Computer Aided Design of Reshaping Process of Circular Pipes into Square Pipes

Parviz Alinezhad, Ali Sanati, and Koorosh Naser Momtahen

Abstract**—**Square pipes (pipes with square cross sections) are being used for various industrial objectives, such as machine structure components and housing/building elements. The utilization of them is extending rapidly and widely. Hence, the out-put of those pipes is increasing and new application fields are continually developing.

Due to various demands in recent time, the products have to satisfy difficult specifications with high accuracy in dimensions. The reshaping process design of pipes with square cross sections; however, is performed by trial and error and based on expert's experience.

In this paper, a computer-aided simulation is developed based on the 2-D elastic-plastic method with consideration of the shear deformation to analyze the reshaping process. Effect of various parameters such as diameter of the circular pipe and mechanical properties of metal on product dimension and quality can be evaluated by using this simulation. Moreover, design of reshaping process include determination of shrinkage of cross section, necessary number of stands, radius of rolls and height of pipe at each stand, are investigated. Further, it is shown that there are good agreements between the results of the design method and the experimental results.

Keywords—Circular Pipes, Square Pipes, Shear Deformation, Reshaping Process, Numerical Simulation.

I. INTRODUCTION

SQUARE pipes (pipes with square cross sections) made by reshaping processes are widely used as structural elements in almost all industries. Despite a long history of the process, because of the complicated deformation behavior of pipes during reshaping, the design procedures for forming rolls and pass-schedules mainly rely on experience-based knowledge. Thus, the fundamental and systematic approaches to the reshaping technology and the guidance for the design of rolls and processes have been required. In order to solve these serious problems, a design method has been developed to determine ideal roll profiles and roll arrangement for the process. It is based on the simulation technique to analyze two-dimensional elasto-plastic deformations of the cross sections of pipes.

Kiuchi [1] conducted a series of experimental investigations for the reshaping processes of the square and rectangular pipes from the circular pipe. Effects of process variables and pass-schedule were investigated on the deformation of formed product, limit conditions for the occurrence of defects and reshaping loads. Moreover, the optimal conditions were investigated to attain the required accuracy of products and the required productivity.

In order to investigate the deformation features of the circular welded steel pipes into the square sectional pipes reshaped, using an extroll-forming mill, Onoda, et al. [2] developed the conventional rigid-plastic finite element method. The calculated cross-sectional geometry of the formed pipe is in good agreement with the experimental result.

Kiuchi, et al. [3] have also developed the 3-D elasto-plastic finite element method by which various deformation features and mechanical characteristics of pipes with square and rectangular cross sections can be simulated. It is also useful for process control, quality control and production management.

Most theoretical studies have been developed based on the membrane theory and subsequently the effect of bending is ignored. However, bending under the peripheral tension or compression causes the thinning pipe; thus, the bending effect may not be neglected and the membrane theory cannot be applied. On the other hand, if the bending is taken into account in the finite element method, a large number of elements and also much calculation time are needed.

For these reasons, this study aims to develop a two-dimensional elasto-plastic theoretical method to analyze and optimize reshaping processes. The developed method introduces a new type of contact model, considered a method to deal with wall-thickness change and is able to handle various roll profiles. Through the analysis, geometrical characteristics and deformation behavior of cross sections of pipes are investigated under required conditions to satisfy the equilibrium equations of peripheral and radial forces and peripheral bending moments [4].

Moreover; the numerical analyses of forward and backward deformations of the pipe are performed by the above-mentioned analysis method and a design method has also been developed to determine the number of rolls, ideal roll profiles and an appropriate arrangement of rolls at each stand [5]. However, the shear deformation between two nearby elements was not considered.

P. Alinezhad is Faculty Member of Islamic Azad University Saveh Branch, Engineering Department, Islamic Republic of Iran (phone: +98-255-2241511; fax: +98-255-2240111; e-mail: p.alinezhad@ yahoo.com).

A. Sanati is Faculty Member of Islamic Azad University Takestan Branch, Mechanical Engineering Department, Islamic Republic of Iran (phone: +98-282-2245324; fax: +98-255-2231557; e-mail: alisanati@Mohand.es).

K. N. Momtahen is Faculty Member of Islamic Azad University Saveh Branch, Engineering Department, Islamic Republic of Iran (phone: +98-255-2241511; fax: +98-255-2240111; e-mail: k.momtahen@ iau-saveh.ac.ir).

II. Method of Analysis

In this analysis, the cross-section of pipe is divided into the appropriate number of elements in the peripheral direction. In this method, the cross section of the pipe is divided into an appropriate number of elements named 1, 2... i... nd from the mid-part of the cross section in the peripheral direction as shown in Fig. 1.

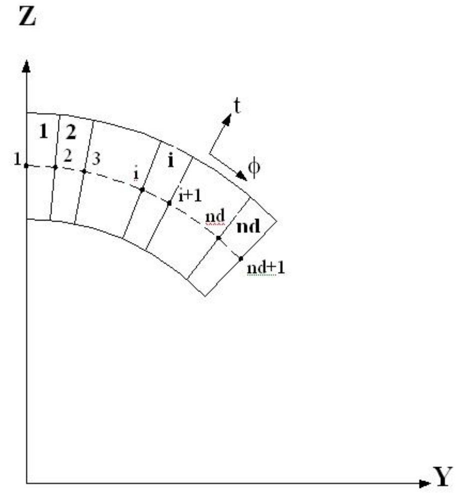

Fig. 1 The cross section of the pipe and the divided elements in the peripheral direction

Each element is also divided into ne small elements in the thickness direction called “sub-element” and named 1, 2...j... ne from the inside of the pipe as shown in Fig. 2. The thickness of sub-elements are hi1 ‘ ... ‘hij ‘ ... ‘hine. The position of the border (nodal point) i is expressed by the components (yi, zi).

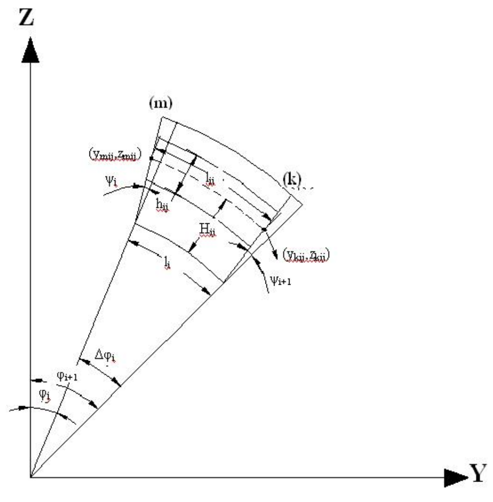

Fig. 2 The divided sub-elements of each element of cross section in the radial direction

In order to consider the shear deformation between two nearby elements in analysis, the extended Kirchhoff-Love assumption [6], i.e. the border planes of elements are not reminded perpendicular to the peripheral surface of pipe during deformation, is used.

To simplify the analysis, the longitudinal strain is neglected, so that the deformation will be the plane strain deformation. The curvature of each element is fixed in the peripheral direction.

The peripheral lengths of the element i and the sub-elements i,j are

$$l_i = \sqrt{(y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2} \tag{1}$$

$$l_{ij} = l_i + (\varphi_{i+1} - \varphi_i - \psi_{i+1} + \psi_i) H_{ij} \tag{2}$$

where Hi,j is the distance from the mid-surface of the element i to the sub-element i,j expressed by

$$H_{ij} = \frac{1}{2}(h_{i1} + h_{i2} + \ldots + h_{ij-1} - h_{ij+1} - \ldots - h_{ine}) \tag{3}$$

The strain increments in the longitudinal direction x, the peripheral direction ϕ, the thickness direction t and the shear strain of the sub-element i,j are defined as:

$$(d\varepsilon_x)_{i,j} = 0 \tag{4}$$

$$d(\varepsilon_\phi)_{ij} = \frac{dl_{ij}}{l_{ij}} \tag{5}$$

$$d(\varepsilon_t)_{ij} = \frac{dh_{ij}}{h_{ij}} \tag{6}$$

$$d\gamma_{ij} = d\psi_i \tag{7}$$

The equilibrium equations of forces in the radial and peripheral directions and the peripheral bending moment about x-axis are as follows (Fig. 3)

$$\begin{aligned} &-N_{i+1}\sin(\varphi_{i+1} - \psi_{i+1}) - N_i \sin(\varphi_i + \psi_i) - \\ &Q_{i+1}\cos(\varphi_{i+1} - \psi_{i+1}) + Q_i \cos(\varphi_i + \psi_i) - P_i = 0 \end{aligned} \tag{8}$$

$$\begin{aligned} &N_{i+1}\cos(\varphi_{i+1} - \psi_{i+1}) - N_i \cos(\varphi_i \\ &+ \psi_i) - Q_{i+1}\sin(\varphi_{i+1} - \psi_{i+1}) - Q_i \sin(\varphi_i + \psi_i) = 0 \end{aligned} \tag{9}$$

$$\begin{aligned} &(M_{i+1} - M_i) + N_{i+1}\sin(\varphi_{i+1} - \psi_{i+1})\frac{l_i}{2} - N_i \sin(\varphi_i + \psi_i)\frac{l_i}{2} \\ &+ Q_{i+1}\cos(\varphi_{i+1} - \psi_{i+1})\frac{l_i}{2} + Q_i \cos(\varphi_i + \psi_i)\frac{l_i}{2} = 0 \end{aligned} \tag{10}$$

In Fig. 3 P_i is a contact force between roll and pipe on the element *i*. N_i, Q_i and M_i are the peripheral, radial (shear) forces