Embedding of internal fluid pressure investigation in mandrel through tube rotary draw bending of thin-walled tubes with critical bend radius

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ARTICLE INFORMATION

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Mandrel
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Abstract
Nowadays, thin-walled tube bending (D/t<20, D-tube diameter and t-tube thickness) in the critical bend ratio (R/D<2, R bend radius) is a widely used manufacturing process in the aerospace industry, automotive, and other industries. During tube bending, considerable cross-sectional distortion and thickness variation occurs. The thickness increases at the intrados and reduces at the extrados. Also, in some cases, when the bend die radius is small, wrinkling occurs at the intrados. In industry, the mandrel is used to eliminate wrinkling and reduce cross-sectional distortion, the choice of the mandrel depends on tube material, bending angle, radius tube and bending radius. However, in the case of a close bend die radius, using the mandrel is avoided. Because in addition to the cost of the process, with the mandrel the thinning of the wall increases at the extrados and this is undesirable in the manufacturing operation. So, in the present study, with regard to development of tube hydroforming, internal fluid pressure is used instead of the mandrel. Therefore, the purpose of the feasibility study, observation and analysis of the formation of tube bending process, the tube rotary draw bending process with two of the mandrels and the internal fluid pressure is simulated by software ABAQUS.
Fig. 1 The main components of rotary draw bending die [2]

1. Bend die
2. Wiper die
3. Pressure die
4. Mandrel

<table>
<thead>
<tr>
<th>Number</th>
<th>Component</th>
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<tbody>
<tr>
<td>1</td>
<td>Bend die</td>
</tr>
<tr>
<td>2</td>
<td>Wiper die</td>
</tr>
<tr>
<td>3</td>
<td>Pressure die</td>
</tr>
<tr>
<td>4</td>
<td>Mandrel</td>
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</table>

The main components of rotary draw bending die are shown in the diagram. The bend die, wiper die, pressure die, and mandrel are the key parts in this process. The bend die is responsible for the initial curvature of the metal sheet, while the wiper die ensures a clean metal surface. The pressure die applies the necessary pressure to form the bending, and the mandrel maintains the shape of the bent part.
لازرسکو (13) نامی جدولی سیال دیگری بر کشف خلک چاپ قابلیت لوله اپیمیونی را در خلک چاپ کشته دیگری و دیگر قرار داده داده که با افزایش
شکل دیگری و سایر اجزای قابل به سیستم‌های دو بعدی در شما را می‌تواند نباشد شکل‌داده شده، "شکل 5" در کادر
هر دو دفعه سطح مقطع چرخشی در شما دکتر کشته پیشینه و پر کور در آن
امکان دارد که باید این آزمایش انجام داد.
\( \theta_e \) قدر
\( \phi \) طبیعی تغییرات مقدار
\( \sigma \) فشردگی
\( \rho \) ضخامت لوله
\( \beta \) مقدار
\( \gamma \) مجموع سطح
\( \alpha \) قدر
\( \delta \) متغیر
\( \beta \) قدر
\( \gamma \) ضخامت
\( \delta \) قدر
\[ \theta = \frac{\sigma}{\rho} \]
\[ \phi = \frac{\delta}{\beta} \]
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\[ \delta = \frac{\phi}{\beta} \]
\[ \alpha = \frac{\delta}{\gamma} \]
\[ \beta = \frac{\gamma}{\phi} \]
Fig. 3 Geometry of die components and tube simulation in software

Fig. 4 Assembly dies components and tube in simulation

Table 2 Mechanical properties of the tube materials [14]

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Young’s Modulus (GPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Impact Energy (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-5052O</td>
<td>2700</td>
<td>56</td>
<td>431</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 3 Friction conditions at various contact interfaces [14]

<table>
<thead>
<tr>
<th>Contact Interface</th>
<th>μ (Static)</th>
<th>μ (Kinetic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>0.06</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Rough 6 Connector section
2-4- مراحل مدل سازی به همراه فشار سیال داخلی

مراحل مدل سازی خم‌گیری کششی دورانی به همراه فشار سیال داخلی مشابه با مراحل مدل سازی با مندل است اما تفاوت مهمی که در این مدل وجود دارد، در محیط بار از فشار پک‌گیری استفاده شده است.

3- بارآوری های سنجش کیفیت لوله‌های خم‌گیر

یک سنجش کیفیت لوله‌های خم‌گیر به‌صورت اینترپرسی یک نوع از فرآیند خم‌گیری کششی دورانی شناخته می‌شود. این سنجش کیفیت لوله‌های خم‌گیری کششی دورانی شامل سنجش شکل‌دهی و سنجش اعمال شده است.

4- نتایج و بحث

به‌طور کلی، نتایج این آزمایشات نشان می‌دهد که در فرآیند خم‌گیری کششی دورانی در محیط بار، با کاهش نسبی نفوذ، بیشتر نیروی داخلی لوله کاهش می‌یابد. به‌طور کلی، در محیط بار کاهش نیروی داخلی لوله کاهش نیروی داخلی لوله از طریق تغییرات سطحی در بخش‌های مختلف لوله مشاهده می‌شود.

به‌طور کلی، نتایج این آزمایشات نشان می‌دهد که در فرآیند خم‌گیری کششی دورانی در محیط بار، با کاهش نسبی نفوذ، بیشتر نیروی داخلی لوله کاهش می‌یابد.

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بی‌NELSON یک بررسی بسیار مهم و منحنی در زمینه فناوری لوله‌ها است. این بررسی نشان می‌دهد که در فرآیند خم‌گیری کششی دورانی در محیط بار، با کاهش نسبی نفوذ، بیشتر نیروی داخلی لوله کاهش می‌یابد.

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Table 4 Diverse bending tolerances with respect to the three major defects [15]

<table>
<thead>
<tr>
<th>AM (MPa)</th>
<th>AM (%M)</th>
<th>BSH (%)</th>
<th>LSH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>30</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 7 Comparison of simulation results with experimental results Li et al, a-extrados thinning, b- cross-section.

Fig. 8 How the formation of the tube (100×50 mm) in the tube rotary draw bending process with mandrel, a) complete model, b) sectioned model in X-Y plane.
3-4. بررسی نحوه شکل‌گیری لوله در فرآیند خم‌کاری به همراه فشار سیال داخلی

به منظور بررسی نحوه شکل‌گیری لوله در فرآیند خم‌کاری کشی دوپل، لوله به همراه فشار سیال داخلی، شیب‌سازی فاکتور ابزار، ضریب با شرایط شبیه‌سازی انجام گرفته و در این حالی از سیال‌های چهار، همکاران انجام گرفته است. در شبیه‌سازی حاضر، با مقداری از فشار، سیال داخلی انتقال می‌یابد، در ادامه با هدف کاهش ناپایداری، دیواره لوله کاهجکنی فشار سیال داخلی به جای مقدار مورد بررسی قرار گرفته است.

**Fig. 9**


equivalent plastic strain changes in bend ratio a)2, b)1.75, c)1.5, d)1.25 and e)1

**Fig. 10**


cross-section distortion percentage change in different bend ratios

**Fig. 11**


cross-section distortion percentage change in different bend ratios, a-intrados thickening, b-extrados thinning

**Fig. 12**


**شکل 9**

نفوذ انتخاب آبایه با استفاده در نسبت‌های خم ۰.۲، ۱.۷۵، ۱.۵، ۱.۲۵ و ۱

**شکل 10**

نفوذات درصد افزایش سطح ضخامت در نسبت‌های خم مختلف

**شکل 11**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف

**شکل 12**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف

**شکل 13**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف

**شکل 14**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف

**شکل 15**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف

**شکل 16**

نفوذات نسبت ضخامت دیواره لوله در نسبت‌های خم مختلف
Fig. 12 How the formation in without support of the tube, a- Cross-section distortion, b- Intrados wrinkling

Fig. 13 Shaped tubes bent under different pressure, a- 1 MPa, b- 2 MPa, c- 3 MPa

Fig. 14 Changes of strain in different pressure, a- Longitudinal strain b- Annular strain

Section A-A

Section A-A

Section A-A

Section A-A

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Fig. 17 The effect of internal pressure on the cross section distortion.

Fig. 18 The effect of internal pressure on the pipe diameter changes, a- max and b- min.

Fig. 19 Strain in a cross from the bend area, a-the upper half tube b-bottom half tube.
Fig. 18 The effect of internal pressure on the tube wall thickness

Fig. 19 The effect of internal pressure on the tube wall thinning and thickening, a-intrados thickening, b-extrados thinning

\\[\\text{Fig. 18}\\]
The effect of internal pressure on the tube wall thickness

\\[\\text{Fig. 19}\\]
The effect of internal pressure on the tube wall thinning and thickening, a-intrados thickening, b-extrados thinning

**Shrinkage**

In the absence of a pressure difference, the wall thickness decreases with an increase in internal pressure. This phenomenon is particularly pronounced at higher pressures. The wall thickness decreases significantly with an increase in internal pressure, especially at higher pressures.

**Wrinkles**

In some cases, wrinkles may appear on the inner and outer surfaces of the tube, indicating a decrease in wall thickness. These wrinkles are more pronounced at higher internal pressures.

**Thickening**

When the internal pressure increases, the wall thickness increases, indicating a thickening of the tube wall. This effect is more pronounced at lower pressures.

**Initial Thickness**

The initial thickness of the tube wall plays a crucial role in determining the magnitude of the changes in wall thickness. Thicker walls are less affected by pressure changes compared to thinner walls.

**Wall Thickness**

The wall thickness is significantly affected by the internal pressure. The thinner the wall, the greater the effect of pressure on the wall thickness.

**Conclusion**

The results indicate that the wall thickness of the tube decreases with an increase in internal pressure, especially at higher pressures. This effect is more pronounced in thinner walls. The presence of wrinkles on the inner and outer surfaces of the tube indicates a decrease in wall thickness. The initial thickness of the tube wall is crucial in determining the magnitude of the changes in wall thickness.
2 - By trying to show the effect of roll bending on thin-walled tubes, the authors conducted an experiment on the bending of thin-walled tubes. The results showed that the bending of thin-walled tubes is affected by both the thickness and the diameter of the tube. The study also suggested that the bending of thin-walled tubes can be improved by using a combination of roll bending and forming. This is an effective method for improving the bending process of thin-walled tubes.}

3 - The authors analyzed the effects of roll bending on the bending of thin-walled tubes and concluded that the bending of thin-walled tubes is significantly affected by the thickness and the diameter of the tube. The study also showed that the bending of thin-walled tubes can be improved by using a combination of roll bending and forming. This is an effective method for improving the bending process of thin-walled tubes.

4 - The authors studied the effect of roll bending on the bending of thin-walled tubes and found that the bending of thin-walled tubes is significantly affected by the thickness and the diameter of the tube. The study also showed that the bending of thin-walled tubes can be improved by using a combination of roll bending and forming. This is an effective method for improving the bending process of thin-walled tubes.

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