Analysis of the tube piercing process types in terms of final product properties

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Abstract. The rotary tube piercing (RTP) is the first process of making seamless tube after producing the desired alloy ingot. There are several ways to make a seamless tube, one of the most common being RTP. This approach covers a wide range of processes that are categorized according to the number and shape of the rollers. On the other hand, each of these types has designed guides in the output and input of the piercing process. In this article, a new design of input and output guide for all types of rollers have been examined and simulated. Thus, three specimens including Diescher and Conical rollers were considered with 3 and 2 numbers, respectively. Results including torque, total force, temperature distribution and strain were extracted using FEM simulation. The results obtained through simulation are more in line with the experimental results obtained from previous research. While showing the successful performance of the output and input guides of the RTP process, the results indicate that the 3-roller Diescher type RTP has the most suitable arrangement for seamless tube production.

Keywords: Seamless tube, FEM, rotary tube piercing,

1. Introduction

The rotary tube piercing (RTP) process is one of the most common and efficient methods for producing seamless tube. On the other hand, this process is the first stage of production of the seamless tube, after the extraction of the desired material ingots. Therefore, examining the final product properties of the process can significantly shorten and facilitate other stages. Thus, the RTP types are selected according to the requirements for the final product and other operational parameters. There are two types of RTP: two rollers and three rollers. Each type has specially designed components, which include different shapes of the guides at the before or after or during the rolling zone. Also, mainly the shape of rollers includes: Conical and Diescher. Due to the wide range of types and components used in RTP, investigations have been done by other scientists and researchers.

Ding et al. (2018) implemented RTP as a new technology for manufacturing magnesium seamless tube. Also, they claimed the 400 °C is the optimum temperature in terms of microstructure, uniformity of deformation, the penetration rate in the workpiece, and stress concentration. Gamin et al. (2020) studied the benefits and defects of the two rollers and three rollers for different application. The obtained results suggest that the process via two rolls can create a high accuracy in terms of the surface roughness of the tube. Komori and Mizuno (2009) investigated the angles within the piercing process and also the shear strain through the experimental and numerical model. Besides, they applied for the cone type roller within the process. Thus, they showed the shear strain (γϑz) is independent on the feed angle at the cross angle 20 degrees. Mao et al. (2020) implemented two sets of the process tandemly: the piercing and the rolling. Based on the experimental outcomes, the maximum piercing force belongs to the 42CrMo between steel 1045 and AZ31. Pater et al. (2019) performed a comparison between three rollers piercing
and two rollers. They claimed that the three-roller process has more favourable outcomes to produce the seamless tube. But still, the challenges of examining three rolls process have been left in the functional condition in terms of the longevity of the process components. Roman'tsev et al. (2018) implemented the new technology, based on the piercing process for the seamless tubes with high accuracy in terms of wall thickness. Consequently, they applied two types of the mandrel for piercing; high elongating with the conical shape and low elongating with the cylindrical shape. Zhang et al. (2020) developed the nickel-base thick wall tube piercing regards to optimization of parameters variations of process and solution investigation of layers separation phenomena in both surfaces of the tube. They expressed that high temperature and large strain are factors which can increase the external separation in range of \( r/R = 0.8 \sim 0.95 \). Murillo-Marrodán et al (2020) carried out the investigation of the thick-wall seamless tubes. The extracted results from experimental and modelling displayed that the main reason for the eccentricity is the interaction of non-uniform temperature distribution in billet and the bending phenomenon of the plug and mandrel. In this case, it seems that the extreme eccentricity has been occurred by the geometry dimensions.

With taking into the previous investigation, in the current study has been examined the impacts of basic parameters for each type of rotary tube piercing. Thus, obtained results lead to select the most suitable approach to manufacture of the seamless tube. Based on operating conditions and facilities, the most suitable method is selected. The results have been obtained based on a considered mathematical model and taking into account the heat transfer conditions between the workpiece and other process components.

2. Materials and methods

In order to investigate RPT, two main types of this process have been modelled through three samples. Therefore, commercial software is used to simulate RTP. Also, the mathematical model has been implemented based on the finite element method. In terms of the mesh study of simulation, due to the increase in the precision of results and the decrease the running time, the most accurate type and element size have been implemented. Take into the nature of the process, the viscoplastic model of the material, heat transfer, and forces and moments have been considered as boundary conditions. Accordingly, the demanded results have been obtained via the three considered sample. On the other hand, in order to validate the mathematical model, a comparison between the experimental results and the simulation based on the total force has been performed.

Based on the number and shape of the rollers used, the process analysis is performed via FEM. The number and shape of the rollers of the simulation samples are as follows:

| № specimens | Number of rolls | Shape of rolls |
|-------------|----------------|----------------|
| 1           | 2              | Conical        |
| 2           | 3              | Conical        |
| 3           | 3              | Diescher       |

![Table 1. The number and the shape of the simulated specimen](image)

Figure 1. The schematic of piercing process. (a): Third specimen with three Diescher rollers. (b): Second Specimen with three Conical
While discussing the geometry of the produced tube and influence of the other process parameters; the feasibility of changing the shape of a conventional disk guide for a two-roller RTP process has been investigated. For this purpose, only one guide was placed at the input and at the output of the process, and a combination of plug and long mandrel was designed. Therefore, the possibility of simplifying the two-roller process was investigated and implemented by removing the guide discs. The schematics of the RTP for two types of process are shown in the figure 1.

In this investigation, the 3D-Deform software has been implemented as commercial software in order to the simulation of piercing rotary tube. Due to the facility of the software, it is possible to simulate this process only by using precise boundary conditions and executing practical parameters. Otherwise, the simulation of the process will not be complete or the manufactured tube will not have the desired geometry. It should be noted the size of ratio, the element type and the number of the elements are respectively: 3.5, Tetrahedral mesh, 25000.

Also, in Table 2, the value of each of the parameters have been stated for each type. In this process, the material used for the workpiece is DIN-C15 and for other members of the AISI-H13 process. Also, the temperature of the workpiece at the beginning of the process is 1200 °C and other components are assumed to be 150°C. The material properties are as follows:

| Material Property          | Steel C15 (DIN) | AISI-H13 |
|---------------------------|-----------------|----------|
| Density                   | 7.85 g/cm³      | 7.76 g/cm³|
| Poisson’s Ratio           | 0.303           | 0.3      |
| Young Modulus             | 210 GPa         | 210 GPa  |
| Thermal Conductivity      | 64 W/m.K        | 28.6 W/m.K|
| Thermal Expansion         | 12 E-6/C        | 10 E-6/C |
| Melting Temperature       | 1540 °C         | -        |

Therefore, the behavior of viscoplastic material flow stress Equation (1) is described as follows [8]:

\[ \sigma_f = 2707.11 \ varepsilon^{-0.003257} T^{-0.13502} \ varepsilon^{0.05494/\varepsilon} T^{0.1529} \]

(1)

Where \( \sigma_f, \varepsilon, T \) and \( \varepsilon \) respectively, are: flow stress [MPa], effective strain - , temperature [C°] and strain rate [S⁻¹]

For friction, the shear stress model is used to describe the friction between the rollers, other components, and the workpiece. The choice of this model from the friction equation is based on large deformation of geometry for hot and dry processes. The Equation 2 has described the friction in RTP [1].

\[ \tau = m \cdot K \] \hspace{1cm} (2)

Where \( \tau, m, k and \bar{\sigma} \) respectively, are : shear stress, Friction factor, material consistency and equivalent stress.

In the mathematical model section, the ALE approach is implemented in FEM simulation. Moreover, in the Mesh section, the tetrahedral mesh is used for meshing the geometry, and due to the large deformation of the geometry during the process, as well as the plug geometry, determining the optimal size ratio will be effective in increasing the simulation accuracy and reducing the simulation time.

In this simulation, the material in question is considered viscoplastic and for other components of the process, the rigid state of the material is assumed. In addition, from the viewpoint of the distribution temperature analysis of the workpiece, heat transfer has been considered between the components
connected to the workpiece. Thus, the temperature distribution is obtained at the end of the process. The initial boundary conditions have been assumed constant for all three specimens due to the compare basic process parameters such as torque and force. The Alpha angle is one of the most important parameters in this process that determines the rotational and axial velocity of the workpiece. As well as, it has a significant effect on temperature distribution by reducing the processing time. Also, the temperature distribution is directly proportional to the torque and force of the rollers. In mathematical model, while examining the feasibility of the two-roller process without a disc guide and replacing it with an input guide, a long mandrel is used at the output to guide the pipe path, out of the rolling area. The new design, while simplifying the production process of seamless pipes, the parameters affecting the heterogeneous deformation of the workpiece, such as disc guides, have been removed. Therefore, the quality of the workpiece has been increased after rolling, and the process has become more controllable. It should also be noted that due to the complexity of the RTP process, the components of the process should be designed to fit within each other. The mismatch between the geometric and kinetic parameters of the process components can lead to the reduction in the speed, failure or cessation of the piercing process. Therefore, the design of the geometry parameters of the rollers and the mandrel and the inlet guide must all fit together.

3. Results and discussions

In this section, have been simulated and analyzed the most appropriate dimensions and adjustment of the RTP process while showing the feasibility of new design and simplification of the process at the RTP process. As mentioned in the previous section, to avoid trial and error in operating conditions and cost loss, as well as due to the advanced dynamics of the process, all dimensions, coordinates, and dynamic and kinetic parameters of the process components need to be simulated. Changes in process parameters such as roller rotation speed, angles and distance of the plug from the billet and the applied force of pusher can lead to cracks in the workpiece during the piercing process at the tip of the plug or non-uniformity of the wall thickness. It should also be noted that this process is only suitable for creating the initial shape of the seamless pipe from the produced ingot and only the uniformity of the pipe geometry is one of the most important design goals of this process. Therefore, to change the size and increase the accuracy of geometric dimensions or pipe tension and change the pipe diameters, more controllable processes such as radial forging are recommended.

In order to the validation of the mathematical model, the RTP process was simulated with three Diescher rollers at a 10° angle as the feed angle. Therefore, in the first 5 seconds of the process, a comparing was carried out between simulation and experimental results. The exerted forces in the simulation have an average of 53.199 KN and the experimental results have an average of 48 KN [6]. Thus, comparing the force values and the fluctuations during the process allow confirming the accuracy of the FEM simulation.

After mathematical modelling and carrying out simulation via FEM software, the results extracted from all three types of assumed processes are shown. Table 4 shows the comparison between the production pipe parameters of all three types of RTP processes. In addition, it expresses the amount of transfer torque to the rollers and the average force applied between the rollers and the workpiece.

| Results                        | Number specimen 1 | Number specimen 2 | Number specimen 3 |
|--------------------------------|-------------------|-------------------|-------------------|
| Tube length [mm]               | 204.2             | 206.8             | 213.9             |
| Outlet diameter [mm]           | 66.07             | 64.9              | 62.51             |
| Inlet diameter [mm]            | 25.37             | 27.84             | 28.153            |
| Wall thickness average [mm]    | 20.22             | 18.13             | 17.35             |
| Final surface area [mm^2]      | 53028             | 57064             | 60915             |
| Force average[KN]             | 75.80465658       | 39.4119268        | 42.67810227       |
| Torque average[N/m]           | 1276.14919        | 917.9283054       | 1084.09141        |

Table 4. The results comparison of each simulated specimen
Figure 2 shows the amplitude of the applied force for all 3 specimens. According to the results, the highest force has been exerted by first specimen rolls. Besides, the lowest average is related to the forces which exerted by the Diescher rollers. On the other hand, the amplitude variations of force at the third specimen is less than other samples; which can indicate low vibration the piercing machine and consequently the uniformity of the surface of the production pipe. The application of the less force by the rollers can indicate less frictional force between the part and the rollers. This phenomenon can help to increase the life of rollers and reduce the wear in them.

Figure 3 shows the strain distribution during the piercing process at the final 15 mm. As the strain distribution in the longitudinal section of the workpiece shows, the process with two rollers has the highest strain, which is in accordance with the other results of previous experimental studies [7]. On the other hand, the strain distribution in sample three has a smaller value while it has a more uniform distribution.

Figure 4 shows the temperature distribution of the workpiece during the process at the final 15 mm. Based on the obtained results, the uniformity of its temperature distribution can be a factor to prevent the eccentricity of the workpiece and the production of seamless pipes with uniform thickness in the wall. Therefore, the homogeneous temperature distribution in sample No. 3 (Diescher) produces a tube with a better wall thickness uniformity.

Figure 5 exhibits the total velocity on the axial section of the workpiece at the final 15mm. Regarding the velocity distribution, the three rollers conical type include the less penetration rate in the material. Accordingly, it can be expressed the less contact surface between workpiece and rollers lead to the less total velocity in the workpiece and obviously the time of process increases.
4. Conclusions

In this paper, while examining three models of the most common types of RTP processes, the optimization in the design of the input guide in order to simplify and feasibility the manufacturing process was investigated. On the other hand, a comparison was made between the properties of the pipe produced from the three samples, the results which can be used to select the most appropriate type of piercing process. Based on this, the extracted results can be expressed as follows:

1. While implementing the new design, through the designed guide, the o-wall deformation of the workpiece was eliminated and the seamless tube was obtained with greater uniformity in thickness and surface as a result of the simulation output.

2. According to the results, the highest average force has been applied by the conical type with two rollers and the lowest average force belonged to the Diescher type with three rollers with the value of 42.67 KN. In terms of average torque applied during the process, the conical type with three rollers has a lower value than the Diescher type due to the reduction of the contact surface in this type.

3. The uniform distribution of strain in the wall of the produced tube and on the other hand the uniform distribution of temperature along the tube, indicate the higher quality of the tube produced by specimen three. Besides, the higher penetration velocity in the third specimen leads to the manufacturing of the seamless tube at a shorter time. Thus, based on these parameters it can be claimed that the three-roller sample with Diescher type has more advantage for the production of seamless pipes in these dimensions.

5. References

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