Inversion of Aluminium Tube under Conical Die by Using FE Technique

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Abstract — *Finite element modelling has been used to study the effect of conical die angle, tube diameter and material behavior both external and internal inversion for aluminum tube. 3D finite element model was used to build the contact pair for the aluminum tube and the conical die. Due to the axial symmetry a 45^o sector for the contact pair has been chosen. It has been found that there is a significant role for conical die angle to govern the inversion process and the mode of deformation beside the value of the applied force. A local buckling takes place in the internal inversion for all half die angles.*

Keywords — *conical die, inversion, finite element, metal tube*

I. INTRODUCTION

One of advanced forming process for thin walled parts is tube inversion by using conical die. Such cold operation becomes a significant part in plastic forming technology. One of the most important parameters that govern the inversion process and determine the behavior of the free deformation is the half angle of conical die.

Therefore, the understanding the influences of the angle die on the inversion process and the deformation behavior for the application of this process. The plastic energy absorption behavior of expansion tubes under axial compression by a conical–cylindrical die has been investigated. Experiments and numerical simulation using FEM are presented in this study. Experiments were conducted on circular 5A06 aluminum tubes with an internal radius fixed at 22.5 mm and different thicknesses between 1 and 5 mm; the tubes were pressed axially onto a series of conical–cylindrical dies each with a different semi-angle from 5° to 20°, where the radius of the cylindrical part was 24 mm [1] .Based on a mechanical model, the mechanism of free deformation and characteristic behavior of forming mode are investigated by a FE system combined with analytical analysis, which permits the condition to realize change in forming mode and inversion to be determined. The results show that for the given tube blank there exists a critical die conical angle αcr, above which the tube will curl to form a double-walled tube; αcr is determined mainly by the tube material parameters, while the geometric parameters have very little effect; the larger the material hardening exponent the smaller the α_{cr} value [2].

An attempt has been made to resolve an apparent anomaly between theoretical predictions and experimental observations on the natural knuckle radius during external inversion of tubes. A rigid, linear strain-hardening material model is used. The Tresca yield condition and associated flow rules along with a kinematic hardening law are employed. Analytical results show good agreement between predicted and experimentally observed values of the critical knuckle radius.

It is found that the strain-hardening parameter which provides the best agreement with the experimental data depends on the magnitude of the strain and hence the geometry of the tube. The calculated inversion loads are seen to agree better with the observed values than those from an earlier analysis [3]..

An elasto-plastic finite element method was used to simulate and analyze inside-out inversion. The objective is to examine how different process factors, such as the geometry and material modulus, influence metal tube inversion. This study also simulates a quarter fillet radius of the die to analyze the tube forming condition and range that can be applied in engineering under these requirements. In addition, the axial compression load under inside-out inversion stability to be suitable for a personal computer, so it can be effectively analyzed and evaluated on line instantaneously [4].

The metal tube with thin-wall pushed against a hard die that have convenient fillet radius, it may then make the tube flow in inverse directions. The large plastic deformation involved in tube inversion occurrence to ductile materials, such as steels and aluminum alloys. The notion of tube inversion can be extended if properties, mechanical behavior and deformation are entirely understood and so many engineering applications can be made depends on this concept especially in safety devices [5].

This paper reviews the common shapes of collapsible energy absorbers and the different modes of deformation of the most common ones. Common shapes include circular tubes, square tubes, frusta, struts, honeycombs, and sandwich plates.

Common modes of formation for circular tubes include axial crushing, lateral indentation, lateral flattening, inversion and splitting. Non-collapsible systems, such as lead extrusions or tube expansions, are considered to be beyond the scope of this review [6].

Nowadays, various applications on tube inversion idea have been done such as cushioning air drop cargo, helicopter seats, force actuating collapsible steering wheels, and soft landing of spacecraft.

An experimental investigation on the rate of impact absorption of metal tubes under quasi-static loading was performed [7]. A classification chart has been conducted that enable estimation on the impact energy absorbing characteristics and collapse mode for specific aluminum alloy tubes.

The aim of this study is to investigate the influence of half die angle, tube diameter and material behavior (elastic-plastic and rigid-perfectly plastic) on the load force in both internal and external inversion of aluminum alloy (Al6061).

II. Deformation mechanism

Figure 1 shows a typical tube inversion process by conical die, in which a thin –walled tube, axially compressed over the die, transforms from zone ab into three zones bc, cd, and de, in order. the process may be developed further to produce inside-out inverting-forming and to obtain a complicated part such as the double-walled tube on the right in fig 1, etc. as shown in fig 1 *p* is forming load, α is half angle of conical die, d_o and t_o are initial diameter and thickness of tube blank, respectively, Δd is the gap of double –walled tube formed. In the process, the tube blank can be divided into three zones such as pre-deforming zone, deforming zone, and deformed zone. Clearly the free exists a free deformation zone and the behavior of the free deformation has an essential effect on the shape and dimension, the precision degree of the product obtained by the process, and the advantages of the process.

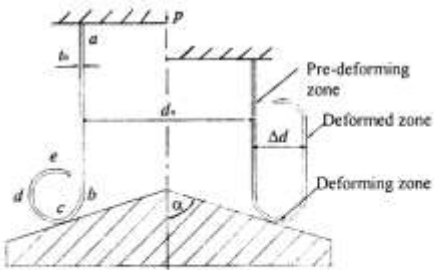

Fig. 1 A sketch of tube inversion process by conical die

During tube inversion forming process the forming load p and the shape of free deformation zone can be described as the function of forming parameters as follows:

$$p = f(to, do, \alpha, n, \bar{r}) \qquad (1)$$

$$\emptyset = \emptyset((to, do, \alpha, n, \bar{r}) \qquad (2)$$

Where μ is the frictional coefficient of contact surfaces $\bar{\mathbf{r}}$ and n are the index of normal anisotropy and strain hardening of the tube material respectively [8].

III. Simulation work

A 3D finite element model has been built using a 45° sector due to the axial symmetry of tube shape, load, and friction condition (figure2.).The simulation has been done by ANSYS Software. 595520 solid elements and contact technique have been used. Nonlinear solutions for multilinear and bilinear isotropic material have been chosen to represent the material behavior during inversion process. Symmetrical boundary condition was used to simulate other sectors. The predicted load multiplied by 8 to get the total value.

An external and internal inversion operation have been performed for aluminum tube with 70 mm long, wall 1.5mm

The investigation has been conducted of the following:

A. Elastic -Plastic Material Behaviour

1) ***External inversion for nine half die angles*** : 60°, 62.5°, 65°, 67.5°, 70°, 72.5°, 75°, 77.5°, 80°, were examined with 21 mm inner tube radius.

2) ***Internal inversion by three different half die angles:***
60°, 65°, and 70° have been chosen.

3) ***External inversion by three different half die angles***:
60°, 65°, and 70° have been chosen with six different tube diameter:24, 30, 35, 42, 47, 52, and 57 mm.

B. Rigid Perfectly Plastic Material Behaviour:

External inversion for nine half die angles: 60°, 62.5°, 65°, 67.5°, 70°, 72.5°, 75°, 77.5°, 80°, were examined with 21 mm inner tube radius.

Fig.2 3D FE Model

IV. Results

A 3D FE simulation has been performed for tube inversion process with different conditions using ANSYS code. The deforming force and double-walled gap Δd are obtained to investigate of half die angle and tube diameter on the inversion process. Two types of material behavior (elastic-plastic and rigid-perfectly plastic) of Al 6061 tube with 42mm diameter and 1.5 mm wall thickness are used. Table

1shows the material properties. The predict results are shown in table 2 and figure 3.

Table 1
Material properties of Al 6061

Modulus of elasticity N/mm^2	**Yield strength MPa**	**Poisson's ratio**
68950	275.8	0.3

Table 2
Predicted results for elastic-plastic material

No.	**d_o mm**	**α degree**	**Δd mm**	**Force kN**
1	42	60	6.5	37.028
2	42	62.5	5.97	37.517
3	42	65	5.6	38.636
4	42	67.5	5.1	38.515
5	42	70	5	38.86
6	42	72.5	4.8	40.161
7	42	75	4.6	40.704
8	42	77.5	4.4	41.741
9	42	80	4.2	43.164

Table 3
Predicted Results For Rigid Perfectly-Plastic Material

No.	**d_o mm**	**α degree**	**Δd mm**	**Force kN**
1	42	42	6.48	33.3252
2	42	42	5.89	33.7653
3	42	42	5.58	34.7724
4	42	42	5	34.6635
5	42	42	4.93	34.974
6	42	42	4.75	36.1449
7	42	42	4.55	36.6336
8	42	42	4.37	37.5669
9	42	42	4.1	38.8476

A) External inversion

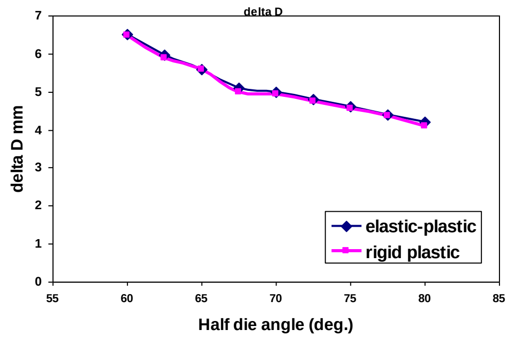

Fig. 3 Double –walled tube gap δd vs the half die angle

Figure 3 shows results of the double –walled tube gap Δd and the half die angle it can seen th3at Δd decreases with increase of half die angle α for both elastic-plastic. and rigid plastic material behaviors, the values of Δd for both materials are almost identical, it means that the material behavior or parameter has little role on the double-walled gap.

Figure 4 shows the relationship between half die angle and forming load. It can be seen that the forming load increase with increase the half die angle (in contrast to what stated in the reference [8]) for both elastic-plastic and rigid plastic material behaviors i. The forming load with rigid plastic material is less than elastic-plastic material; it means that the material behavior or parameter has an influence on the forming load.

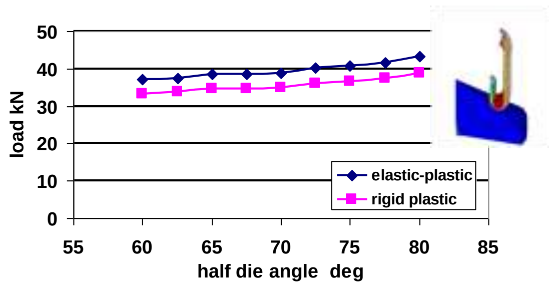

Fig.4 Half die angle vs forming load

Figure 5 shows the relationship between tube diameter and forming load for three different half die angles. It is clear that the tube diameter has a big influence on the forming load, where the forming load increases with increase tube diameter for all different half die angles. A local buckling takes place at tube diameters more than 52mm for all half die angles, and for half angle 60^o (and less) at tube diameters less than 36 mm.

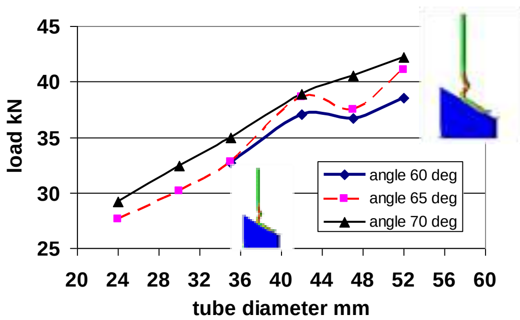

Fig.5 Tube diameter vs forming load for three different half die angles

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