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EFFECT ON FINITE ELEMENT SIMULATION OF TUBE HYDROFORMING PROCESS

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Abstract: - *Hydroforming process may be defined as a metal forming technology using hydraulic or fluid pressure to deform the tubes and sheet. Increasing use of hydroforming in automotive applications requires intensive research and development on all aspects of this relatively new technology to satisfy an ever-increasing demand by the industry. Tube hydroforming process and sheet hydroforming process are some variations of hydroforming process. Tube hydroforming is one of the most popular unconventional metal forming processes which is widely used to form various tubular components. By this process, tubes are formed into different shapes using internal pressure and axial compressive loads simultaneously to force a tubular blank to conform to the shape of a given die cavity. In this work, FE simulations of Tube Hydroforming Process are performed and effects of various geometrical and process parameters are analyzed. Pure Aluminium is used for simulation of T-shape hydro forming process. Effect of axial punch velocity, friction and different die fillet radii on strain is studied. Parameters like, maximum strain regions are simulated to judge whether the protruded tube is allowable for industrial and commercial use.*

Keywords: *internal pressure, axial component, hydroforming process, maximum strain, equivalent strain*

I. Introduction

Hydroforming processes have become popular in recent years, due to the increasing demands for lightweight parts in various fields, such as bicycle, automotive, aircraft and aerospace industries [1]. This technology is relatively new as compared with rolling, forging or stamping, therefore there is not much knowledge available for the product or process designers. Compared to conventional manufacturing like stamping and welding, Tube Hydroforming Process (THF) and Sheet Hydroforming Process (SHF) offers several advantages, such as decrease in work piece cost, tool cost and product weight, improvement of structural stability and increase of the strength and stiffness of the formed parts, more uniform thickness distribution, fewer secondary operations, better surface finish etc. [2]. hydroforming process uses fluid pressure in place of the punch as comparing with a conventional tool set to form the component into the desired shape of the die. Generally, hydroforming processes can be classified as tube or sheet hydroforming depending on the initial shape of work-piece. In the tube hydroforming process (THP), the initial work-piece is placed into a die cavity, which corresponds to the final shape of the component. Next, the dies are closed under the force and the tube is internally pressurized by a liquid medium to effect the expansion of the component (internal pressure) and axially compressed by sealing punches to force material into the die cavity (axial force). Hence the component is formed under the simultaneously controlled action of internal pressure and axial force. [3]

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II. MATERIAL OF THF PROCESS AND FORMABILITY

The overall success of hydroforming product heavily depends on the incoming tubular material properties. Material properties such as composition, weld type, yield and tensile strength, ductility, anisotropy must be determined for tubes [4]. Followings are the required characteristics of tubular materials for quality THF applications:

- High and uniform elongation
- High strain-hardening exponent
- Low anisotropy
- Close mechanical and surface properties of weld line to the base material
- Good surface quality, free of scratches
- Close dimensional tolerances (thickness, diameter and shape)
- Burr free ends; ends should be brushed
- Tube edges perpendicular to the longitudinal axis.

III. INTRODUCTION TO FINITE ELEMENT MODELLING

The finite element method (FEM) is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points. The response of the mathematical model is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements. The disconnection-assembly concept occurs naturally when examining many artificial and natural systems. For example, it is easy to visualize an engine, bridge, building, airplane, or skeleton as fabricated from simpler components. Unlike finite difference models, finite elements do not overlap in space.

Rheology is the study of the flow of matter, primarily in the liquid state, but also as 'soft solids' or solids under conditions in which they respond with plastic flow rather than deforming elastically in response to an applied force.
Theoretical aspects of rheology are the relation of the flow/deformation behavior of material and its internal structure (e.g., the orientation and elongation of polymer molecules), and the flow/deformation behavior of materials that cannot be described by classical fluid mechanics or elasticity.

IV. Effect of Friction and Lubrication on Process Output

A Due to high contact pressure and large contact surfaces in the tube hydroforming process, high frictional forces exist between the tubes and die. These forces affect not only the required process parameters for a specified hydro formed part but also affect its quality, such as its wall thickness distribution. The knowledge of coefficient of friction is essential in the THF process analysis. Some of the tests for determining coefficient of friction in THF process are push through test. In this test a tube is subjected to internal pressure is pushed through a die.

The friction force is calculated as the difference between the forces measured at the both punches. The friction force is calculated as the difference between the forces measured at the both punches [5].

Lubrication use is very important in the successful hydroforming as good lubrication conditions allow a tube to reach its final desired expansion and shape in the die, whereas poor lubrication often results in premature failure, due to excessive local thinning. Using lubrication was found to decrease wall thickness differences between bulged and non-bulged regions. [6]. Effect of lubrication on the bulge shape was reported in the axis-symmetric and asymmetric hydroforming. Bulged dome was more pronounced if there was no lubricant between the

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tube and the die where as a flatter dome was achieved with lubricants in the interface [7].

From the friction attitude, hydro formed component can be divided into three different zones:

- Guided
- Transition and
- Expansion

Due to the difference in the material flow and the state of stress, the three zones are exposed to different tribological conditions.

In the guiding zone, due to the high values of the relative velocity at the die/tube interface, different types of lubrication can be efficiently used to lower the interface friction.

In the transition and expansion zones, the relative velocity at the die/tube interface drops, and the interface friction increases, meanwhile, high forming pressure causes the conventional lubricants to break down. Therefore, dry film lubrication is more appropriate for these zones, especially when protruding high bulges as it follows the surface expansion without breaking down. The relation between the coefficient of friction and both of the lubricant viscosity and surface roughness was investigated [8]. Test results showed that friction coefficient was high when surface roughness is extremely low or high, while lubricant viscosity was found inversely proportional to the friction coefficient value. The effects of the internal pressure and the axial feeding velocity on the friction forces and coefficients of friction were discussed. A higher pressure was found to decrease the coefficient of friction whereas the effect of feeding velocity on coefficient of friction value was found insignificant.

V. Effect of geometrical factors on the process output

Geometry of the tube and die was observed by different researchers to have an important influence on THF process success. A series of experiments were carried by Hutchinson to explain the limits of the process. Tee pieces and cross joints were formed successfully from various dimensioned sizes of copper tubes. It was concluded that the ratio between the wall thickness and outside diameter gives the extent of the forming range (the lower the ratio, the larger the forming range). The tube diameter effect on formability of the process was investigated for a member with complex section of vehicle bumper rail. In their study it was observed that a remarkable reduction to about one-third in thinning rate and more uniform thickness distribution were reported when bigger diameter tubes were used. Moreover, pre-pressure influence was found more effective when applied to bigger diameter tubes. Based on the finite element modeling of X-branch tube hydroforming, it was observed that with the initial tube length increase, a smaller bulge height was resulted simultaneously with increasing of wall thinning at the branch top and decreasing in wall thinning at the X-junction.

An integration of finite element modeling and design of experiment was conducted to study the influence of geometrical factors on tube hydroforming process. Bulge height was modelled as a function of geometrical parameters and plotted between the protrusion and edge was concluded as the most influential factor as forming of shorter tubes yields higher protrusions than that of longer tubes with less thinning in the protrusions. Effect of die fillet radius on minimum wall thickness was examined in T-shape tube hydroforming. From their study, it was noticed that thinner protrusion tips were resulted from increasing the die corner fillet radius. Hydroforming with different outer layer thicknesses were conducted and maximum bulge height was achieved when the minimum outer layer thickness was used. More recently, the effect of geometrical factors on the bi-layered hydro formed cross junction specifications (bulge height, wall thickness reduction and wrinkle height) was investigated [9].

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VI Effects of material properties on process output

Material properties were found effectively affecting the tube hydroforming process output. However, several tests are used in industry to determine the material properties. The uni-axial tensile test is widely used to determine material parameters and stress-strain relationship. Due to the different stress state encountered in the tensile test (uni-axial stress state) and in tube hydroforming (bi-axial stress state), it is better to use the bi-axial test in order to obtain reliable material parameters and stress-strain relationship.

An experimental research on the effect of the hydroformed material tensile strength was conducted since 1966 that performed tube hydroforming experiments on different materials and concluded that a small increase in tensile strength of the material would lead to a considerable increase in process formability. Assuming that the tube materials obey power law of strain hardening, the influence of strain hardening of the material (n) was conducted. Increasing the strain-hardening exponent was found to lead to a better thickness variation along the rube wall, which indicates a decrease of corner thinning during the expansion of a circular tube into a square die. Bulge forming of finite-length thin walled cylinders was studied using incremental plasticity theory and the effect of strain-hardening exponent (n) on bulge height limits was covered. Longitudinal anisotropy was reported to have a significant effect on thinning ratio and the critical expansion limit while anisotropy in hoop direction was affecting the maximum internal pressure required.

VII. Results and Discussion

In this work, Finite Element Simulations of T-shape Tube Hydroforming Process are done. Various components in THF setup are studied. Various factors affecting the THF process output are reviewed and simulated, like effect of material properties, geometrical factors, process parameters, and friction and lubrication conditions.

FEM simulation of double T-shape hydroforming process is done with A199 under different conditions of frictions, axial punch velocity and different fillet radius. The strain generated, and hence protrusion height achieved in the process is studied.

Table1. FE results for strain during application of various parameters

EQUIVALENT STRAIN GENERATED				
Die fillet radius (mm)	Punch velocity (mm/sec)	High friction	Medium friction	Low friction
2	1	0.6823	0.6497	0.6237
	5	0.6901	0.6582	0.6355
	10	0.6981	0.6741	0.6482
3	1	0.6501	0.6478	0.6206
	5	0.6598	0.6501	0.6289
	10	0.6667	0.6585	0.6361
4	1	0.5996	0.5805	0.5635
	5	0.6001	0.5888	0.5774
	10	0.6024	0.5916	0.5895

VIII. Conclusion

With increase in the fillet radius the strain generated of the tube slightly decreases. Also with increase in axial punch velocity, there observed an increase in strain generated that is calculated and depicted in Table1 above. With no fillet, the desired protrusion shape cannot be achieved. Moreover, high strain gets generated at the transition zone.

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