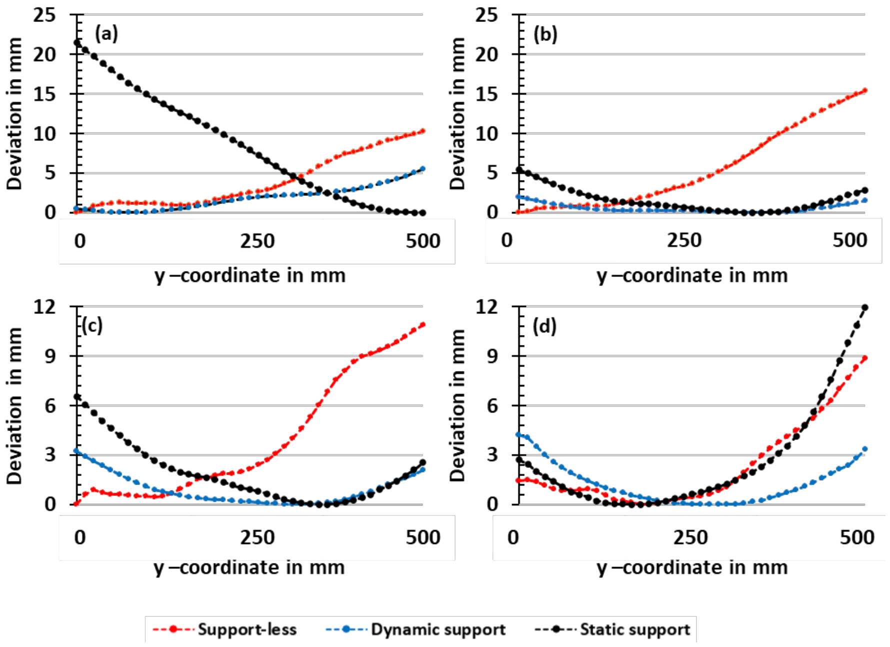

Fig. 7. Straightness of weld line; (a) 7mm, (b) 9mm, (c) 11mm, and (d) 15mm tubes.

Forming Forces

Fig. 8 shows the deformation forces along the x, y, and z directions, as well as the total force, for tubes produced under different support conditions and thicknesses. While in the case of the support-less and dynamic support configurations, F_x is the dominant component of the deformation force, F_z is the dominating force in the case of the static support. The F_y which represents the force along the tube axis, remained the smallest contribution of the deformation force components. The values of the F_y remains constant when the thickness is the same and the support configuration changes.

In the support-less condition, the forces rise steadily with thickness, with the total force in the range of 48 kN for the thinnest to 198 kN for the thickest tube. Using the dynamic/static support, the overall force level rises between 2 and 3 times compared to the support-less case, revealing that dynamic/static support redistributes the deformation more uniformly but requires greater load.

From a manufacturing standpoint, these results highlight that support strategies not only influence the geometric quality of the tube but also affect the forming load requirements, similar to the comparison of die-less and die-assisted forging processes.

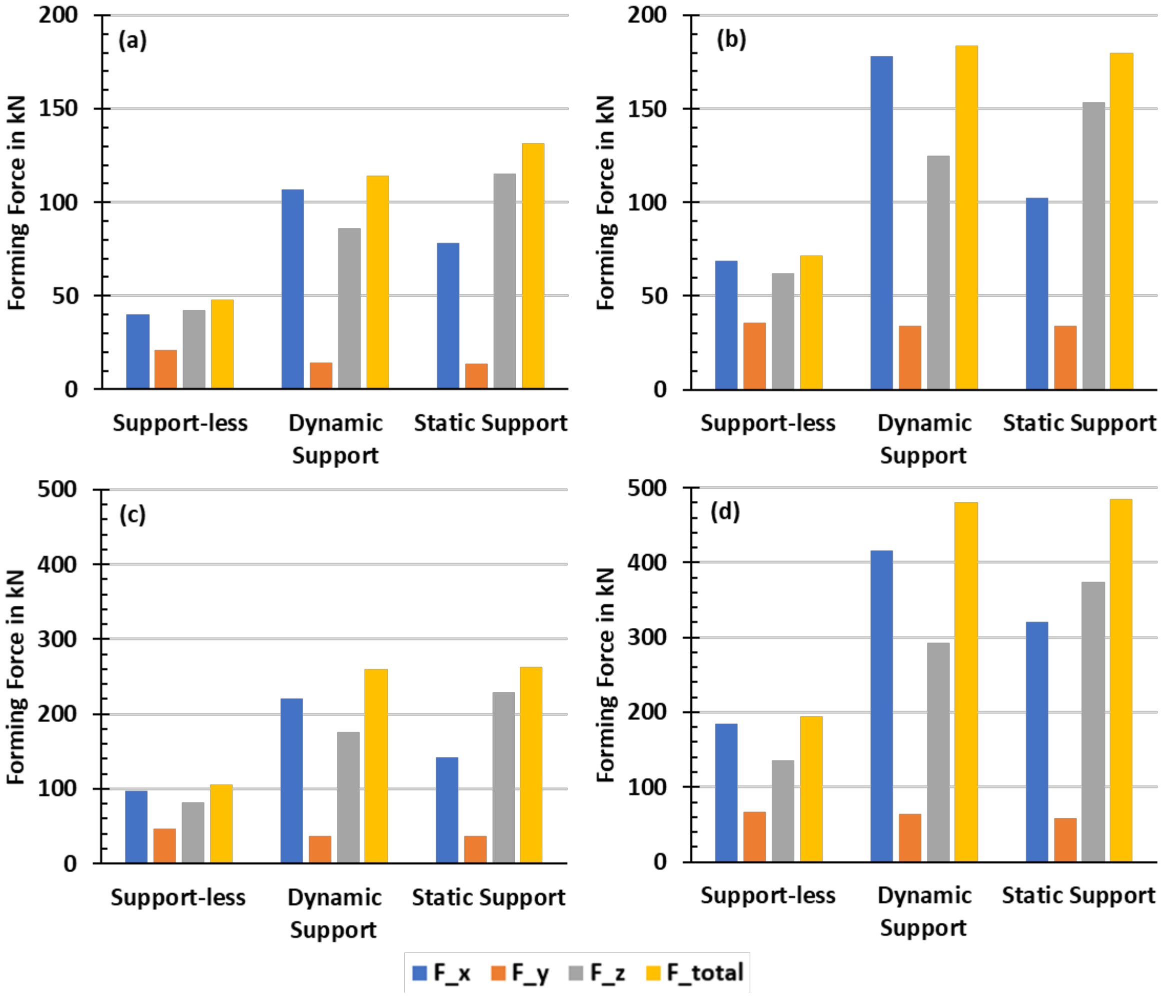

Fig. 8. Force diagrams; (a) 7mm, (b) 9mm, (c) 11mm, and (d) 15mm tubes.

Conclusion

This paper depicts the potential of the novel agile tube roll forming process to manufacture thick tubes with three different strategies. This process decreases the initial costs of the manufacturing setup compared to the conventional tube roll forming processes by decreasing the number of the roll stands and tube pressing (UOE and JCOE) by using the smaller presses.

From manufacturing standpoint, while the support-less condition represents the most economic condition combined with the less complexity of the machine design and lower forming forces, the support assisted processes represent better cross section by decreasing the ovality of the tube and better strain distribution.

In summary:

- Using a dynamic support results in localized plastic strain around ζ=0˚ and ζ=90˚.
- Ovality decreases from 18% (support-less) to 4.5% (dynamic) and 3.6% (static), representing reductions of 75% and 79%, respectively.
- Dynamic support yields the highest weld line straightness.
- Deformation forces increase 2–3 times with support compared to support-less condition, reflecting a trade-off between precision and deformation force.

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