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New Method of Cold Forming by the Spheres for Pipe Converting to the T-shape Tube

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Abstract

In the current paper, finite element simulation for forming C12200 copper alloy and transforming it to T-shaped tube via balls has been done. The main purpose of this paper is to introduce a new cold forming method which is similar to hydroforming having the difference that instead of using fluid, metal and rigid balls have been used to form tube. Simulation results indicated that by decreasing the size of the balls, the rate of stress concentration in tube forming area will be increased and the rate of tube forming will be increased. Therefore, by applying smaller balls, the rate of tube forming can be increased. Also, results obtained from simulations showed that by applying larger balls in the mandrel's edge and smaller balls in forming area, rate of elements' strain and also forming in the forming area will be increased.

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Keywords: Cold forming; Finite element simulation; T-shape tube; Hydroforming; Metal forming.

1. Introduction

Tube hydroforming process is a forming process to transform initial tube to the respective mold using simultaneous application of hydraulic pressure to the internal surface of tube and axial force to two ends in which tube is being transformed and gets the internal form of its mold. Producing pieces with high strength besides having

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low weight have caused hydroforming to be widely used in different industries. Despite massive application of hydroforming, this method is accounted as one of the complicated methods of forming and due to tube nonlinear transforming and having variable friction surface between the mold and the tube, producing optimal pieces in this method is along with several problems. Thus, similar and new methods can be considered to produce pieces. Using finite element method to simulate forming processes such as hydroforming is an appropriate method to anticipate forming methods and different forming modes. For example, to study and predict the results of hydroforming process, researchers have employed a finite element method. In these researches, pipe bursting while doing hydroforming process, finite elements analysis has been employed using ductile fracture criterion [2,3,4], Yingyot et al. [5] have studied optimal load path in hydroforming using experimental verification and finite elements simulation. Heo et al. [6] have studied the effect of hydroforming loading paths on thinning rate using finite elements simulation and have determined the optimal loading path.

Also, finite element method can be studied for forming unsymmetrical pieces like forming T-shaped tubes in different processes like hydroforming. For example, Kadkhodaian et al. [1] has proposed a new method of loading paths optimization in ultrasonic hydroforming process to study T-shaped joints using design of experiments method and the most important loading paths to cover the most current possible cases which were chosen and then by applying a finite element simulation, the effect of each loading path was studied. Koc [7] studied the effect of loading paths and variations in material properties on the robustness of the final product. For this purpose, he studied 3-piece hydroforming and for each process, he recommended 2 loading paths for internal pressure and axial punch and also he inquired and compared the obtained results for thinning values and branch heights. In this query, T-shaped joints are one of the pieces which have been investigated and to produce this piece, reciprocal punch wasn't used. This piece was hydroformed using an internal pressure and axial punch. In this study, the effect of loading paths has been investigated using finite element methods. Ashrafi et al. [8] conducted a research on finite element simulation of hydroforming process of C12200 copper alloy and transforming it to T-shaped tube using mechanical properties obtained from Bulge test and forming limit curve and also predicting the final piece geometry. Results of this paper indicated that hydroforming piece simulated by the assistance of stress-strain curve obtained from the proposed method has been precisely fitted with the real hydroforming piece. Ray and Mac Donald [9] have determined optimal loading paths for hydroforming of T-shaped joints using fuzzy load control algorithm method. This method is considered one of the very complicated methods to design loading paths and due to this issue the behavior of each element has to be studied along the optimization process, time and cost of optimization is very high. In the aforementioned study, an especial path was presented to produce T-shaped joints and the effect of other paths on the process hasn't been studied. On the other hand, the effect of reciprocal punch was not generally considered to produce T-shaped joints. Lin and Kwan [10] predicted the optimal loading path for hydroforming of T-shaped joints combining the finite element method and the Abductive network. Also, the effect of ultrasonic loading on hydroforming of T-shaped pieces was studied by Loh-Mosuavi et al. [11]. In spite of all conducted works in the context of thermal transmission and or studying fluid flow by ball, there hasn't been any specific action for cold forming through ball pressure.

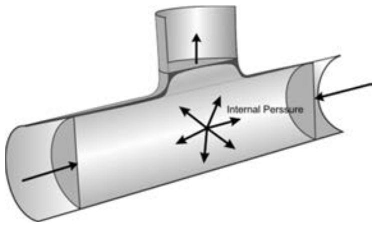


Fig. 1. Producing T-shaped joints by hydroforming process.

Figure 1 shows the hydroforming process for producing T-shaped joints. At first, the tube is being put in the mold and then by applying internal pressure and axial forces via axial punches, tube transforming is started up and respective joint is formed. In the forming method by balls, instead of fluid, balls have been employed to transfer mandrel' forces to the area of tube forming and metal flowing.

2. Finite element model

Finite element method has been extensively used to simulate metal forming processes like tube hydroforming. Ray and Mac Donald [12] conducted a research on simulation of hydroforming process of X and T-branch tubes through finite element method and with loading and boundary conditions similar to experiments. Also, combining finite element method and experiments designing has been used to optimize loading paths in hydroforming process of T-shaped piece [13, 14].

Simulation is being done using finite element software of ABAQUS. Chief parameters affecting on friction coefficient are, ball size, tube internal diameter, mold diameter as well as tube material. Due to trivial effects of other parameters like process temperature and etc. in simulation, applying their effect has been ignored. The type of used tube is C12200 copper alloy which its properties have been obtained from figure 2 [8].Tube external diameter, rim's thickness and tube length are 28.56 mm, 1.27 mm and 100 mm, respectively. To reduce rate of errors in results, features of forming mold material of balls and mandrels have been modeled with the high rate of stress and strain in order not to be deformed by high force. To simplify and decrease problem solving time and enhance the accuracy of the results, forming simulation with ball has been done in 2-D form. In T-shaped forming simulation via balls, in order to transfer more force to the forming area by mandrel, mandrels have been modeled in a gradient mode. With regard to modeling, mandrels have a displacement of 20 mm in the vertical direction and are opposite to each other. Element applied in analyses is CPS4R type. Figure 3 displays how to model finite elements.

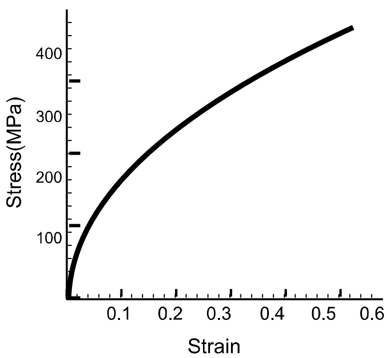


Fig. 2. Strain-Stress diagram for C12200 cooper alloy.

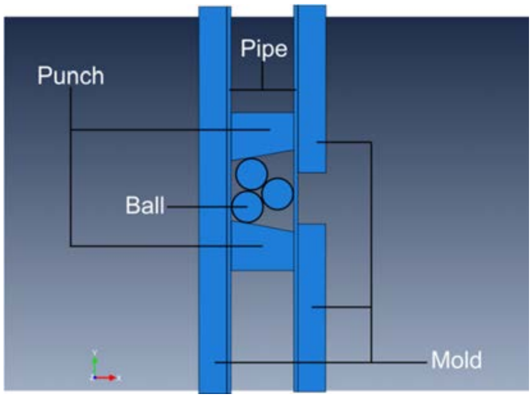
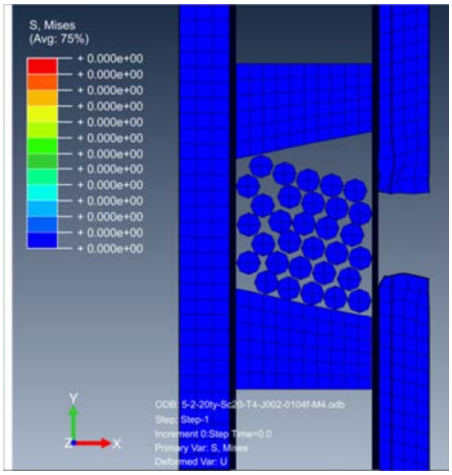


Fig. 3. Finite Element Models.

To improve the results, tube FEM elements have been modeled in 0.001mm size which are smaller than mandrel and mold FEM elements in 0.0022 mm size. By changing the parameters affecting on the process, their effect on the rate of forming can be shown. In this paper, studying the effect of balls' size on the forming rate was considered. The friction coefficient is equal to 0.4 between tube and mold and is 0.1 between balls and tube and also between balls, it has been considered 0.1. The tube and mold dimensions and the friction coefficient have been similarly determined in all of simulations in order to specify the effect of ball size on the forming rate. To ensure accuracy of analyses results, 28 modes of finite element analyses were conducted. In the first group, 19 analyses were considered. In those analyses, size of all balls in each analysis was similar to each other and balls size in each new analysis has been considered greater than the previous analysis, respectively to specify the effect of balls' size on the tube forming. Diameters considered for the first group of analyses have been exhibited in the table 1. To determine the effect of different sizes of the balls in different tube area on the forming rate, 9 other analyses modes were conducted. In each analysis, balls sizes were considered variable and weren't necessarily chosen the same. Figure 4 show the solving process of finite element of the tube forming process and transforming it to T-shaped tube via balls having 2.5 millimeter.

(a) 

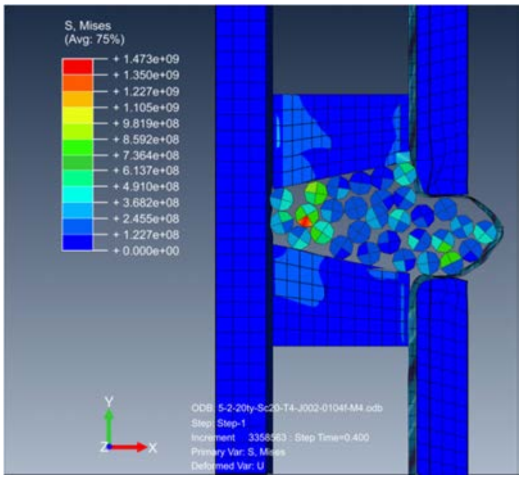
(b) 

Fig.4. Finite element process of T-shape tube via balls with 2.5 mm. (a) before solving; (b) after solving.

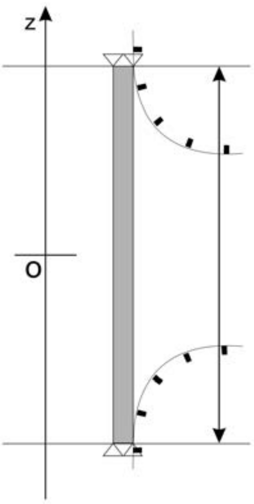
Similarly, other simulation analyses also were conducted. The rate of strain and stress in the forming area element in the first category of the simulations has been displayed in table 1. Also, the rate of strain and stress in the forming area for the analyses of the second group has been expressed in table 2. To investigate the rate of forming changing, measurements on the rate of strain of the respective element in forming area in different modes has been used. By comparing obtained values, the effect of balls' dimensions on the strain rate of element of forming area can be specified (Figure 7).

Table 1. The effect the ball size on plastic strain and stress for element in forming area (Number 308)
(a) Ball size 2.5-3.5 mm; (b) Ball size 3.75-4.75mm; (c) Ball size 5-6mm; (d) Ball size 6.25-7mm

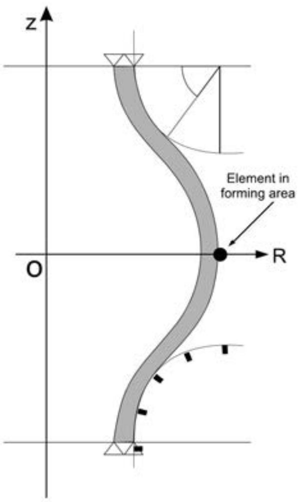
	Ball size effect	Ball Size (2.5 mm)	Ball Size (2.75 mm)	Ball Size (3 mm)	Ball Size (3.25 mm)	Ball Size (3.5 mm)
(a)	Plastic strain	0.458052	0.148492	0.0890419	0.102249	0.151275
	Stress (pa)	1.02628e+08	1.9473e+08	4.20471e+07	1.45715e+08	8.14208e+07
	Ball size effect	Ball Size (3.75 mm)	Ball Size (4 mm)	Ball Size (4.25 mm)	Ball Size (4.5 mm)	Ball Size (4.75 mm)
(b)	Plastic strain	0.288785	0.374308	0.0980666	0.111472	0.0899194
	Stress (pa)	1.02241e+08	1.57288e+08	1.20523e+08	1.49729e+08	1.01584e+08
	Ball size effect	Ball Size (5 mm)	Ball Size (5.25 mm)	Ball Size (5.5 mm)	Ball Size (5.75 mm)	Ball Size (6 mm)
(c)	Plastic strain	0.0753675	0.169966	0.0801323	0.0197964	0.0147426
	Stress (pa)	9.59485e+07	1.85026e+08	3.20228e+07	1.15043e+08	5.48693e+07
	Ball size effect	Ball Size (6.25 mm)	Ball Size (6.5 mm)	Ball Size (6.75 mm)	Ball Size (7 mm)	
(d)	Plastic strain	0.118227	0.128196	0.161187	0.0385812	
	Stress (pa)	4.60646e+07	1.72209e+08	1.05593e+08	7.57728e+07	

Table 2. The effect the ball size on plastic strain and stress for element in forming area (Number 308) with several balls diameter.

	Ball size effect	Ball Size (2.75 mm - 4.75 mm)	Ball Size (3.25 mm - 4.75 mm - 5.75 mm)	Ball Size (3.25 mm - 4.75 mm - 5.75 mm)	Ball Size (3.25 mm - 5.75 mm)	Ball Size (4 mm - 5.75 mm)
(a)	Plastic strain	0.36422	0.0582514	0.231905	0.174702	0.538463
	Stress (pa)	1.92553e+08	3.75171e+07	3.12471e+08	2.09984e+08	2.3047e+08
(b)	Ball size effect	Ball Size (4 mm - 5 mm - 5.75 mm)	Ball Size (4 mm - 5 mm)	Ball Size (4 mm - 5.75 mm -7 mm)	Ball Size (4 mm - 5 mm -7 mm)	
	Plastic strain	0.357716	0.0791884	0.0409923	0.477131	
	Stress (pa)	8.16278e+07	1.11074e+08	8.05048e+07	2.02149e+08	



(a)



(b)

Fig. 5. Deformation element in forming area (a) before forming (b) after forming

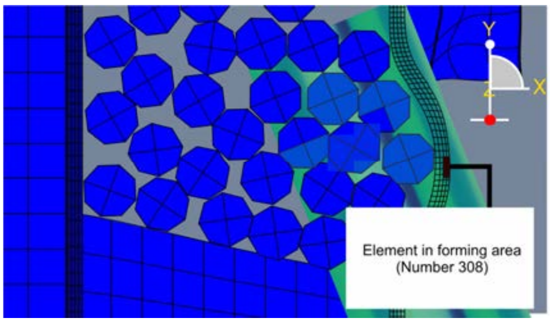


Fig. 6. Position of number 308 element in forming area.

3. Results and discussion

Figure 7 indicates the strain rate of tube element 308 in the forming area in ratio with balls diameter sizes in the analyses of the first group. In figure 7, it can be observed that the strain rate of tube element in the analysis with ball diameter of 7 mm is equal to 0.0385812. Also, in the analysis with the ball diameter of 2.5 mm, the strain rate is equal to 0.458052 and has the highest value. In the analyses with 7 mm and 5.25 mm diameter, the strain rate of similar element 308 has been recorded in Table 1.

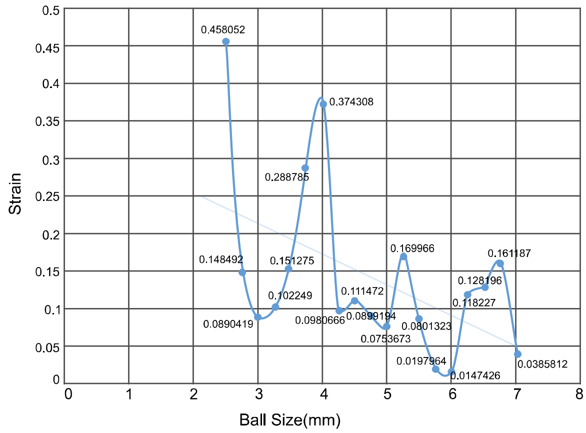


Fig. 7. The effect of the balls' dimensions on the strain rate of element of forming area.

Due to the falling steep of the diagram, it can be concluded that by decreasing the ball size, the stress concentration in the forming area will be increased and it will cause an enhancement in forming in that area. The forming and the protrusion rate of metal flow from mold by balls required for forming tube have been noticed. Thus, it can be noted that this method can be employed to form tube and transform it to a T-shaped one. Figure 8 indicates that the strain rate of element 320 of tube is according to table 2. It is concluded from this diagram that the balls movement and the forming rate of the deforming area will be enhanced when in in this area, smaller balls such as balls with dimensions of 32.5 and 4 mm and in the area connected to the press jaws, balls with greater dimensions like 5.75 and 7 mm will be placed.

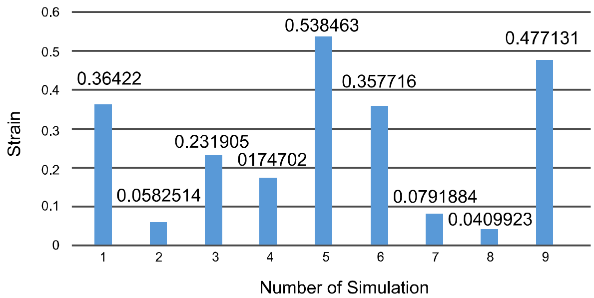


Fig. 8. Effect of balls' dimensions on strain rate of element of forming area with several diameter.

4. Conclusions

In this paper, the finite element simulation of tube forming with the C12200 copper alloy and transforming it to the T-shaped tube was conducted. Studying on the effect of balls' size on the forming rate will be possible by comparing the forming rate of the first group analyses (balls with the similar diameters) and the second group (balls with dissimilar diameters) and considering a constant value for other effective parameter such as friction and tube material. Simulation results indicated that by decreasing balls' size, stress concentration in the forming area will be increased and it will lead to increase strain in the forming area and also forming rate. Although, simulation results indicate an increase in forming rate along with the decrease in balls' size, but conducted query was only an initial study in the context of this new forming method and effect of its balls' size. It is recommended that in this context, to conduct confirmatory experimental test to transform tube to the T-shaped tube and also finite element simulation to transform tube to double-stepped pipe and its respective experimental tests.

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