INVESTIGATION FOR SHEET WIDTH AND THICKNESS DURING PIPE MANUFACTURING BY ROLL FORMING IN A ROLLING MILL

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Abstract: The paper experimentally investigate the anisotropic elastic properties of sheet metal and to find the satisfactory correlation between the strip widths, thickness to the diameter of steel pipe. The work has been focused to investigate the variation in strip thickness, while forming the strip in a rolling mill for constant roller loads and constant line velocity. It was found that there is negligible change in the thickness of the strip while forming. In other words, the strain in the thickness direction is negligible while the stretch in the width direction of the strip is almost increasing linearly with the increase in the thickness. In other words, the strain in the circumferential direction is considerable.

Key words: steel pipe, anisotropic elastic properties, rolling mill, strip thickness & width, steel pipe diameter, strain

Istraživanje širine i debljine ploča u procesu proizvodnje cevi profilnim savijanjem valjaka. U ovom radu su ispitivane anizotropne elastične osobine lima i tražena je zavisnost između širine i debljine trake lima u odnosu na prečnik cevi. Istraživanje je fokusirano na variranje debljine lima tokom oblikovanja lima u cevi pri konstantnoj sili valjaka i brzini proizvodne linije. Primećena je neznatna promena debljine trake lima pri oblikovanju. Drugim rečima napon u pravcu debljine lima je zanemarljiv dok je rastezanje u pravcu širine trake približno linearno sa povećanjem debljine. Sto znači da je napon po obimu popriličan.

Ključne reči: čelične cevi, anizotropne elastične osobine, linija za profilisanje pomoću valjaka, debljina i širina trake, prečnik čelične cevi, deformacije

1. INTRODUCTION

Pipe manufacturing refers to how the individual pieces of pipe are prepared in a pipe mill; it does not refer to how the pieces are connected in the field to form a continuous pipeline. Each piece of pipe formed by a pipe mill is called a length. Steel pipes are long, hollow tubes that are used for a variety of purposes [1]. The majority of steel products are made from these four primary forms of raw steel: ingots, billets, blooms and slabs. These forms can be produced in huge volumes and are easily re-heated, extruded, squeezed or formed into many other configurations so as to make nearly every steel product used today. Steel pipe is produced from these two fundamental forms of steel, the round billet and the slab. A billet is a solid round bar of steel used to make many other downstream products such as seamless pipe. The other types of steel pipe are manufactured from slabs that are solid rectangular blocks of steel. The slabs are reheated and processed into plate and coils. Broadly, production of steel pipe is grouped into two general categories: Welded and Seamless. In both, raw steel is first cast into a more workable preparatory form. It is then made into a pipe by stretching the steel out into a seamless tube or forcing the edges together and sealing them with a weld. Further, there can be following methods used to produce steel pipe: Lap Weld, Electric Resistance Weld, Flash Weld, Double Submerged Arc Weld and Seamless [2].

The first methods for producing steel pipe were initiated in the early 1800s and they have gradually progressed into the new processes we utilize today. Different authors have explained the manufacturing of pipes in their unique way. Here two best elaborated descriptions are presented so as to understand the basics and concepts involved in pipe manufacturing. As per the first explanation, historical aspect along with evolution of production processes for pipe manufacturing is clearly stated. At first, pipe was manufactured by hand – by heating, bending, lapping, and hammering the edges jointly. The foremost automated pipe manufacturing process was commenced in 1812 in England. The utilization of lap welding to manufacture pipe was introduced in the early 1920’s. In the lap welding process, steel was heated in a furnace and then rolled into the shape of a cylinder. The edges of the steel plate were then “scarfed”. Scarfing involves overlaying the inner edge of the steel plate and the tapered edge of the reverse side of the plate. The seam was subsequently welded using a welding ball and the heated pipe was passed between rollers which forced the seam together to build a bond. The welds formed by lap welding are not much reliable as compared to shaped using more modern methods. Based on the type of manufacturing process, the American Society of Mechanical Engineers (ASME) has developed an equation for calculating the permissible operating pressure of pipe. This equation comprises a variable called a joint factor, which is dependent on the type of weld used to create the seam of the pipe. A joint factor of seamless pipe 1.0. Lap welded pipe has a joint factor of 0.6. Electric resistance welded (ERW) pipe is manufactured by cold-forming a sheet of steel into a cylindrical shape. Current is subsequently passed
between the two edges of the steel to heat the steel to a point at which the edges are forced together to make a bond without the utilization of welding filler material. In the beginning this manufacturing process used low frequency alternating current to heat the edges. This low frequency process was used from the 1920’s until 1970. In 1970, the low frequency process was outmoded by a high frequency ERW process which produced a higher quality weld. Eventually, the welds of low frequency ERW pipe were found to be prone to selective seam corrosion, hook cracks and poor bonding of seams. Accordingly low frequency ERW is not used to manufacture pipe these days. The high frequency process is still being utilized to manufacture pipe for use in new pipeline construction. Electric flash welded pipe was first manufactured in 1927. Flash welding was carried out by forming a steel sheet into a cylindrical shape. The edges were heated until semi-molten, then forced together until molten steel was forced out of the joint and formed a bead. Like low frequency ERW pipe, the seams of flash welded pipe are vulnerable to corrosion and hook cracks, but to a lesser extent than ERW pipe. This type of pipe is also at risk to failures due to hard spots in the plate steel. Because the bulk of flash welded pipe was produced by a single manufacturer, it is supposed these hard spots arose due to accidental quenching of the steel during the manufacturing process utilized by that particular manufacturer. Flash welding is no longer employed to manufacture pipe. The manufacture of Double Submerged Arc Welded Pipe also involves first forming steel plates into cylindrical shapes. The edges of the rolled plate are formed so that V-shaped grooves are created on the interior and exterior surfaces at the location of the seam. The pipe seam is then welded by a single pass of an arc welder on the inner and outer surface (therefore double submerged). The welding arc is submerged under flux. The benefit of this process is that welds pierce 100% of the pipe wall and make a very strong bond of the pipe material. Seamless pipe has been manufactured since the 1800’s. Seamless pipe is manufactured by piercing a hot round steel billet with a mandrel. The hollowed steel is then rolled and stretched to attain the desired length and diameter. The main benefit of seamless pipe is the eradication of seam-related defects but the cost of manufacture is higher. Early seamless pipe was liable to defects caused by impurities in the steel. Though the steel-making techniques have improved but they have not been totally eradicated. Seamless pipe is presently available in lower grades and wall thicknesses than welded pipe [3].

As per the second explanation, different types of processes that have been used to manufacture various type of pipes along with their specific applications are clearly stated. Steel tubes and pipe can be generally classified according to manufacturing method as seamless tubes and pipe made by hot rolling or hot extrusion, and welded pipe and butt-welded pipe made by bending and welding sheets or plates. When seamless pipe is prepared by rolling, the rolling method involves piercing the material while it is being rolled, and is appropriate for mass production. The Figure 1 shows the manufacturing process utilized in the Mannesmann plug mill, which is a usual rolling process. The Mannesmann-type piercer lessen the material by rolls that are inclined diagonally to each other. When the round billet is rotated while being compressed in the diametric direction, the central part of the billet becomes slack, which makes it simple to pierce a hole through the center. This is called the Mannesmann effect. The pierced portion is enlarged by the elongator and the wall thickness is then thinned and elongated by the plug mill. The internal and external surfaces are smoothed by the reeler and the final dimensional adjustments are prepared by the sizer. The hot-extrusion method involves working in the compressive-stress field. Therefore, it is feature of this method that high-alloy steel pipe of low deformability can be formed along with heavy-wall and large-diameter pipes. Seamless pipe has exceptional homogeneity in the circumferential direction and is thus highly resistant to internal pressure and torsion. Hence, seamless pipe is commonly used for drilling and pumping petroleum and natural gas. Welded pipe is divided into electric-resistance welded (ERW) pipe, spiral pipe, and UO pipe based on the forming and welding method. ERW pipe and butt-welded pipe are manufactured by continuously forming a hot-rolled coil into a tubular shape by forming mills. ERW pipe is manufactured by cold forming, and the seam is welded by electric-resistance welding. This type of steel pipe is utilized in large quantities as line pipe for transporting petroleum and gas. Butt-welded pipe is manufactured by hot forming after the entire material has been heated and seams are then butt welded. This type of pipe is hot-dip galvanized and utilized for transporting water and gas. The outer diameter of ERW pipe and butt-welded pipe is determined by the width of the material coil. Spiral pipe is made by forming the coil into a spiral shape, that makes it doable to attain a large outer diameter despite of the width of the material. UO pipe is typically large in diameter and manufactured one piece at a time by forming plates. Firstly, the plate is pressed into a U shape by the U-press and then into an O shape by the O-press. Because comparatively thick material is utilized for building spiral and UO pipes and submerged arc welding is utilized for joining. The major purpose of spiral pipe is pipe piles.

Fig. 1. Manufacturing Processes for pipes[4]
UO pipe is chiefly utilized as line pipe for transporting petroleum and natural gas in huge quantity over long distances [4].

Originally category of pipes that contains a solid phase butt weld was manufactured by means of resistance heating to create the longitudinal weld (ERW), however most pipe mills currently use high frequency induction heating (HFI) for better control and consistency. Figure 2 shows a diagrammatic representation of the HFI welding. The process occupies the relevance of a high-frequency alternating current in the range 200 to 500 kHz with the tube forming and energy input operations being performed by separate units. This welding method again simultaneously utilizes pressure and heat in order to join the strip edges of the open-seam tube together without the addition of a filler metal. Squeeze and pressure rolls in the welding stand bring the edges of the open-seam tube gradually together and apply the pressure necessary for welding. The open-seam tube 1 to be welded is introduced in the direction of the arrow to the welding table where it is engaged by the squeeze rolls 5. These initially press together the incoming open seam edges approaching at angle 2. The high-frequency current supplied by the welding generator 4 forms an electro-magnetic field around the induction coil 3 which induces an AC voltage in the open-seam tube corresponding to a current travelling around the tube circumference. This current is focused at the open seam edges and travels next to edge a through point 6 to edge b and back to the circumferential plane of the induction coil, with the circuit being closed at the rear of the tube. The heated edges are pressed together and welded by the squeeze rolls 5. The internal and external ridges (weld flashes) which form are trimmed from the finished weld 7 [5].

If the plain strain conditions are assumed in this condition, the strain in circumferential direction is given by [6]

\[
\varepsilon_1 = n \left( 1 + \frac{\sigma_3}{E} \right) = n \left( 1 + \frac{t_0}{aR} \right)
\]

where: 
\( \varepsilon_1 = \) Strain
\( t_0 = \) Initial Thickness
\( R = \) Radius of roller
\( a = \) material and geometry dependent constant
\( n = \) hardening coefficient

Every year, millions of tons of steel pipe are produced. Its adaptability makes it the most frequently used product produced by the steel industry. Steel pipes are found in different places. Because they are tough so they are mostly used underground for transporting water and gas all the way through cities and towns. They are also utilized in construction to guard electrical wires. As steel pipes are strong, they can as well be lightweight. This makes them ideal for utilization in cycle frame manufacture. Steel pipes also find their application in vehicles, refrigeration plants, heating and plumbing systems, flagpoles, street lamps etc. The first manufacturing plant to use welded pipe is formed by rolling steel strips through a series of grooved rollers that mold the material into a circular shape as shown in Figure 4. Subsequently, the un-welded pipe passes by welding Electrodes. These devices close the two ends of the pipe together [1].

Table 1 shows chronological survey of pipe material used and its manufacturing techniques

<table>
<thead>
<tr>
<th>Year</th>
<th>Material used and manufacturing Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 BC</td>
<td>Clay tubes were used by Chinese for transporting water.</td>
</tr>
<tr>
<td>1652</td>
<td>Bamboo tubes were used to transport water.</td>
</tr>
<tr>
<td>1800’s</td>
<td>Welded Steel Tubes.</td>
</tr>
<tr>
<td>1820’s</td>
<td>Edges of a flat iron strip were joined to produce tubes patented by James Russell.</td>
</tr>
<tr>
<td>1880’s-1890’s</td>
<td>Tube was made by drilling a hole through the center of a solid cylinder.</td>
</tr>
<tr>
<td>1950’s</td>
<td>Roll forming of strips to make pipes in large quantity.</td>
</tr>
<tr>
<td>Upto 2000</td>
<td>Continuous research in the pipe/tube manufacturing by joining seam of strip.</td>
</tr>
</tbody>
</table>

Table 1. Chronological Survey of Pipe material used and its Manufacturing Techniques

If a strip is dragged over a curved tool then there is a contact stress acting on the strip. This contact stress alters the stress state in the material that was investigated by a few of the researchers with a simple
model. It has been found that the yield stress in tension is reduced. Forecasting by these models concur with observation from a 90° bending test found in literature and not directly with observation from a stretch-bend test also found in literature [6]. In accordance with the great importance given to the subject of stiffness degradation, in particular with regard to metal forming, this work aims to experimentally investigate the anisotropic elastic properties of sheet metal (steel IS:10748, also IS:6240). In the past, many researchers investigated the pipe manufacturing processes, but the satisfactory correlation between the strip widths, thickness to the diameter of steel pipe has not been found. So the present work aims to investigate the minimum strip width required for different thicknesses of steel strips while manufacturing the pipes.

2. LITERATURE REVIEW

Cage roll forming process was simulated with the explicit elastic–plastic finite element method in the MSC Marc Mentat software. Simulation results have shown that by increasing the initial strip width, more circumferential length reduction was induced to the deformed strip in the fin-pass stands. The difference of longitudinal strains at the edge and center of the deformed strip has been increased by this effect. As a result, it has lead to a high longitudinal compression at the strip edge. Thus, edge buckling would be unavoidable if the initial width is selected bigger than a specific limit. The circumferential length and the horizontal distance between two deformed strip edges were obtained from the simulation and were compare with the experimental data from a production line. The comparison has shown that a good concurrence was found with the finite element simulations [7]. The whole cage roll-forming process was simulated with the explicit elastic–plastic finite element method. The strip deformation during the cage roll forming process was investigated. The “non-bending area” phenomenon was found and the ranges of the non-bending area at different forming stands were obtained through simulation. As well, the longitudinal strain at the inside edge and center were predicted. Further by comparison it has been observed that the deformation of the strip edge was usually larger and edge buckling is most likely to occur at the entry sides of No.1–No.3 fin-pass stands. Lastly, the circumferential length, opening distance and the profiles of the deformed strip were measured on the cage roll-forming mill. A good agreement between the experimental and simulated results were obtained [8]. Influences of foremost process parameters of thermomechanical tube-spinning process i.e. preform thickness, thickness decrease, mandrel rotational speed, rollers feed rate, solution treatment time & aging treatment time on internal diameter growth and wall thickness changes for manufacturing of 2024 aluminum spun tubes using design of experiments were determined by authors. It has been found that lower thickness reduction with thin preform thickness, high feed rate of rollers, low mandrel rotational speed and low solution treatment time have benefits for obtaining smaller internal diameter growth and wall thickness changes [9]. Two aluminum killed draw quality (AKDQ) steels and one high strength low alloy (HSLA) steel were selected to foresee the performance of tube from sheet tensile tests. Tensile properties and plastic strain ratios were measured on sheet material in the longitudinal and transverse directions. Residual stresses in the production and quasi tube were established by displacement methods. Effective strains resulting from tubemaking were calculated for two discrete operation i.e. bending and sizing. A linear relationship was found between a load factor (strength times thickness) and effective sizing strain for the production tubes. The association between load factor and residual stress was also linear [10]. The effect of thickness reduction on mechanical properties and spinning accuracy were experimentally investigated on 7075-O aluminum tube. A prototype spinning machine was designed and manufactured. It has been shown that with augmentation of thickness reduction; the yield point strength, ultimate strength, crystal refining and surface hardness, increase. In contrast, it has had effect on growth of diameter, accuracy of geometry, surface roughness and percentage elongation of spun tube [11], 15 tensile coupon tests and 12 full section tests on VHS tubes were performed. The tested VHS tubes had a diameter varying from 31.8 -75 mm with wall thickness varying from 1.6 -2.0 mm. The non-heat-treated tubes were also tested for comparison purposes. The ultimate strength to yield stress ratio of VHS tubes was compared with different cold-formed hollow sections, sheet steels and quenched/tempered steels. It has revealed that the VHS tubes fulfilled the material ductility requirement specified in the Australian/New Zealand Standard for Cold-Formed Steel Structures AS/NZS4600 [12]. The tube and pipe industries face many challenges that are requests for tube products in a wider variety of shapes and sizes by the end users, applications that require special materials, and demand for improved product quality from manufacturer to produce high quality tubing in a cost effective and productive way in today's marketplace. Different facets of manufacturing, processing, design, utilization, quality control, handling, cost and safety in tube and pipe production has been reviewed to present a general idea relating to these issues [13]. The results of the numerical study of rectangular cup drawing of steel sheets using finite element methods were discussed. For the intention of the results of the numerical solutions, an experimental study was performed where the material behavior under deformation was analyzed. A 3D parametric finite element model was made using the commercial FE-package ABAQUS/Standard. It has been found that plastic anisotropy of the matrix in ductile sheet metal has influence on deformation behavior of the material. Once the material and friction anisotropy were considered in the finite element analysis, it gives better approximate numerical results for real processes. The maximum wall thickness in all directions was observed near the edge of blank, while minimum thickness is at the punch shoulder. The variation of thickness at bottom is relatively small as compared with deformation on the corner. It has been
suggested that FEM method for optimization of initial blank shape is an attractive approach which eliminates time-consuming experimental methods [14]. An experimental investigation to check an accuracy of skelp profile-geometry prediction that can be used to model the strain history during forming was described. Skelp geometries predicted from roll-stand geometries were compared to profiles measured on an actual 16” rolling mill. A method of correcting theoretically-predicted geometry was developed and found to produce good agreement with mill-recognized geometry. Also, it was suggested that skelp geometry predicted from theoretical roll-stand geometries was not sufficiently accurate to adequately define strain state in deformed skelp [15].

3. EXPERIMENTAL DETAILS

To investigate the behavioral relationship between the stretching of the strip in the width direction to form a pipe of certain diameter, the pipe forming line was studied under different working conditions. The parameters which are assumed to be affecting the forming of strips in to pipes are: strip width, strip thickness, speed of rolling mill line, roller loads, strength of the steel strip and type welding method used to join the seam. In the present study, the roller loads, speed of rolling mill line and the welding technique are assumed to be non variable. For investigations in the various geometrical quantities of the steel strip to form a pipe under constant roller loads and line speed, the material for the steel strip was selected as IS:10748 and IS: 6240. The thickness of the strip is measured with the help of micrometer with vernier scale. The variation of initial to final thickness of strip is discussed below:

The observations obtained for thickness reduction were given in Table 2.

The pipe diameter is also measured with the help of micrometer. An initial strip width and final pipe diameter for steel IS: 10748 and IS: 6240 were observed. The observations obtained for width elongations for steel IS: 10748 and IS: 6240 are given in Table 3 and Table 4 respectively.

4. RESULTS AND DISCUSSIONS

From the observation obtained in Table 2, it has been observed that there is a negligible change in the thickness of strip during forming. The figure below represents the Initial Vs. Final strip thickness.

From the observation obtained Table 3, it has been observed that there is a considerable change in the width of sheet while forming. From the observation Table 4, it has been observed that there is a considerable change in the width of sheet while forming. From above it is cleared that there is negligible change in the thickness while a considerable change has been observed in width. This refers to a plain strain condition in which the strain in the circumferential direction is inversely proportional to the radius of the roller and is given by Equation 1.

\[ \varepsilon_c = n(1 + \varepsilon_t) = n\left(1 + \frac{L}{aR}\right) \]  

(1)
Further for Roll forming process, this relation can be extended as shown in equation number 2:

$$\varepsilon_i = n.1 + \sum_{i=1}^{n} \left( \frac{1}{R_i} \right)$$

(2)

2. The stretch in the width direction of the strip is increasing almost linearly with the increase in initial thickness. In other words the strain in circumferential direction is considerable.

From above two conclusions, it may be assumed that for the calculation of strain in width and thickness direction can be calculated on the basis of equation for the calculation of strain in width and thickness.

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5. CONCLUSION

1. From the results of the study it has been concluded that there is negligible change in the initial thickness of a strip while forming/stretching over a roller. In other words, the strain in the thickness direction (radially outward from roller) is negligible.

2. The stretch in the width direction of the strip is increasing almost linearly with the increase in initial thickness. In other words the strain in circumferential direction is considerable.

From above two conclusions, it may be assumed that for the calculation of strain in width and thickness direction can be calculated on the basis of equation for the calculation of strain in width and thickness.

6. REFERENCES