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Springback Behavior of AA6082T6 Tubes in Three-point Bending Operation

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Abstract

Springback is an inevitable phenomenon in bending operations. For the geometrical accuracy in manufacturing, springback should be predicted and a required compensation should be applied to the operation. The numerical method is a very popular approach to predict the behavior of material in the operations. This method provides the reduction in time, effort and costs in comparison with the trial and error method. In this study, springback in the three-point bending operation of AA6082T6 tubes is investigated. A numerical model is established, and results are compared with experimental outputs for verification of the model. Effects of the indenter travel distance and a wall thickness of a tube in springback are studied.

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Keywords: three-point bending; aluminum tube; springback

1. Introduction

Bending is widely performed as a manufacturing operation in the industry. There are different kinds of bending operations such as V-die bending, air bending, U-bending, wipe bending and rotary bending. For tube products, operations such as rotary draw bending and push bending are mainly preferred. Although, three-point bending does not act as a manufacturing operation for tubes in common industry, this paper investigates the springback behavior of tube products under three-point bending conditions.

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Springback is defined as undesirable change in product shape which takes place upon removal of the constraints after forming. This dimensional change is seen during the unloading by the effect of elastic recovery of the material. In other words, springback describes the shape change after release of tooling [1–3]. Magnitude of springback is related to the ratio between the residual stress and the elastic modulus of the material. For the aluminum products, springback phenomenon is highly troublesome due to low elastic modulus of the material. However, aluminum is extensively used in industries such as automotive and aerospace. Therefore, springback is important and should be accurately predicted in manufacturing operations. Factors such as material thickness, bend radius, tooling geometry, friction have significant influences on springback phenomenon [4, 5].

There are many studies investigating bending and springback phenomenon in the literature. Most of them focus on main parameters affecting springback. On the other hand, numerical studies are common to predict the response of different materials in the bending operations. Some studies intend to improve numerical modeling by comparing the experimental results. Palanisway et al. [6] studied optimization of blank dimension to minimize the springback angle. Gan et al. [7] investigated tool design to compensate the springback effect. Cheng et al. [1] proposed a compensation method which is called “accelerated springback compensation method”. In this method, it is stated that required iteration steps are decreased with respect to the other methods. Wagoner et al. [8] studied the effects of material properties numerically. It is noted that mechanical properties implemented in the numerical model should be reliable to obtain accurate solutions. Oliveira et al. [9] investigated the work hardening in springback prediction. Esat et al. [10] studied the process parameters influencing the springback in bending. Livatyali et al. [11, 12] developed a design method for springback and numerical springback predictions are verified by experimental results. Zhan et al. [13] investigated springback phenomenon in tube bending by proposing numerical-analytical method. Stelson et al. [3] studied springback of thin walled tubes in cyclic loading of rotary draw bending. It is stated that successive loadings decrease the springback in comparison with the full loading in the operation. Al-Qureshi et al. [14, 15] studied analytical method to predict springback and residual stress distribution in thin-walled aluminum tubes. Analytical results are compared with experimental results and good agreement is obtained. Gu et al. [16] investigated the springback phenomenon of thin-walled tubes in NC precision bending operation. It is stated that numerical simulations can be performed to predict the springback and observe the effect of process parameters. Jiang et al. [17] studied the effect of grain size on springback phenomenon of micro tubes in press bending operation.

This paper deals with springback behavior of AA6082T6 tubes in three-point bending operation. Two variable parameters are selected as wall thickness of tube and indenter travel distance. Bending operation of 2 mm wall thickness tube is performed experimentally by using the indenter travel distance of 60 mm. The experimental results are compared with the numerical results for the verification of the numerical model. Then, effects of parameters are investigated by numerical analyses.

2. Materials and method

In the experimental study, AA6082T6 tubes are investigated. Chemical composition of AA6082T6 tubes purchased from Altek Metal Co. Inc. is shown in Table 1. The tubes have outer diameter of 30 mm, wall thickness of 2 mm and length of 300 mm. Tensile testing is applied with a constant speed of 0.2 mm/s to obtain the mechanical properties of the material. Fig. 1 shows the stress-strain curve of AA6082T6 material. Three-point bending test is applied to an AA6082T6 tube with indenter travel distance of 60 mm to verify the numerical model with experimental results. In three-point bending test, the distance between the 30 mm diameter supports is set as 200 mm and the indenter geometry is selected as hemi-cylinder with diameter of 30 mm. Indenter speed is fixed at 0.2 mm/s by using a servo-hydraulic dynamic Instron 5985 testing machine.

Table 1. Chemical composition of AA6082 tubes.

Elements (weight %)											
Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ga	V	Al
1.02	0.31	0.01	0.48	0.84	0.003	0.002	0.002	0.013	0.017	0.01	Bal.

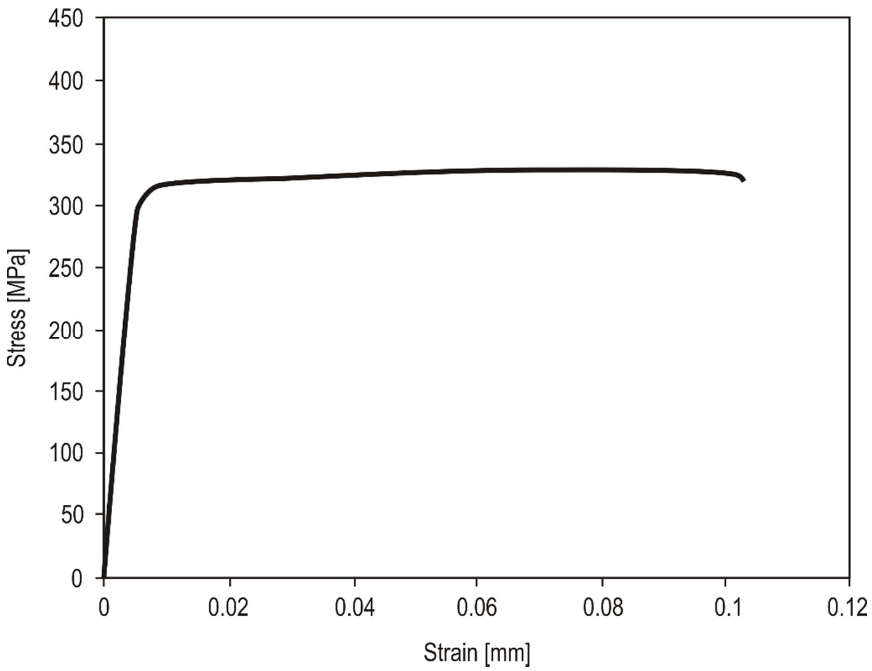

Fig. 1. Engineering stress–strain curve of AA6082T6.

In the numerical study, simulations are performed by Ls-Dyna. Explicit integration scheme is applied for general solution and then springback simulation is performed by using implicit integration scheme. AA6082T6 tube is modeled by using fully integrated shell elements which improve in-plane bending behavior. Material model of AA6082T6 is decided as isotropic plasticity with power law hardening rule ($\sigma=K.\varepsilon^n$) according to the tensile testing data. Mechanical properties of AA6082T6 tube are given in Table 2.

Table 2. Mechanical properties of AA6082T6 tube.

ρ (kg/m^3)	E (MPa)	ν	K (MPa)	n
2700	70000	0.30	343.16	0.017

In the modeling, finer mesh size is used for the deformation zone and therefore, average mesh size for mid-portion of the tube is used as 1.5 mm where the deformation is extreme. Portions in the vicinity of contact points with the supports are meshed by 2.3 mm size. Remaining portions of the tube are meshed by coarser size due to the time expense during the run. Tools (supports and indenter) are modeled as rigid and Belytschko-Tsay shell elements are applied. Uniform size of 2.3 mm is used for tool meshes. Adaptive remeshing option is enabled to increase the accuracy of the simulations. The supports are fixed at their locations and the tube is freely located on the supports. The indenter is moved in the down direction and the other directions are constrained for it. Numerical model of the operation is seen in Fig. 2.

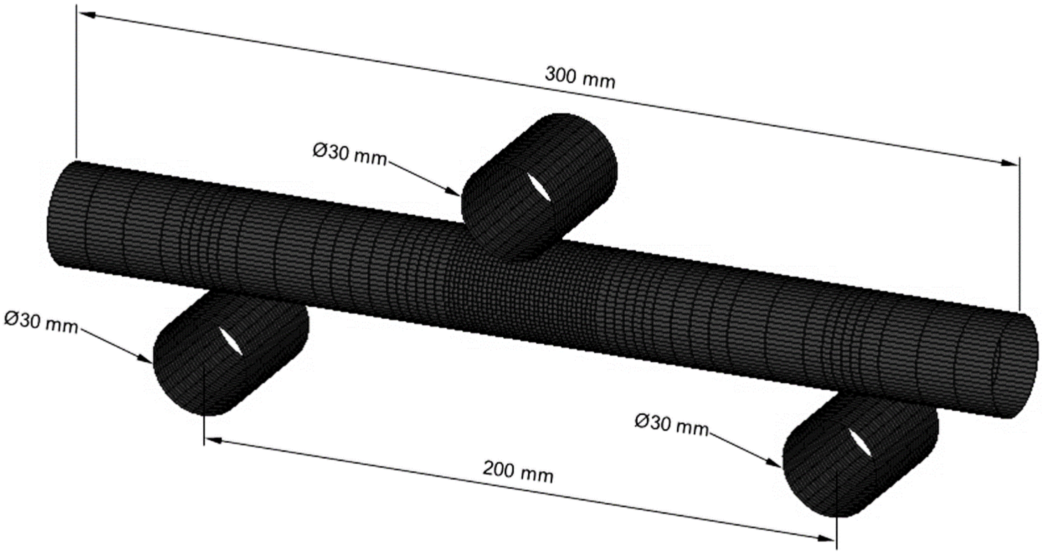

Fig. 2. Numerical model of the three-point bending operation.

In the numerical study, simulations are performed for tubes with two different wall thicknesses subjected to indenter travel of three different distances. Table 3 shows the design of the simulations according the variable parameters.

Table 3. Design of the simulations.

Run	Wall thickness	Indenter travel distance
1	−1	−1
2	−1	0
3	−1	+1
4	+1	−1
5	+1	0
6	+1	+1

Wall thickness: −1: 2 mm; +1: 4 mm
Indenter travel distance: −1: 20 mm; 0: 40 mm; +1: 60 mm

3. Results and discussion

Experimental and numerical results are compared in the verification of the simulation. Therefore, the case exhibiting the three-point bending of tube with 2 mm wall thickness subjected to 60 mm indenter travel distance is used. Springback is defined as the difference between the bending angle before and after release of the indenter force at the end of the bending process. The bending angles are measured using the simulation software in the numerical model. In the experimental results, photos are imported a computer aided design software and the bending angles are measured using the measurement tools in the software. Springback results are given in Table 4 and the images are shown in Fig. 3. It is seen that springback in simulation is quite close to the experimental result. The difference compared to the real behavior is 0.09°. It is also seen in the results that bending area of the tube is excessively deformed as the indenter travel distance increases. It is common to obtain flattened cross-section after the bending of tubes. For this reason, internal mandrel is required to avoid this kind of collapsing in the forming operations of hollow tubes.

Mandrels are generally made of flexible materials such as elastomer [14]. In this testing, there is no internal mandrel used and therefore, excessive collapsing is observed on the top surface of the tube.

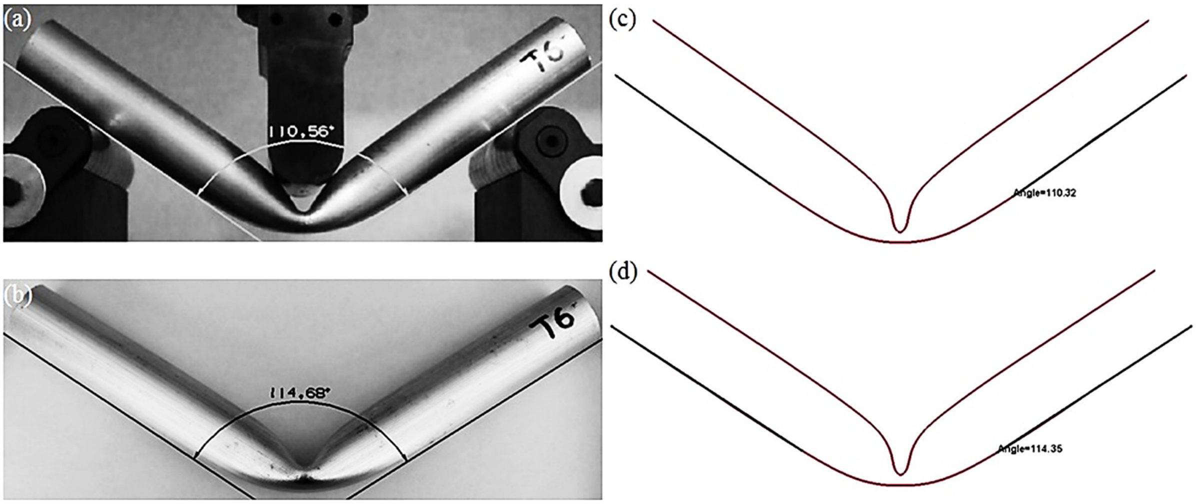

Fig. 3. Bending angles for springback (a-b) in experiments and (c-d) in simulations.

Table 4. Experimental and simulation results.

	Before	After	Springback
Experiment	110.56°	114.68°	4.12°
Simulation	110.32°	114.35°	4.03°

In the three-point bending of tubes with different wall thicknesses, it is seen that springback angle increases as the wall thickness of the tube reduces. For example, for the simulation with indenter travel distance of 20 mm, springback angle is 2.89° in 2 mm thickness tube and 1.84° in 4 mm thickness tube. Indenter travel distance is another factor in springback behavior of the tubes. This distance directly affects the bending amount of the tube and it can be said that bending is increased as the indenter travel distance increases. Simulation results show that springback angle exhibits an accelerated trend as the indenter travel distance increases. Bending and springback angle of the tubes are given in Table 5 and Fig. 4 shows the relation of springback angle with wall thickness of tube and indenter travel distance in the three-point bending testing.

Table 5. Simulation results of three-point bending test.

Indenter	Wall thickness of 2 mm			Wall thickness of 4 mm		
travel distance	Before	After	Springback	Before	After	Springback
20 mm	164.89°	167.78°	2.89°	160.10°	161.94°	1.84°
40 mm	136.20°	139.28°	3.08°	131.91°	134.10°	2.19°
60 mm	110.32°	114.35°	4.03°	106.20°	108.84°	2.64°

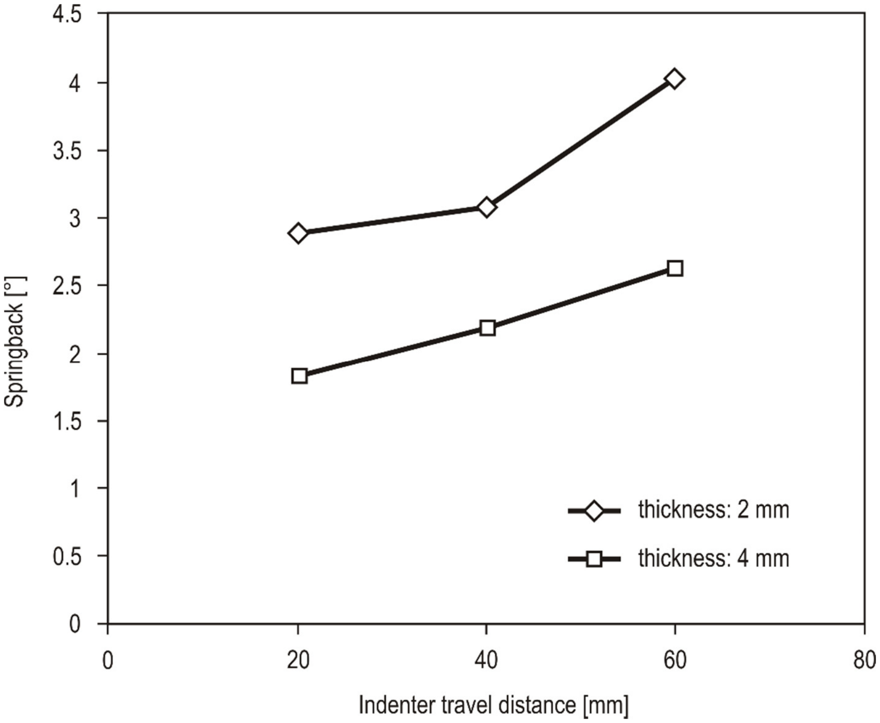

Fig. 4. Relation of springback angle with wall thickness of tube and indenter travel distance.

4. Conclusion

This study investigated the springback behavior of the AA6082T6 tubes in three-point bending operation. In the verification of the numerical model, springback angles in experiment and simulations are compared. It is observed that simulation results are in a good agreement with experimental results. The investigated parameters; indenter travel distance and wall thickness of tube are investigated to obtain their effects on springback. Results show that in increased bending conditions springback is more significant. In other words, as the indenter travel distance increases impact of the springback accelerates. On the other hand, springback becomes more severe when wall thickness of the tube increases. Therefore, in three-point bending operations of thicker wall AA6082T6 tubes under excessive bending conditions, springback compensation is more important. For the final shape of the product, compensations should be taken into account therefore, geometrical accuracy can be acquired.

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