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Investigating the Factors Affecting the Tube Hydroforming (THF) under Impact Loading

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Abstract

The hydroforming process is used to form pieces that are transformed into the internal shape of the designed mold under fluid pressure. Adopting the optimal loading path is one of the most important points related to this process. This study has used a projectile hammer to apply the dynamic loading path in the experiments, which in addition to reducing the time, fewer systems are used, and in this regard, an energy source has been used for two different actions of axial feeding and internal pressure. Therefore, there is a need to design a form suitable for the dynamic loading path to perform the mentioned factors at the same time. This study has studied the numerical investigation of the deformation of pipes based on the impact and the amount of fluid in the mold. Also, it is worth mentioning that axial feeding is applied using different lateral punches on the sides of the pipe, so it is obvious that the kinetic energy, amount of fluid, sealing, lubrication, material and thickness of the pipe must be proportional to each other for proper shaping. The mentioned hydrodynamic loading path can be researched using the simulation model, which has been used Abaqus to observe the changes resulting from this process, which can be used to investigate the state of the system and predict fields such as displacement, thickness and pressure distribution. Furthermore, several responses from the simulation were checked for the accuracy of the final result to lead to convergence.

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1. Introduction

Hydroforming entered the manufacturing industry as a forming process for metal parts with even unconventional geometries. In this process, internal pressure is used to form complex parts in the form of design cavities within the mold [1]. Pipe hydroforming has found wide applications in the automotive and aircraft industries due to various unique advantages such as weight and cost reduction, optimal structural strength and stiffness [2]. Nevertheless, the most obvious advantage of this technology is eliminating the need for secondary phases in the manufacturing process, because in many cases it is able to provide parts with relatively complex geometries with different shapes in a unified manner.

Quasi-static hydroforming or the formation of internal hydrostatic pressure by fluid has been studied many times [3] where a hydraulic press is usually used to create water flow inside the empty space of the tube and mold. This technique is associated with limitations such as slow cycle time and high cost of equipment, despite the mentioned advantages [4]. Several methods of tube hydroforming have been introduced to solve these problems, which differ in terms of how the loading path is applied and the rate of kinetic energy transferred to the fluid inside the mold.

Impact forming technologies have been implemented under high speed with success in the hydroforming process in recent decades. Impact forming is an example of high-speed technology used in tube hydroforming. In addition to speeding up process time, which is very important in mass production, dynamic loading can significantly increase the formability of low plasticity alloys [5]. On the other hand, high-speed forming technologies still have disadvantages in achieving optimal results, and the increased need for process measurements is another problem [6].

Impact hydroforming (IHF) has some outstanding features, such as the possibility of making complex parts in a short period of time, and the spring return can effectively have more controllability and improve the forming accuracy [6]. Efforts have

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been made to use it in industrial applications due to these important advantages.

Kashanizadeh and Mousavi Mashhadi [7] investigated the construction of aluminum tee pipe with finite element simulation and experimental study and examined the effect of axial feeding, internal pressure and opposite punch and presented a report on the effect of geometric characteristics and friction on Changes in thickness, height of bulge and possible defects (cracking, wrinkling and buckling) based on the loading path.

Kadkhodayan and Erfani Moghadam [8,9] adopted the method of applying the internal pressure in two forms of linear and decreasing-increasing pressure curves, and concluded that fluctuating pressure on the pipe is considered as a kind of hard work on the pipe, so fluctuating pressure increases the strength of the pipe and leads to a delay in the process of reducing the thickness of the pipe.

They tried to use the optimization system to study the construction of T-shaped pipes by designing different loading paths, which would result in the least changes in thickness and the maximum height of the projection, and considered it as a measure of formability, and introduced a relationship in order to establish a relationship between the input and output parameters by benefiting from modeling and observation results for optimization, but the upcoming research has dealt with numerical and experimental investigation for the construction of T-shaped tee pipes under hydrodynamic loading, and investigated forming by hydroforming process.

Applying the loading path is the main difference of the dynamic hydroforming method compared to other static methods, and subsequently, both internal pressure factors and axial force must be applied with one stroke according to the type of loading determined. In the method used for this study, a different loading path is considered, which provides axial feed and internal pressure through the medium fluid simultaneously and from an energy source, and the amount of pressure produced is provided for shaping. Based on the kinetic energy and the amount of fluid column in the mold, it is also worth mentioning that the amount of bulge according to the surface quality and changes in length indicates the thickness distribution of the pipe after deformation, which is investigated.

An internal pressure controller pump is used in the usual way that is observed from loading in the hydroforming process, which is a quasi-static approach [10]. Reddy and his colleagues [11] concluded in 2019 that the minimum reduction in the thickness distribution of the bulge is a criterion for optimal shaping. Although, thickness changes in hydroforming are mentioned as a factor for research in determining the desirability of the forming process in some studies, but the difference is observed regarding what basis and criterion is important in knowing the appropriate thickness distribution and introduces the desirable shape change.

Also, this tip can be adopted based on the type of loading path. As mentioned earlier, the uniform reduction of the thickness in each part of the piece after deformation may be considered as a measure of thickness distribution, although the optimal amount of reduction is about 40% in some researches [12]. Also, minimizing the thickness changes has been introduced in some researches as an indicator of adopting the optimal loading path among the available paths for the entire final part [13].

Therefore, some of the important factors in knowing the right product as a measure of desirable deformation are:

1. Deformation of the maximum similar to the internal design of the mold [14]
2. Appropriate thickness distribution [11-13]
3. Absence of wrinkling, thinning and tearing [14]
4. Quality of bulge based on thickness distribution [11]

This study deals with the numerical analysis of the construction of T-shaped pipe by Abaqus based on the experiments. The loading path determined for this study is a dynamic approach and is applied as a low rate impact. For the experimental observation of this type of experiments, the mold used in order to use a projectile hammer is designed in such a way that by a blow, the ability to apply sudden internal pressure and axial feeding is established, therefore, the same conditions as mentioned are also considered in the simulation model in order to implement the dynamic loading path, and the results of this numerical investigation will be compared with the experimental observations of the recent research of the author of this research. Some important points in this study are the longitudinal changes of the tube based on the height of the bulge , which will be adapted in a different simulation model compared to the previous research [15] to be correct on the test method and its numerical analysis, as well as the results of investigating the effect of the geometric characteristics of the pipe and the axial feeding factor in the path of dynamic loading will be compared by adopting different thickness of the initial pipe.

2. Examination of experiments and equipment

This study has investigated the test simulation of tubes that have been subjected to forming at a low rate by a projectile hammer. The schematic view of the system used can be observed in Fig. 1. Also, the schematic view of the process of preparing the test for forming the tube by incompressible fluid inside the mold can be examined in Fig. 2, the method of conducting and experimental investigation is mentioned in the previous research of the author of this research [15] in detail from the beginning to the end of the experiment.

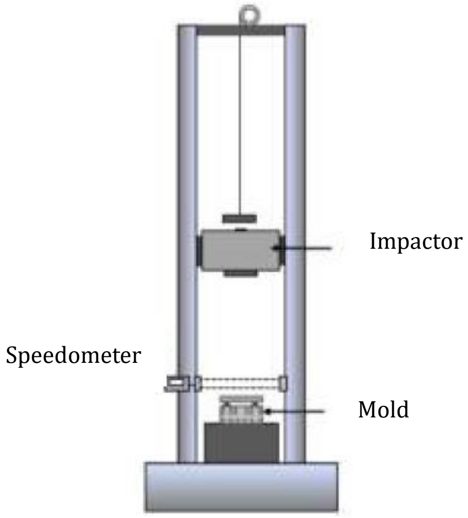

Fig. 1. Schematic view of drop hammer

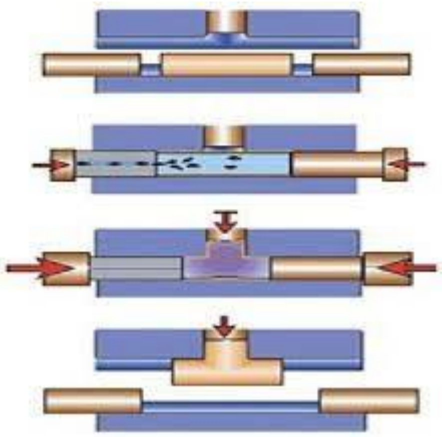

Fig. 2. Schematic view of the preparation of the tube inside the fluid content mold for the deformation process [3]

It is obvious that a certain kinetic energy will cause hydrodynamic pressure in the mold due to the impact of the weight of the projectile hammer on the connected pistons, which leads to deformation. In addition, it is worth mentioning that the conditions of applying axial feeding are created by placing lateral punches on the sides of the pipe, and by embedding the central hole in this punch, the dynamic pressure wave of the fluid penetrates and by applying it to the inner surface of the pipe, it can be considered as the cause of the growth of the bulge. It is a tariff. Meanwhile, the opposite punch is also used to complete the calibration pressure. Fig. 3 shows a view of the side punches used in the experimental study with the central hole radius of 2.5 mm. As mentioned earlier, a formwork is used in order to correctly apply the dynamic loading for the hydroforming of the pipe, which is shown in Fig. 4.

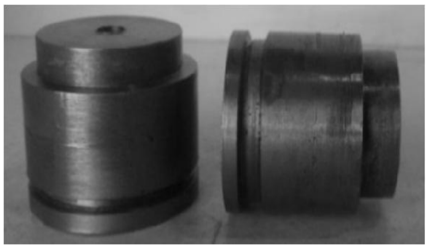

Fig. 3. A view of the side punch [15]

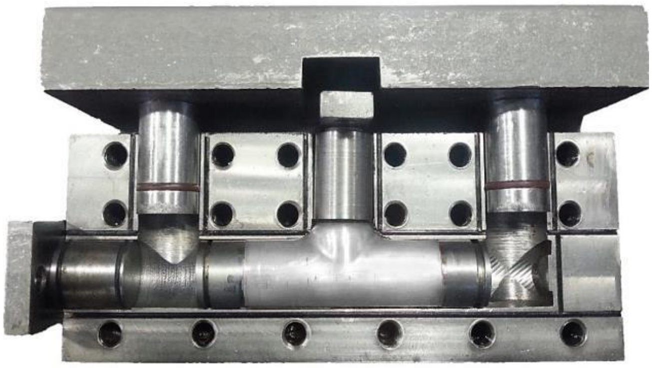

Fig. 4. Image of the mold used in the experiments [15]

The initial conditions of the samples of the tested tubes are observed based on Table 1 and Fig. 5, in which the geometrical characteristics and mechanical properties of the used aluminum tube are presented.

In the loading path of this study, a report of the test results can be seen in Table 2, regarding the measurement of changes after forming, which is related to aluminum tubes. This study mentions a study of the simulation model with the hydrodynamic approach of smooth particles to firstly be validated based on experimental observations [15,16], and secondly to compare the new points for the changes resulting from shaping in this study, which includes a tube with an initial thickness and the result of the investigation of its effects will be mentioned.

Table 1. Geometric specifications of aluminum tube [16,17]

Value	Parameter
25 mm	External diameter
1.2 and 2.8 mm	Thickness
80 mm	Initial length
70	Young's modulus
2700	Density

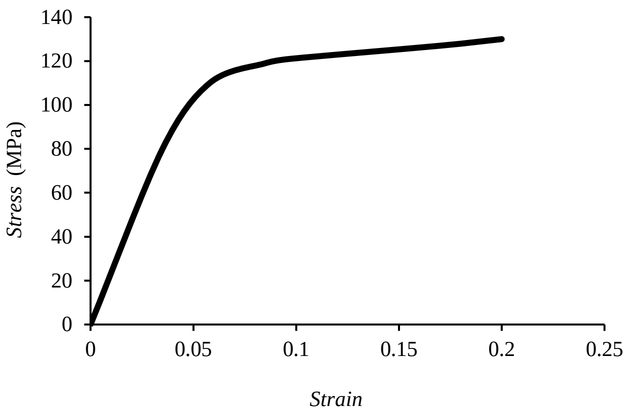

Fig. 5. Stress-strain diagram expressing the mechanical properties of aluminum tube [15]

Table 2. Aluminum tube tests report (2.5mm lateral punch radius) [15]

Test No	Fluid column (h_w)	Kinetic energy	Reduced length	bulge
T.1	12	210	1.4	2.2
T.2	18	285	2	5.6
T.3	13	190	1.3	4.6
T.4	13	285	1.6	5.3
T.5	13	327	1.8	5.4
T.6	14	327	2	5.8
T.7	20	306	2.2	6.4

In the following, the simulation is examined according to the experiment.

3. Modeling principles

The fluid particles and the pipe element under loading are coupled in the modeling of the experiment by Abaqus (6.14).

The elements in the Abaqus library are used for different types of geometric models in order to simulate the process. The C3D8R element, which represent elements with a reduced formulation capable of controlling the hourglass phenomenon, are selected in this modeling for the pipe under loading. Each group of elements in Abaqus has a special formulation, and finite element solutions are performed based on it.

The order of the element and the method of numerical integration have a direct effect on the accuracy of the solutions created in an analysis. The fully integrated elements return the number of Gauss points needed to integrate the polynomials in the right-cornered element-related stiffness matrix. Right corners mean that the edges are smooth and the corners of the element are straight, and all the nodes on the edges must be right in the middle.

Due to the phenomenon of shear locking, this group of elements should be used in loadings where bending is minimal. Therefore, it seems necessary to provide an alternative solution with the aim of analyzing bending problems. One of the existing proposals is to use elements in which integration points are reduced and known as reduced integral. The schematic view of these two elements is shown in Fig. 6. It is necessary to explain that several responses from the simulation were examined for the accuracy of the final result and the size of the metal pipe elements to lead to the convergence of the results and finally, 501760 elements were considered for this member of the said simulation.

Some elements are not supported in the software environment, such as contact elements, distribution couple and particle elements and must be created in an environment outside the mesh module. The inp file created in the job module should be used to use these types of elements in the problem solving process. It should also be noted that other parts of the test such as the water chamber, piston and mold are modeled in a rigid way and by specifying the dimensions of the element, they are elemented appropriately.

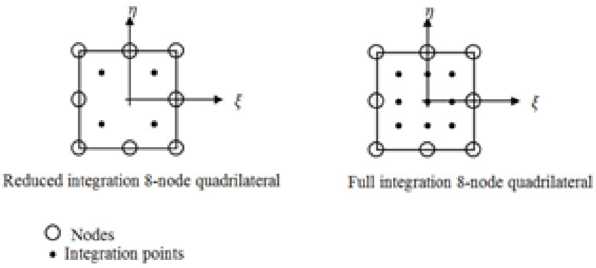

Fig. 6. Full and reduced integration elements [18]

It should be noted that the rigid members are modeled discretely, because in metal forming problems, due to the contact conditions between the members, it is necessary to element the rigid members as well [18]. The tube is simulated in the geometry section of the software as solid and deformable. According to the type of experiment performed (releasing the weight of the hammer from a certain height to shape the tube), the available parameters for solving the problem include: energy, mass and speed of the projectile hammer at the moment of impact. Choosing the speed parameter as one of the inputs for solving the problem is suitable considering the importance of the strain rate in the problems related to the forming of metals.

It is important to use kinetic energy and fluid quantity for software modeling, taking into account all measurable parameters in the experiment. The experiment performed is accurately simulated by assigning the mass to the hammer and determining the initial velocity at the moment of impact, which is obtained from the laser speedometer installed at the test site.

It should be noted that the use of interaction module will be able to determine the said parameters if the problem includes contact between parts, interaction between parts, restriction of degrees of freedom, definition of relationship and constraints. Abaqus only recognizes the contact between two or more members, if the user has previously defined the mechanical properties of the contact, the involved parts and other desired characteristics in the superposition module. Furthermore, the interaction between different parts of the system, as well as the surfaces of the parts, is defined by the friction coefficient value of 0.1.

4. Results

According to what was mentioned about the process of conducting the experiment and modeling according to it, the results of the simulation will be numerically investigated, first, an adaptation of the experimental observations will be mentioned, and then the modeling results from the previous study [15], is validated in this study. It should also be mentioned that new reviews of the effect of pipes with different thicknesses will be presented, among the importance of which can be mentioned the provision of predictability for tests. A view of the simulated and experimental model of the deformed aluminum tube related to the T.4 test can be seen in Fig. 7, which provides a good fit.

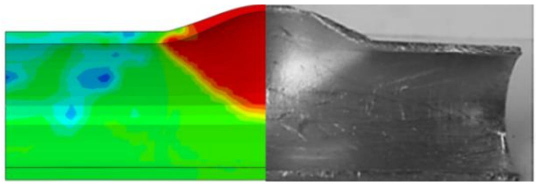

Fig. 7. A view of the simulation and experimental model of the deformed aluminum tube in the test T.4

The changes in pressure versus bulge are shown in Fig. 8. As shown in this Fig., back pressure occurred for the 2.8 mm thickness, which can be due to the repulsion of the axial punches in a fraction of a second and the continuation of the formation at a higher pressure. It should be noted that the internal pressure suddenly increases to 16.5 MPa in 0.13 milliseconds. This result seems obvious due to the larger thickness of the main tube, and this temporary pressure drop occurs in about 0.1 ms, which is a suitable period of time to compensate for the thinning caused by internal pressure to prevent defects such as bursting which can also help to increase the height of the bulge with increasing the axial feed.

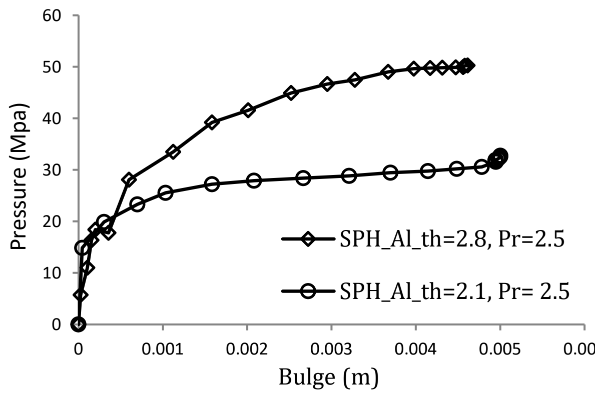

Fig. 8. Pressure – Bulge diagram for aluminum tube in two different thicknesses for same condition of T.5 and axial punch 2.5 mm

According to Figure 9, the changed pressure based on the effect of axial feeding and while the behavior is similar in the deformation process, a tube with a greater thickness has back pressure during the process, which can be caused by the resistance of the thick tube against pressure, because the increase in pressure is affected by energy. A movement has occurred in a smaller volume in the same period of time with the thinner tube, and on the other hand, by increasing the axial feed and observing the momentary pressure decrease, it reports the growth of the bulge at that particular moment, which is probable, and the process suffers shrinkage. Otherwise, However, the maximum bulge growth did not occur due to the greater initial thickness and due to the occurrence of back pressure, which could be due to the lack of sufficient fluid and disproportion with the kinetic energy. According to Table 3, with the increase of the initial thickness, there is more resistance in the effectiveness of the axial feeding, so more pressure is needed, which is affected by the proportion of fluid amount and kinetic energy.

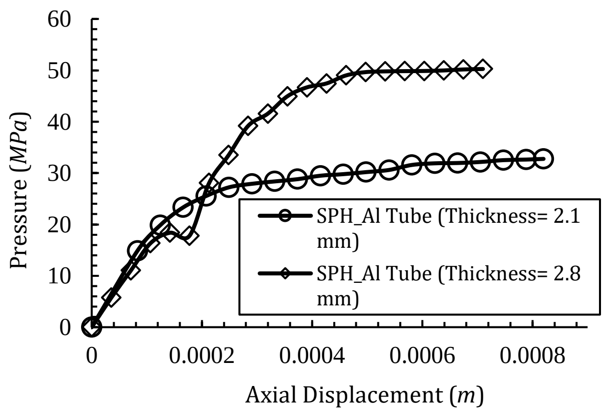

Fig. 9. Internal pressure - axial displacement diagram of aluminum tube in two different thicknesses (same conditions T.5)

Table 3. The effect of lateral punch changes based on different initial thickness on axial changes (same conditions T.5)

Lateral punch radius	Experimental 2.1 mm	Simulating the thickness of 2.1 mm	Simulating the thickness of 2.8 mm
2.5	0.9	0.82	0.71

5. Discussion

The observations obtained from the study of the experiments and the validation of its numerical analysis, are presented as the following results:

1. Any small change in the implementation of input factors such as kinetic energy and amount of fluid column makes a significant difference in the process result.
2. The initial thickness of the tube can be mentioned as one of the characteristics that greatly affects the process.
3. The impact hydroforming process is done at a low speed by applying kinetic energy with a projectile hammer, which means forming at a low rate, which can also have the ability to perform quickly with high power.
4. Choosing the right amount of fluid according to the input kinetic energy leads to obtaining the optimal deformed tube.
5. In this method, characteristics of the deformation along with the effect of the axial force are started and the evolution of the formation is observed with acceptable accuracy.
6. In this study, it has been observed that the tube with lower initial thickness had a better forming process in T.4 conditions.
7. It should be mentioned that according to the comparison results of samples T.4 and T.5, d, that more kinetic energy has led to more deformation by maintaining the same fluid column for the aluminum tube.

As mentioned earlier, it can be claimed that it is of great importance to choose the primary pipe with less thickness, and while all the factors must be proportional to each other and the mentioned points are compared to each other, it provides the accuracy of the research report and review. Also, it should be noted that the maximum thickness reduction of the optimal sample was observed below 40%, which indicates a suitable deformation. Choosing a tube with better plasticity is another very effective parameter to have an optimal final product, which makes it easy to check the conditions of the test in the detection of the loading path.

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