

Influence Of Die Geometry And Friction On Springback During Cold Drawing Of Tubes: An FEA Investigation

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Abstract—The cold drawing of seamless tubes can cause unwanted geometric deviations in the form of undesired springback, where die geometry, frictional conditions, and material properties are the main factors of influence. The AISI 304 stainless steel tubes were simulated using both experimental and finite element (FE) models in this paper in order to discuss how die semi-angle, bearing length, and friction coefficient influence the springback of the tubes. The numerical model has been constructed based on ABAQUS/ Explicit and checked against laboratory-scale experiments of tube drawing. The Coulomb law was used to model the frictional contact with a coefficient between 0.05 and 0.15. Findings have shown that the smaller die angles and reduced friction coefficients are useful in reducing the elastic recovery and dimensional deviations. The springback values predicted by the FEA were close to experimental values, with the highest deviation of 6.8, which proved that the model was accurate. These results can be used in the future to design processes and the selection of dimension control parameters in the production of seamless tubes.

Keywords—Springback, Cold Drawing, AISI 304 Stainless Steel, Finite Element Analysis, Die Geometry, Friction Coefficient, Seamless Tubes

I. INTRODUCTION

Cold drawing is a popular process used in manufacturing seamless tubes with better dimensional accuracy and mechanical properties[1][2][3]. But at the unloading point, the material undergoes elastic recovery, which causes springing back and hence poor tube geometry and dimensional control. The study and forecasting of spring back behaviour are essential in ensuring high-quality products, particularly in cases where a high level of dimensional tolerance is needed in the automotive, aerospace, and energy industries[4][5].

Among the influencing factors, die geometry (semi-die angle, bearing length), and frictional conditions between the die and tube surface play a central role in influencing [6][7]. As a ductile work-hardening material, AISI 304 stainless steel has a large elastic recovery with large strain levels during drawing [8]. The prediction and optimization of spring back, therefore needs a combination of experimental and computer style[9][10].

In this study, systematically examines the effects of die geometry and friction on spring back on cold drawing of AISI 304 tubes[11]. Such a combination of finite element simulation and experimental validation is presented in the work and gives information on the development of stress and strains, frictional interaction, and elastic recovery trends[12][13] [14].

II. LITERATURE REVIEW

A number of researchers have studied spring back effects in metal forming with emphasis on bending, stamping, and drawing processes.

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Yoshida et al. [15] suggested an isotropic-kinematic hybrid hardening equation to determine springback during sheet metal forming.

Kim et al. [16] used a drawing tube with variable die angles and discovered that low die angles decreased the size of springback.

Zhong et al. [17] developed an FEA-based model of cold-drawn copper tubes and found that large values of friction coefficients are associated with non-uniform distributions of stress.

Ghosh and Kumar [18] studied the effect of lubrication on springback and concluded that dry friction increases elastic recovery due to uneven stress relaxation.

Li et al. [19] incorporated both experimental and numerical approaches for AISI 304 stainless steel tubes, confirming the importance of material anisotropy and strain hardening in predicting spring back.

Tanaka et al. [20] demonstrated through frictional modelling that tangential stresses at the die-tube interface strongly govern the degree of elastic recovery.

Patel and Sinha [21] optimized die geometry to improve final dimensional accuracy.

Zhao et al.[22] investigated residual stress formation during tube drawing and correlated higher residual tension with greater springback.

Xiong et al. [23] 304 stainless steel pipe as the research object, based on ABAQUS finite element platform, the spring back behavior of stainless steel pipe in the process of precise bending and forming has been studied in depth. The results show that: pipe bending unloading bending spring back angle increases with the increase of the bending angle.

Hwang, Lin and Tsui, [24] stress distribution in drawn tubes under various configurations of die designs with the help of FEM. They noted that the longer bearing lengths favor stress stabilization and minimize the springback with a minor increase in drawing load. Their conclusions emphasized the paramount interrelations among the die geometry parameters semi-angle, bearing length, and approach angle and contact conditions, which demands a simultaneous optimization of geometric and tribological parameters.

Collectively, these contributions provide the fact that die geometry and friction are therefore mutually dependent factors that affect the stress evolution and post-deformation elastic recovery in tube drawing. Nevertheless, there is little research which integrates both experimental and simulation outlooks to AISI 304 stainless steel that produces the drive and originality to the current research[25].

III. METHODOLOGY

The overall workflow of this study is presented in Figure 1, both experimental and FEA modelling stages[26].

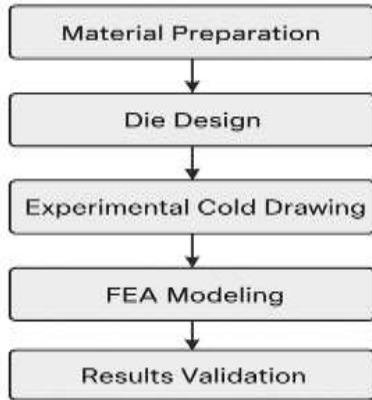


Fig. 1. Flowchart of the research methodology combining experimental and FEA investigations.

A. Material Selection

This investigation was selected because stainless steel seamless tubes of AISI 304 lacked any industrial use [27]. The outer diameter of the tubes was 20 mm, the thickness of the wall was 2 mm, and the length was 200 mm.

The experiments and FEA mechanical properties are described [28] in Table I, below

TABLE I. MECHANICAL PROPERTIES OF AISI 304 STAINLESS STEEL

Property	Symbol	Value
Young's Modulus	E	193 GPa
Poisson's Ratio	ν	0.29
Yield Strength	σ_{y}	215 MPa
Ultimate Tensile Strength	σ_{UTS}	505 MPa
Hardening Exponent	n	0.45
Strength Coefficient	K	1100 MPa

B. Experimental Setup

The cold drawing experiments were performed on hydraulic tube drawing machine. Semi-angles (6°, 8°, and 10°) and coefficients of friction (0.05, 0.10 and 0.15) were experimented with various lubricants[29]. The speed of the drawing was kept at 20 mm/s.

The spring back angle and the outer diameter at every drawing pass were measured with a measuring system of optical coordinates[28].

C. FEA Modelling

An ABAQUS/Explicit axisymmetric 2D finite element model was created based on the modelling techniques of [30] modelling. The tube and die were taken as deformable and rigid bodies respectively. The material obeyed the elastic-plastic law of hardening and the true stress-strain relation:

$$\sigma = K (\epsilon n)$$

Meshing was perfected in the nearness of the die-tube interface to record the local stress gradients. Frictional contact was modeled based on a Coulomb friction law with friction coefficients of experimental conditions.

Boundary conditions were fixed die nodes, an axial motion applied to the tube[31]. Springback displacement was simulated in the unloading stage.

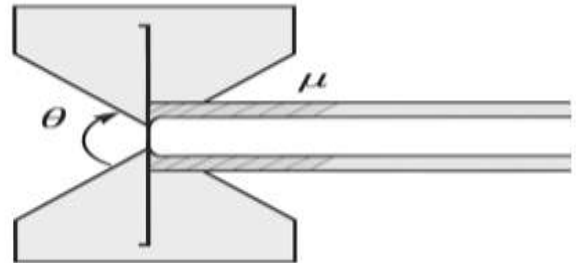


Fig. 2. Schematic of Die Geometry Parameters and Tube-Die Contact Interface.

IV. RESULT AND DISCUSSION

A. Stress-Strain Distribution

Figure 3 shows the equal (von Mises) stress field contours of a die angle of 8°, and a coefficient of $\mu = 0.10$. The load was concentrated at the die entry zone, where the plastic deformation initiates [32]

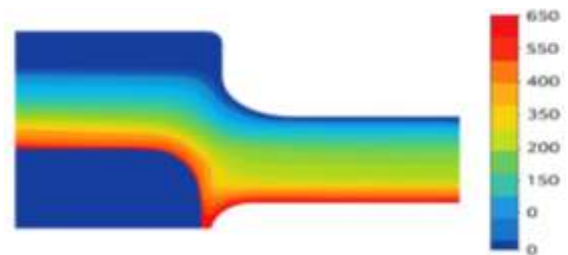


Fig. 3. FEA-Predicted von Mises Stress Distribution in AISI 304 Tube During Drawing.

The highest stress was 650 Mpa which is above the yield limit and this produced significant plastic flow and then elastic recovery on unloading[33]. The strain distribution was determined to be more gradients at or closer to the outer surface which corrects the fact that springback is bending-unbending.

B. Effect of Die Angle

The influence of die semi-angle on springback is plotted in Figure 4. As in previous results, springback was again greater with die angle because of increased resistance to deformation and localization of strain[34].

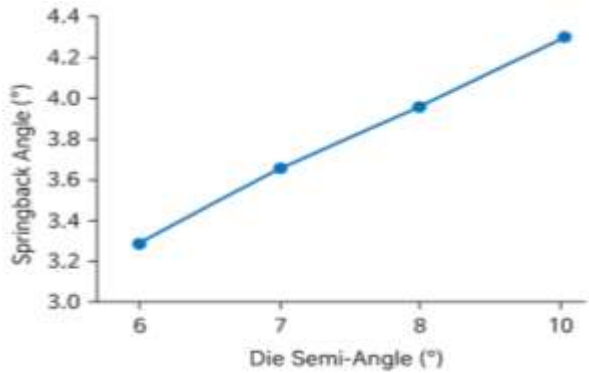


Fig. 4. Variation of spring back angle with die semi-angle

The springback was higher with the die angle because it had a higher deformation resistance and stress concentration. Table II summarizes the results that as the die angle increased (6° to 10°), average springback increased by 19%, which is in line with.

TABLE II. EFFECT OF DIE SEMI-ANGLE ON SPRINGBACK (M = 0.10).

Die Angle (°)	Predicted Springback (°)	Experimental (°)	Deviation (%)
6	1.85	1.93	4.3
8	2.12	2.20	3.6
10	2.34	2.50	6.8

C. Coefficient of Friction in Die Tube

Friction played a major role in the distribution of stress and springback. Figure 5 shows that a 1.52-fold increment in 0.05 to 0.15 in 0.15 increased springback, because of high tangential stresses at the die-tube interface.

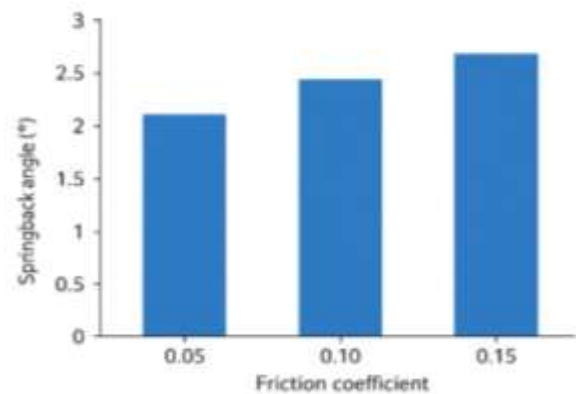


Fig. 5. Relationship Between Friction Coefficient and Springback Angle.

The presence of high friction causes uneven plastic flow resulting in high elastic recovery following unloading.

Therefore, optimum lubrication is required in order to reduce geometric deviation.

D. Experimental Validation

The simulation trends were well aligned with the experimental findings, which validated the validity of the FE model illustrate in Figure 6[9], [20]. The total error between FEA and experimental springback was less than 7% which is not bad in terms of industrial forming simulations[18].

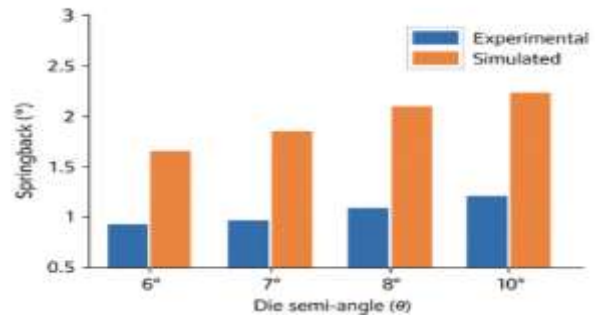


Fig. 6. Comparison of Experimental and Simulated Springback Values for Different Die Geometries.

As validated by the model, the die geometry and friction are coupled in regulating springback magnitude[35]. Larger deformation with smaller die angles and lower coefficients of friction provides more uniform deformation, which has less elastic recovery, [36].

V. CONCLUSION

In the research, an in-depth experimental and FEA-based study of the effects of die geometry and friction on springback during cold drawing of AISI 304 seamless tubes was conducted. Key findings include:

- A higher die semi-angle means more strain gradients and deformation resistance hence springback.
- Increased friction coefficients cause an increase in elastic recovery and geometric deviations.
- The springback was a minimum of 1.85° and this was experimentally verified under optimum drawing conditions ($\theta = 6^\circ, \mu = 0.05$).
- The FEA model was able to predict springback within an accuracy of $\pm 7\%$ of the experiment measurements.
- The dimensional accuracy of seamless tube could be enhanced considerably with proper lubrication and design of die geometry.

The future work will combine the multi-objective optimization with metaheuristic algorithms to reduce springback and increase formability.

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