Reshaping of Thick Tubes into Square Passes at Ends with FEM Simulation

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Abstract

The manufacturing of the non-circular pipes made by reshaping process is becoming more and more important because of their utilizations as in different industries. In this work, a reshaping process is presented with cold rolling of a circular thick tube into a square cross section between four flat rolls in different passes. The influence of the amount of roll gap reduction in each pass on the final rolled product was investigated. Quantities such as separated force energy, wall thickness, and corner radius of the tube were observed and measured.

Index Terms—cold rolling, tube shaping, noncircular pipe, FEM

I. INTRODUCTION

Recent advances in high temperature and high pressure applications (e.g. natural gas, chemical liquid transportation, construction of boilers, heat exchangers, etc.) have made significant increase in industrial applications of square and rectangular seamless tubes. These tubes have many advantages over the circular ones such as the facility to fit, the increase of high torque in twist and the weight reduction of structure parts. Nevertheless, duo to simple production process of circular tubes, they have been studied by several authors in energy absorbing systems [1, 2].

In seamless tubes fabrication, piercing and extrusion processes usually are used. The shear deformation occurring in shaping of square-tube - made by these processes - would result in the non-uniform property in the transverse direction. In order to avoid this defect, the cold roll-forming method by passing a circular tube through flat rolls can be more efficient.

Several numerical and analytical methods have been presented to analyze the reshaping process. In order to predict the material deformation, an advanced tooling design which utilized numerical analysis, is used by Wen [3]. Besides, it improved the tooling performance. A finite element numerical simulation was used to calculate the amount of shrinkage and the round tube size. Through this study, effects of many factors such as final tube size, the number of reshaping passes, the amount of performed work in each pass and other parameters on the shape of the corner have been investigated. He also represented a formula to estimate the shape of the tube at each pass.

Moreover, Kiuchi and Feizhou [4] developed a computer-aided simulation program based on 3D elasto-plastic finite element method, which was able to analyze all of deformation features and mechanical characteristics of a pipe. In addition, Kiuchi et al. [5–8] presented theoretical methods to analyze and optimize the reshaping process. In these researches, a mixed method composed of the finite element and finite difference was applied and called finite differential method.

Another research, Bayoumi gave an analytical solution for the problem of cold flattening of a round tube into an oblong shape through rolling between two flat rolls [9], in which a velocity field to yield the strain-rate components was formulated. The solution predicted section geometry, roll surface pressure distribution, roll load and rolling torque.

Abrinia and Farahmand [10] presented a new solution based on upper bound method that is used to solve the reshaping of thick square tube from a round one. The tube material is assumed to be isotropic, incompressible and follows a rigid–plastic behavior. The influence of various process parameters such as radius of rolls, initial pipe dimensions; amount of roll gap reduction and the roll speed on the final rolled product were investigated. Finally, in order to verify the theoretical results, an experimental rolling rig was designed and built which comprised of four flat rolls.

For determining the forming tool load in plastic shaping of a round tube into a square tubular section through a head comprising four idle flat rolls, Bayoumi and Attia [11] presented an analytical solution and finite element simulation using finite element code ABAQUS/ STANDARD and LS-DYNA. In order to verification, theoretical results were compared to experimental ones that were obtained from a specially designed test-rig simulating actual production conditions.

The most of these works, which were mentioned above, have concentrated on the reshaping of thin-walled tubes or pipes. In fact, very little analytical work on reshaping of thick tubes could be found in the literature. In other words, most of the previous works are in the field of roll forming in which very little or no bulk material flow occurs, whereas bulk forming is the main object considered in this study.

In this paper, the influence of the amount of roll gap reduction in each pass on separated force energy, wall thickness, and corner radius of the tube was discussed. The above information maybe of practical helps to the manufacturers and designers.

II. THEORETICAL ANALYSIS

A. Deformation Zone Geometry

The tube cross-section at entry is circular with an outer diameter 2R, and a uniform thickness t0 . The exit cross Section is a square with round corners, the outer corner radius being r0 , and the width of flats equals 2be . The Corners were taken as circular arcs tangent to the flat sides (Fig. 1).

The different stages of tube reshaping were studied and that was the deformation, which happened on each pass of the rolling sequence. Here, the outer profile of tube's cross section is expressed by 1/4 of a circle.

B. Finite Element Modeling

The general purpose finite element code ABAQUS/EXPLICIT v.6.5-1 is used to analyze the plastic flow pattern of a circular tube reshaped into a square cross-section, by passing through four flat rolls. The dimensions and material properties of the finite element simulation tube are given in Table 1.Upon exceeding the material yield strength,

The C3D8R elements were used in the FE simulation; these elements are 8-node 3D stress linear brick elements with reduced integration, and hourglass control. Due to symmetry conditions, only a quarter of the rolls and tube are modeled. The tube is meshed using continuum elements and the rolls are modeled as analytic rigid surfaces. The analytic rigid surface option in ABAQUS is computationally less expensive than the use of rigid elements to model the rolls, and has a more efficient contact algorithm. A surface-to- surface contact (Explicit) approach is used in the analysis between the rolls (rigid surfaces) and the outer surface of the tube.

The interaction between the tube outer surface and the rolls is formulated using the penalty approach, which allows for the possibility of separation between the two surfaces. During the finite element simulation the following assumptions were made:

(1) The initial tube cross-section is perfectly circular.

(2) The deformation behavior of material is isotropic.

(3) The tube is elastic-strain hardening plastic.

(4) The tools are rigid.

Symmetry boundary conditions are applied along the X and Y axes, also the upper and side rolls are allowed to

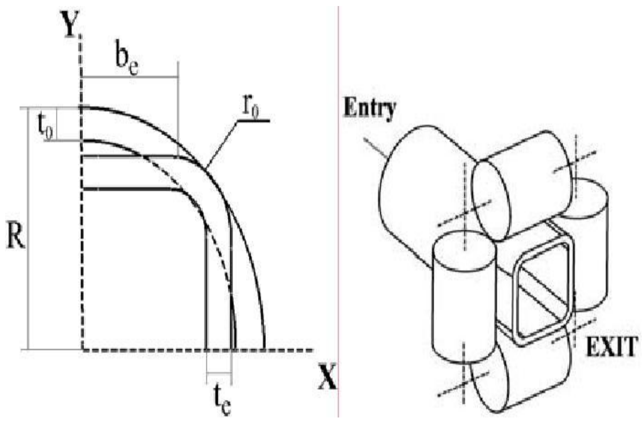

Figure 1. Shape rolling process deformation zone.

TABLE I.

TUBE DIMENSIONS AND MATERIAL PROPERTIES

Outer diameter (mm)	76
Thickness (mm)	8
Length (mm)	70
Modulus of elasticity (E, MPa)	15000
Poisson's ratio (υ)	0.4
Yield strength (MPa)	15

Rotate around themselves axis only. The upper and side rolls are set in contact with the tube at the beginning of the shaping process. The rolls are rotated with 20 rpm. The deformed shape of the tube at the end of the shaping process is shown in Fig. 2.

III. RESULTS AND DISCUSSION

Theoretical analysis of reshaping thick circular pipes into square tubes was carried out using the method presented in section II and the following results were obtained. The corner radius is plotted against the flat side length, as obtained FEM in Fig. 3.As the flat side length 2be increases in each pass, the value of the final rolled

Tube corner radius r0 decreases.

The effect of roll gap reduction on the power dissipated during the process in different passes has been considered in Fig. 4. It could be said that as the roll gap reduction parameter increases in each pass the power increases too. Such result is also indicated in Fig. 5, by expressing the tube deformation in terms of the power dissipated versus the corner radius r0.

The separated force versus the corner radius r0 in Different passes as obtained from ABAQUS finite element simulation is plotted in Fig. 6. However, as the value of the roll gap reduction parameter increases in each pass and decreasing the corner radius, the value of the separated force increases.

On the other hand, although the value of roll gap reduction is constant in each pass, but higher values of power and separated force are required for shape rolling in subsequent passes due to the decrease of the tube corner radius r0 and increase of the flat side length 2be.

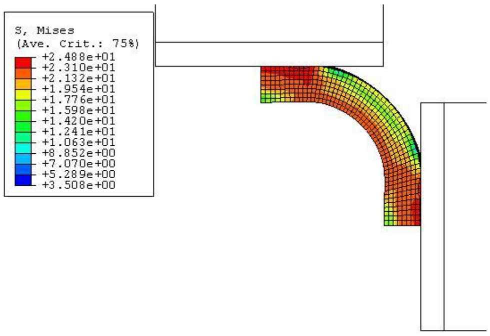

Figure 2. Tube deformed shape after passing through rolls.

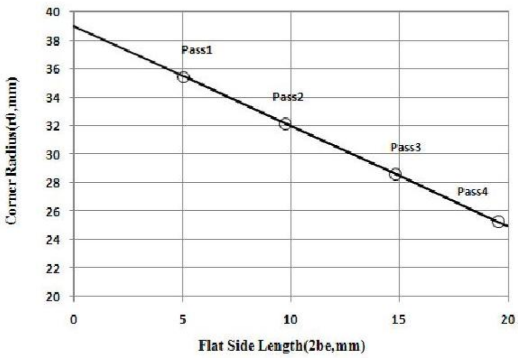

Figure 3. Corner radius versus flat side length.

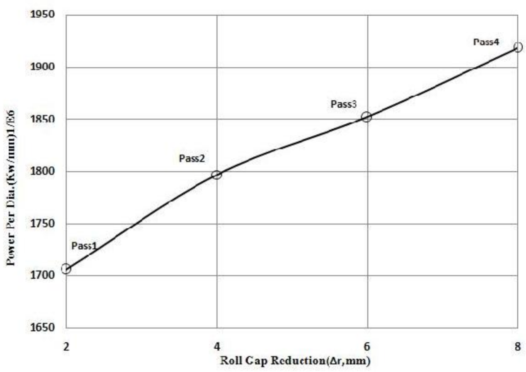

Figure 4. Power dissipated versus roll gap reduction.

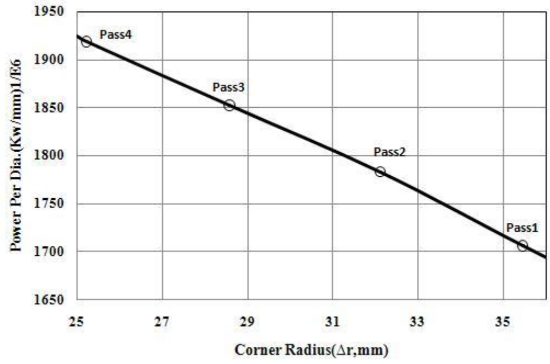

Figure 5. Power dissipated versus tube corner radius.

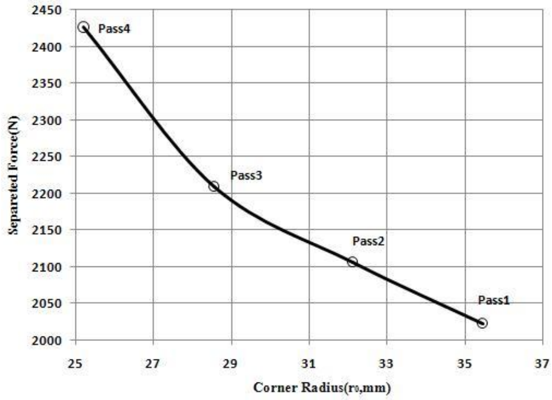

Figure 6. Separated force versus tube corner radius.

FE simulation result for the variation of the final shaped tube thickness, te in different passes is shown in Fig. 7. It indicates that as the roll gap reduction parameter increases, the thickness for the final rolled tube

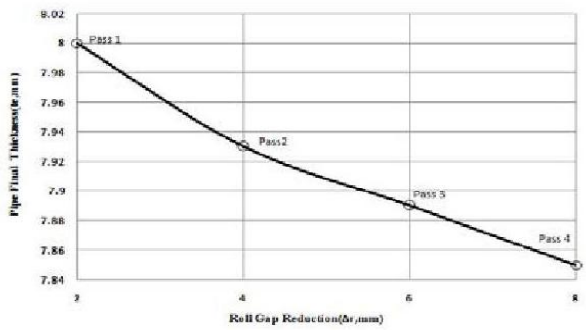

Figure 7. Final rolled tube thickness versus roll gap reduction.

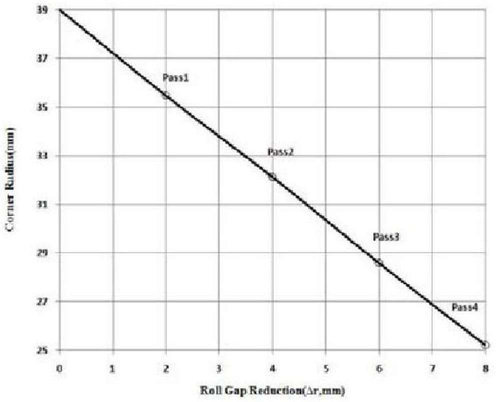

Figure 8. Corner radius versus roll gap reduction.

t_e decreases in each pass, although the amount of the reduction of t_e is very small.

Variation of the final shaped tube corner radius r0 with The roll gap reduction in different passes is indicated in Fig. 8. It could be observed as the value of the roll gap reduction parameter increases, the value of the final rolled tube corner radius r0 decreases in each pass.

CONCLUSIONS

The general purpose finite element code ABAQUS/EXPLICIT is used to determine the influence of the amount of roll gap reduction parameter in each pass on the final rolled product. It was concluded that as the reduction in the rolling process is increased in each passes, the amount of energy dissipated and separated force increase. However, with a further increase in the reduction parameter smaller corner radius was achieved and the thickness for the final rolled tube t_e decreases in Each passes, although the amount of the reduction of t_e is Very small. It could be said that the method developed and the simulations based upon it were successfully used to predict different process parameters and their influence on each other.

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