Investigation of the Effect of Loading Paths in the Tube Hydroforming Process

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***Abstract* - The precise control of internal pressure and axial feeding loading paths important influences the final tube quality. In this research the impact of loading path of the tube hydroforming process and final part requirements (i.e. thickness specification and shape conformation) were studied numerically. Small bulge shape tube hydroforming parts were utilized in the finite element analyses to get several guidelines on the effect of the relation between the internal pressure and axial compressive feeding programs. Two dimension model of bulge shape tube (50 mm) bulge width has been developed from cylindrical tube with thickness (2mm) of the copper and (60 mm) outer diameter. A commercial available finite element program code (ANSYS 11), is used to perform the numerical simulation of the tube hydroforming operation. The results demonstrate that, the loading path has very important influenced on the thickness distribution over the tube and capability attained the target shape of the required product.**

Key words: Tube hydroforming, Process parameters effect, Finite element method.

I. Introduction

The hydroforming operations have found a broad variety of exercises in the metal forming manufacture because of the fact that, with hydroforming, industrialist are able to manufacture the tube with very complicated shape, lightweight and fewer welds than with traditional metal forming processes, reduce cost of tooling, part consolidation on assemblies, very good materials employment, less number of processes, and enhanced part quality are advantages of hydroforming process [1]. In the tube hydroforming process, a tubular blank is shaped in a die cavity through the application of hydraulic internal pressure on the wall tube and axial compressive forces on the both ends of the tube as shown in Fig.1 [1,2]. Since the implementation of tube hydroforming process into mass production is relatively new compared to other metal forming technology for example forging and stamping; existing information base, rules of design, and experience for design of part, process and tooling are limited. As a consequence; for this reason, use of these innovation to novel tubes requires broad advancement and try labors. therefore, this prompts high capital cost, which makes the application of tube hydro forming operation is lesser competitiveness as compared with traditional metal forming [1].

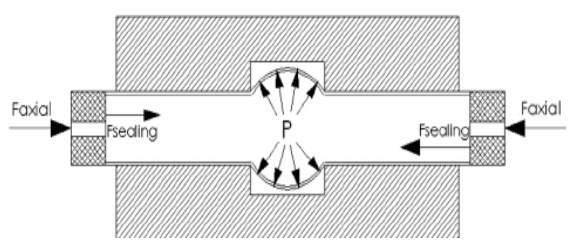


Fig. 1 Tube hydroforming process.

At the beginning of the operation, excessive use of axial compressive feeding for a certain tube, result in buckling defect. additionally, increasing of apply application of the internal pressure may lead for bursting. Moreover, inadequate axial feeding on the end of the tube may result in decreasing of the thickness at regions of the tube which subject to large expansion that may not be satisfactory for performance requirements [3]. Fundamentals of this operation returns to 1939 when Grey et al [4] presented research for manufacturing of seamless copper fittings with T bulges by application of internal hydraulic pressure and axial forces simultaneously. The hydroforming procedure obtain popularity after his study and specialists carried on more studies on this subject to manufactured tubes with complicated protrusions. An general survey of the tube hydroforming procedure was introduced by M. Koc and T. Altan [5]. This paper briefs a technological survey of hydro forming technology from its initial years to very modern years on different subjects for example tube hydroforming parts, technology, process, hydraulic and control system, materials and formability in THF, friction and evaluation lubrication, performing of tube for hydroforming process, at last advancements and directions in hydroforming innovation, so that other researcher at different parts of the world can application it for further studies here. Ken-ichi M. Masaaki A [6] concentrated on factors influenced wall thickness distribution of the hydroforming tube by FEM simulation and experimental work. FEM commercial code LS-DYNA3D was utilized for investigation of the hydroforming process of tubes. The model of this work involve plain hydroforming of a square expanded part from a cylindrical tube using combined internal pressure and axial feed. Considered as variables, the stress ratio, coefficient of friction, strain hardening exponent, and anisotropy parameter. The results demonstrate that axial feeding and better lubrication conditions enhance the thickness distribution, while the anisotropy parameter is one of the most important materials parameters for tube hydroforming. It is found that fracture location of tube depends on process conditions and materials properties and is not confined to a free bulged portion. Experimental results utilizing an AL alloy tube (A6063) are in pretty harmony with FEM simulation experiments. Xianghe X., Shuhui L., weigang Z., Zhongqin L [7] investigation mathematically the thickness distribution along the square cross-sectional hydroforming part. Explored numerically the impacts of the (μ-value), (n-value) and the (R-value) on the thickness distribution, and the different regularity of the wall thickness. The results show that the thickness decreases gradually along the side wall from the middle points to the tangential points at the corner of a rectangular-sectional hydroformed part. The analytical and simulation outcomes demonstrate that the results are the same as those of the work tests. The simulation were performed using the finite element code LS-DANA. Method of simulated optimization connected to a commercial FE code is presented by S. M. H. Seyedkashi, et al [8] to examine of the impact of different geometrics of tube on the loading paths (relation between the internal pressure and axial feeding). In order to investigated the dimensions of tube on the optimized internal pressure and axial feed, kept all the variables process as constant in all experiments such as expansion ratio, lubrication condition and materials, then these results extracted from these experiments are compared with experimental work to validity of this method described above. Finally the impact of tube geometry (diameter and thickness) on the optima; axial feeding and internal pressure, accuracy of final shape are presented. This unfamiliar method of optimization is used for metal forming process specially tube hydroforming based on Simulated Annealing algorithm. Because of the complex combinatory condition of loads in tube hydroforming, theoretical methods are not capable of determining the optimal loading paths. Based on the results obtained by this method for optimization of internal pressure and axial force in tube hydroforming, several guidelines are provided to help the designers estimate the appropriate relationship between internal pressure and axial compressive feeding, with a constant initial diameter, corner fillet and expansion ratio, the increase of thickness results in less shape conformation, with a constant wall thickness, the increase in diameter results in better shape conformation, with a constant diameter, the increase in thickness should be compensated by increasing both internal pressure and axial force, with a constant thickness, the increase in diameter has more effect on axial force in comparison with internal pressure, the effect of thickness on needed axial feed and pressure is higher than that of initial diameter. Simulative analysis of THF process was discussed by B. sreenivasulu, G. Prasanthi, T. Kumar [9], in this work, free bulge shaped tube die was modeled by using Auto CAD. Subsequently, the processes ere simulated using DEFORM-3D and it has been verified with experimental work under proper boundary and loading condition. Process parameters study also been conducted. It has been found that the estimated process parameters, developed height of protrusion and the wall thickness distribution along different planes are in pretty coincidence with work tests. From different simulations carried out for free bulge shaped tubes, it could be reasoned that, so as to make a tube with moderately uniform wall thickness during the modern shape while largest bulging can be attained , it is very significant to choose the optimal radius of die, initial length of tube and adequate lubricates are used. From the different variable researchers, the wall thickness and the height of protrusion are very critical to internal pressure, lubrication , and axial compressive feeding.

II. Experimental Work

In this work in order to simulate of tube hydroforming for tubular blank of copper material must be introduce the materials properties for this material in the FEA. The mechanical properties values can be obtained by set of experimental work. The chemical composition of tube material were found out by spectrometry device in the state company for inspection and engineering Rehabilitation activities (S.I.E.R) / Baghdad and reported in the table 1. The heat treatment operation was done of the tubular blank of copper material to improve the ductility property based on the results extracted from previous researches, the tube was annealing by heavy-duty electric furnace of type CWF 12/13. The annealing temperature considered for copper materials were 462˚C, the holding time in the furnace was 75min and then cooled in the furnace, the specification of furnace included maximum temperature 1200 ◦C, 3KW and 220V. Tensile test was done to determine the stress-strain curve for finding the mechanical properties values for the copper tube which used in the numerical simulation. Specimens in the longitudinal direction of the tube for this test are cut directly from the tube by CNC machine in an ASTM EM8 standard, the dimensions of tensile specimen as shown in the Fig. 2, then the specimen was fixed carefully by the special gripper which suitable for curvature surface of the specimen cut from tube on the universal testing machine, after that it loaded until fracture. This test was conducted under constant velocity of cross head of 10 mm/min using an WDW-200E computer controlled electronic universal testing machine with capacity 200KN. The tensile test has been done in the University of Technology / Baghdad, the universal testing machine used in this study as shown in Fig. 3. The true stress-strain curve was concluded from engineering stress-strain curve that obtained directly from testing machine. The slope of linear elastic region define the modulus of elasticity while the slope of the flow curve at specific level of stress (yield stress) is tangent modulus, the yield stress was evaluated by taking the 0.2% offset from this curve, while the passion ratio take from the standard tables. Mechanical properties for copper materials are shown in table 2.

III. Numerical simulation

The numerical analysis have been proven to be a helpful tool in the past for traditional metal forming operations to obtain reliable and accuracy information about the material, process and geometry variables. Now a day's application of finite element method for tube hydroforming process simulations has become a standard development tool after numerical investigations and experimental validations conducted by numerous analysts since the early 1990's and use of various commercial finite element method software into tube hydroforming operations were performed and displayed successfully.

Table 2 chemical composition of copper tube.

Cu	Zn	Fe	C	Al	Ni	Sn	Mg	Pb	P	Ag	S
99.9	0.0522	0.0126	0.0064	0.0025	0.004	0.01	0.00013	0.0077	0.0222	0.001	0.0021

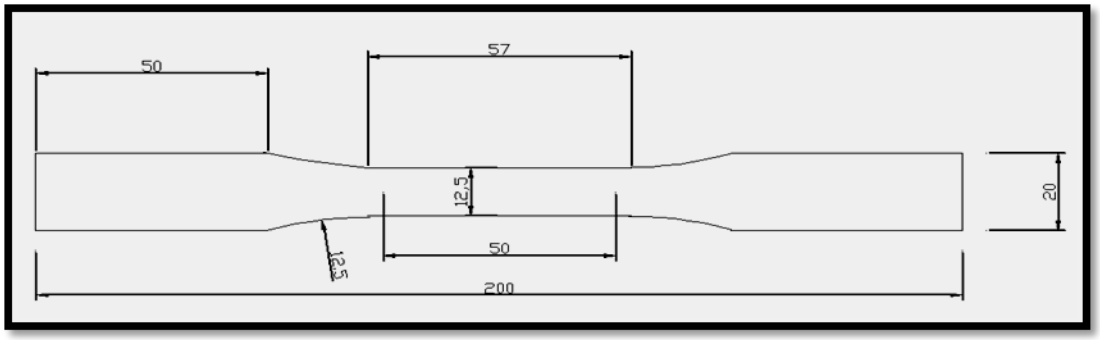


Fig. 2 The dimensions of the tensile test specimen according to ASTM standard E8M specification.

Table 2 The material properties used in simulation of the tube hydroforming process.

symbol	Parameters	value	unit
E	Young's modulus	118	Gpa
Ʋ	Passion ratio	0.34	_
$б_y$	Yield stress	57	Mpa
E_t	Tangent modulus	1.2	Gpa

The feasibility of forming a given tube can be predicted by analyzing decreases of thickness, increases of thickness, and the values of strains and stresses on a final part, the impacts of various variables could be researched by changing the internal pressure and axial feeding, materials, process conditions on a given tube. In this manner guidelines could be setup for aftertime issues [10]. For simulating the tube hydroforming processes, commercial finite element analysis software ANSYS11.0 was utilized, in which the "Newton-Raphson" implicit approach was used to solve nonlinear issue. In these processes, the internal pressure applied on the wall tube and axial feeding are defined explicitly through a time extend. Within each step, several solutions (substepes or time steps) are performed to apply the pressure gradually. At each substep, a number of equilibrium iterations are performed to get a converged solution. In this study, different case studies of tube hydroforming tubes with two dimension finite element analysis were introduced. Two dimension 2-D 4-node structural solid axisymmetric element (PLANE42 2D LARGE STAIN SOILD) was used for tube (tubular blank). The tool set (punches to provide the axial feeding in the end sides and die) was modeled as rigid bodies. Element sizes are controlled by controlling the partition specification of lines. Mesh density of the tubular blank and tools affect the accuracy of the results. So the meshes in the tubular blank are softer. The most imperative regions of the tool whose mesh intensity influenced the accuracy and reliability of the results is its arc section and the meshes of this portion are softer than other portions.

Fig. 3 The tensile test machine used.

The movement of the punch for axial feeding was defined using a pilot node. The degrees of freedom of the pilot node represent the motion of the entire rigid surface. Automatic contact step in ANSYS11.0 was exercised to model the complex interaction between the blank and tooling. For rigid tool set-flexible blank contact, target elements of TARGE196 was utilized, to explain 2D target tool set surfaces which were associated with the deformable body blank represented by 2D 8-node contact elements of CONTA175. The contact and target surfaces constitute a "contact pair", which were utilized to explained contact and sliding between the surfaces of tool set and blank. A tube hydroforming model was created. Due to the symmetry in the specimen geometry, constraints and boundary conditions, two dimensional (2D) model needed was analyzed. For simplifying the simulation of this process, the subsequent hypotheses were made: temperature of workpiece (tubular blank) stayed stationary, no heat transfers between workpiece and tool set, the dies were rigid. Bilinear isotropic hardening BISO option uses the von Mises yield criteria coupled with an isotropic work hardening assumption. This option is often preferred for large strain analyses. The principal axes of anisotropy coincide with the material (or element) coordinate system. Elasto-plastic constitutive model with isotropic strain hardening was used to simulate the tube response. The elastic behavior was taken to be linear and the plastic response was modeled using von Mises yield criterion, the friction coefficient is assumed to be uniform and constant for all contacting surfaces and equal to 0.1. Fig. 4 shows the finite element simulation of the forming sequences for the tube throughout the forming to reached to the target shape for final product (die cavity shape conformation) with axial feeding.

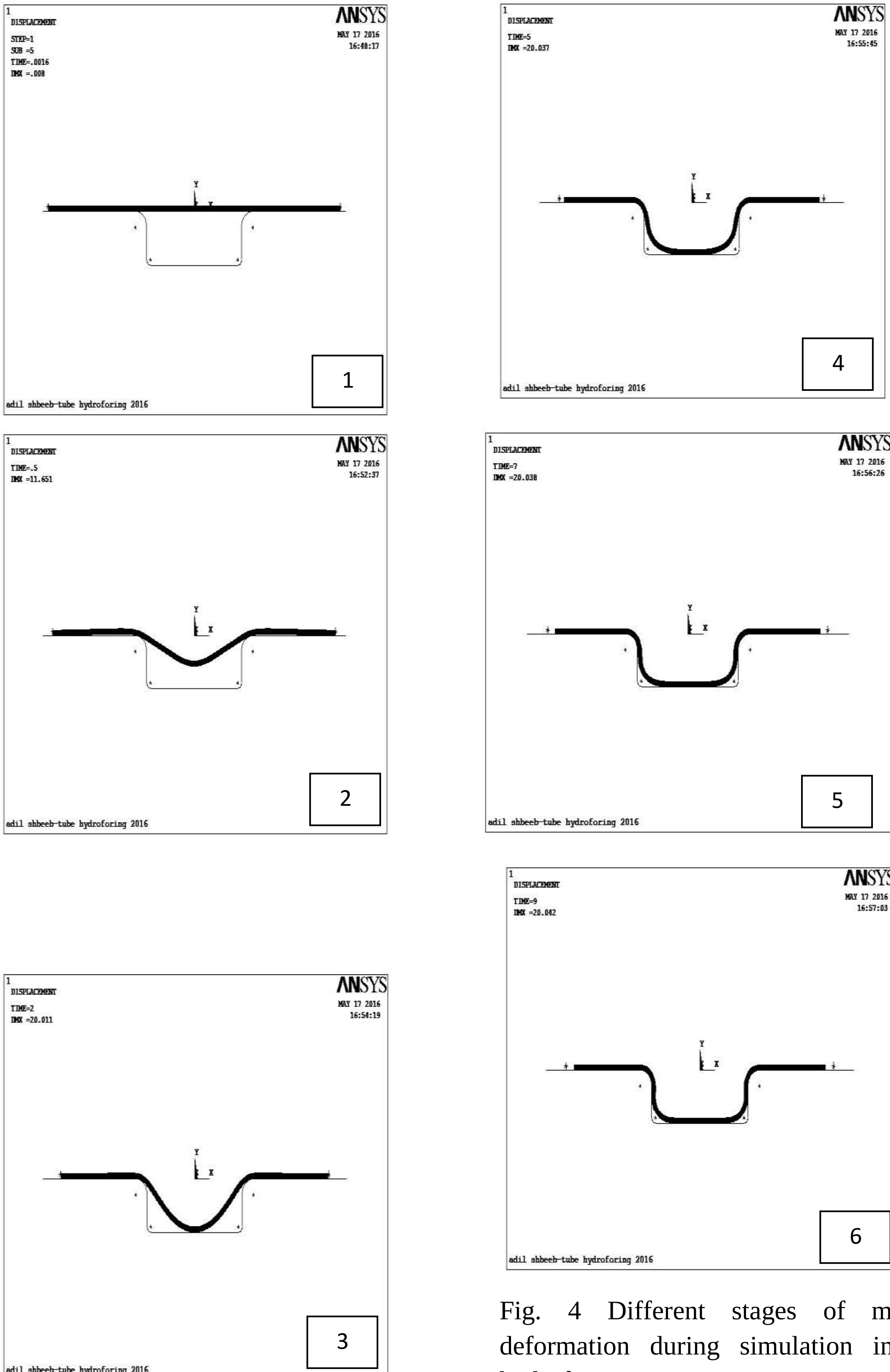


Fig. 4 Different stages of material deformation during simulation in tube hydroforming process.

III. Result and Discussion

In tube hydroforming process, the hollow parts with various cross sections can be done by applying an internal hydraulic pressure and additional axial compressive which loads to force a tubular blank to conform to the shape of a given die cavity. In this study, tubular blank is having an outer diameter of 62 mm and thickness 2 mm is placed fitting in the die which have square cavity with flat base, the entry radius of die is Re= 6 mm and the corner radius of the base of protrusion of Rc=2 mm. The schematic illustration of tube hydroforming process as shown in Fig. 5 and table 3 illustrates the geometric parameters process used in the simulation.

Variation in thickness from center to the edge of tube wall was examined in numerical simulation, it shown in Fig. 6a. It clearly seen that tube wall get on thinning at bulge region (in the middle of the tube) due to subject the metal in this region to maximum bulging during the forming process, after this region the tube wall get excessive thinning at nearly (20-40) mm from tube center due to subject the metal in this region to excessive deformation in order to form the corner part of the bulging region, and then the thickness increases toward the tube edge because of its low deformation was occurred in this region, the thickness remains almost constant in the regions which the tube wall be in direct contact with the die surface during the progress of the forming process while the wall gets thickening at outer edges due to compressive stresses.

The change in thickness in the middle of the tube (tube pole) throughout the forming process shown in Fig. 6b, it is obviously the thinning in the tube pole increases throughout the forming process due to increase in the internal pressure applied which it cause additional stretching of the tubular blank during the progress of the process, the thickness was reduced from 2mm (initial thickness of tube) before forming to 1.862mm (final thickness) for the middle point of the tube at the end the process. The effect of the loading path (the relation between the pressure inside the tube and axial feeding) on tube hydroformed was discussed, due to effect the combinatory conditions of loading in tube hydroforming process it is difficult to determine the accurate result between of the effect of the internal pressure and axial feed, therefore, discussed two cases in the tube hydroforming technology, first case without axial feed and other case with axial feeding, to avoid the effects of tube dimensions, time, material parameters and fillet radii, these parameters was kept constant in all cases in order to find the effects of internal pressure and axial feeding on the wall thickness and shape conformation of the final tube.

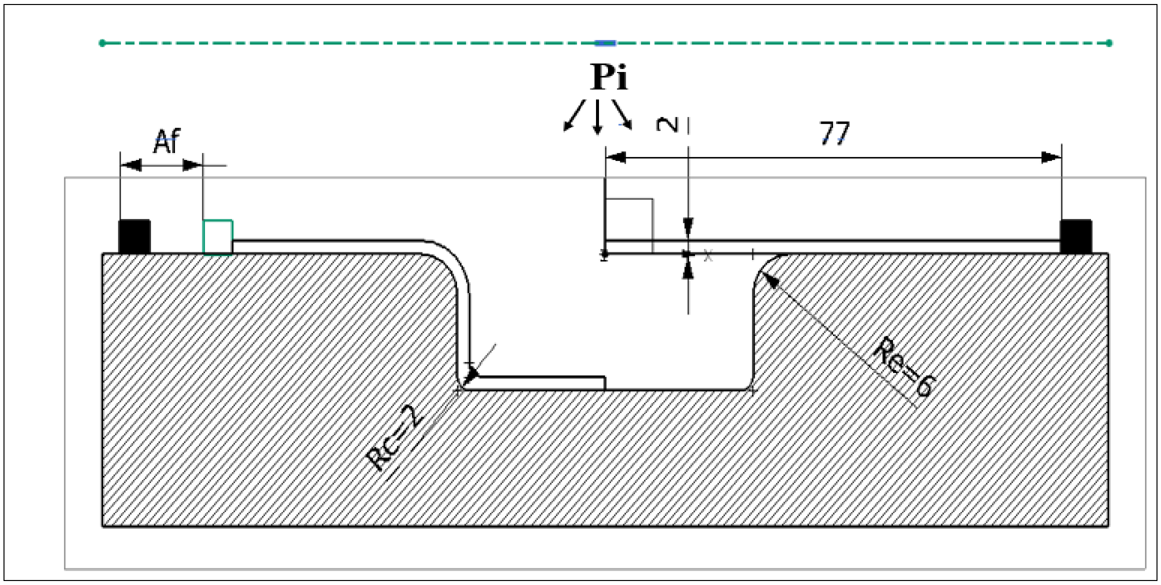
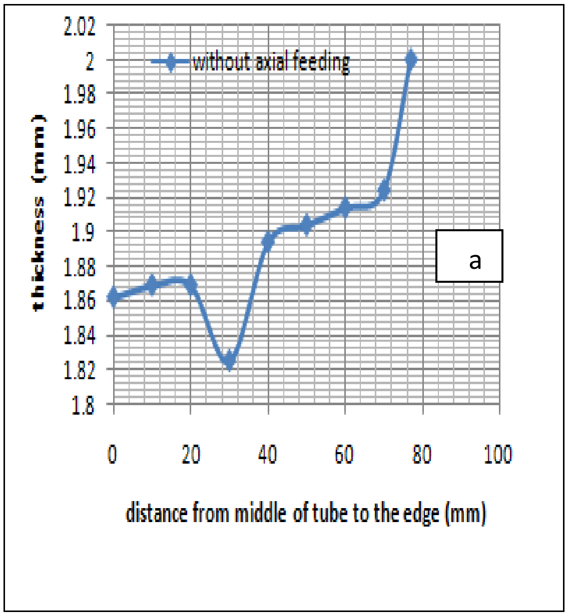


Fig. 5 Representation of the tube hydroforming process .

Table 3 The tube dimensions and process conditions used in this study.

symbol	parameters	value	unit
T	Thickness of tube	2	mm
L	Length of tube	154	mm
D	Outer diameter of tube	62	mm
W	Bulge width	50	mm
Re	Fillet (entry) radius	6	mm
Rc	Corner radius	2	mm
Af	Axial feeding	0, 7.5	mm
μ	Coefficient of friction	0.1	



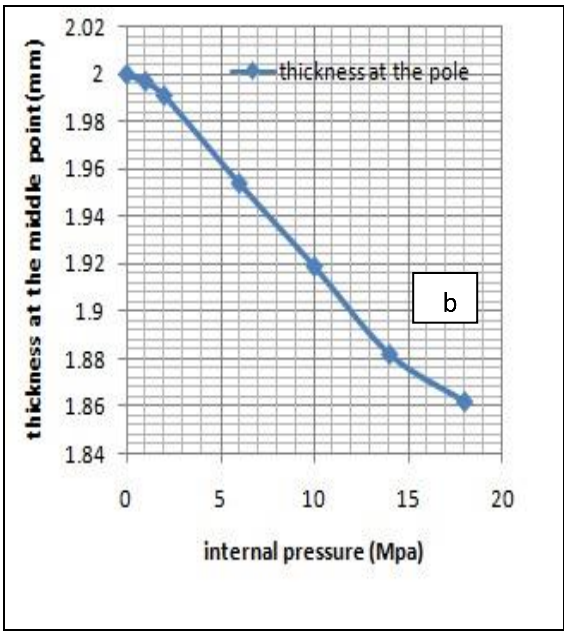


Fig. 6 The thickness distribution on the tube wall. 6a, thickness distribution from middle to the edge tube. 6b, variation in the pole thickness during the hydroforming process.

Fig. 7, is explain the variation in thickness in two cases (without axial feeding and with axial feeding value of 7.5mm over tube wall from middle to the edge of the tube), it is clearly two curves have similar trend, the maximum decreasing in thickness would take place in the mid of the part where the largest bulge occurs and it is observed from the figure (7) decrease in thickness in tube wall with axial feed case is less than found without axial feed case because of the compressive axial feeding improves flow the metal into free bulge region, therefore the thinning decreased in this region.

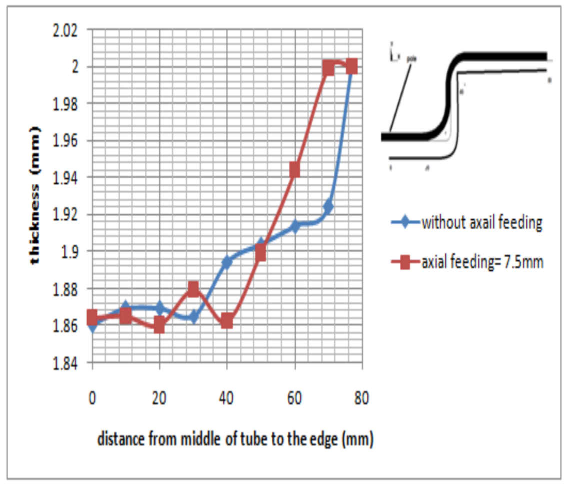


Fig. 7 The variations in thickness on the tube wall from middle tube to the edge, for two cases (without axial feeding and with axial feeding value (7.5mm).

Fig. 8 shows the effect of loading path on shape conformation, it is clearly from the figure the best tube to die shape conformation when use axial feeding because of the use of the axial feeding improves the flow of the metal in to the die cavity and therefore helping to reach to the required shape while the case of without axial feeding there are high difference between the tube produced and target tube therefore the tube hydroforming process without axial feeding has the least shape conformation in this study.

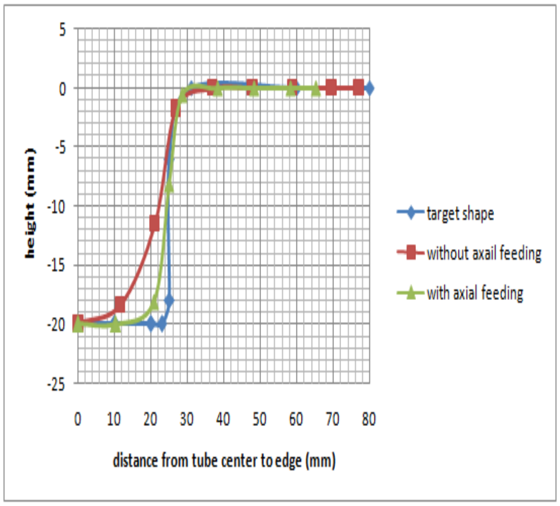


Fig. 8 Shape conformation of the final tube from center to the edge after forming process.

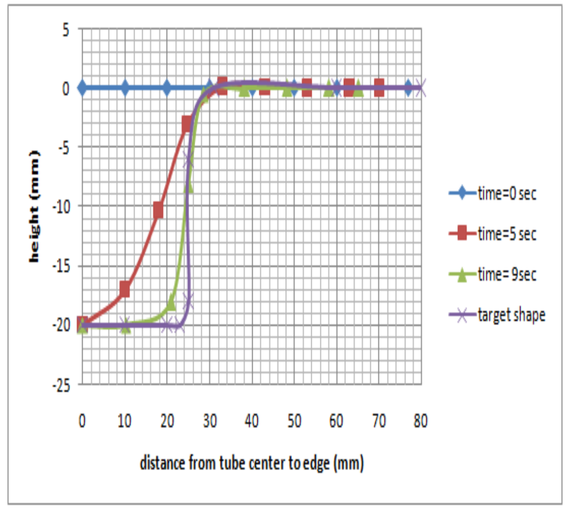


Fig. 9 Shape conformation of the tube from center to the edge throughout the forming process.

Fig. 9 shown the stages of deformation of the blank tubular over the time span during of the forming process progress with axial feeding. One of the most important difficult which face it in the tube hydroforming with square cross section die is the formation of corners of the bulged region especial when the small corners required will lead to increase the internal pressure applied to reach to the die shape conformation in order to discuss this problem the difference between the required tube and produced tube in the two cases (with and without axial feeding) are shown in the Fig. 10, it noted in case used axial feeding value (7.5mm) the error distance between the target shape (die cavity) and the tube formed at the corner radius region reached to 3.327mm, while in case don't used the axial feeding this distance reached to 9.95 mm under same conditions such as (internal pressure, materials parameters and process conditions).

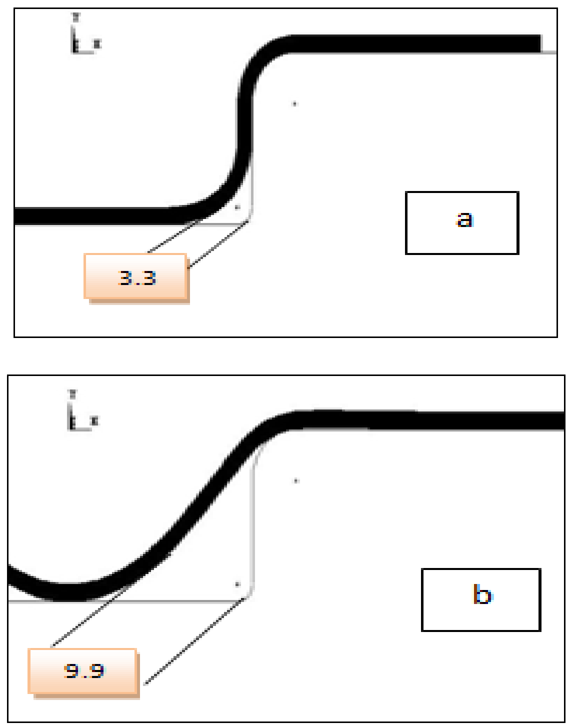


Fig. 10 Shape conformation of the final tube at corner radius (a) with axial feeding, (b) without axial feeding.

IV. Conclusions

The tube hydroforming process was simulated using finite element method with implicit formulation and using von miss yield criteria. It clearly form various simulations which conducted for bulge shaped tubes in the closed die cavity, the task is even very difficult because there are a lot of parameters affect on results, some of these parameters and their effect on shape conformation and thickness distribution were discussed in this study. It can be concluded, tube wall gets extensively thin during forming at bulge region (in the middle of the tube), the wall gets thicker at outer edges due to compressive stresses and remains almost constant wherever the part is in touch with the surface of the die. One of the important parameters was loading path, it is noted, when we used the axial feeding the thickness distribution over the tube wall and shape conforming is better than in case don't used the axial feeding, because the compressive axial feeding will lead to improve the flow of materials from edge region to the bulge region, and error distance between dimensions of final tube required and formed tube is decreased when used axial deeding, especially in the sharp corner radius for the die.

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