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Research Paper

ENCOMPASSING ROTARY-DRAW-TUBE BENDING PROCESS WITH SHEET METAL ROLLING BY THREE-ROLL-PUSH-BENDING

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Sheet metal bending processes are some of the most commonly used industrial manufacturing operations. The development and optimization of these processes are exhausting and costly. Therefore, FEM may serve as an optimal alternative as the design and quality assurance of sheet metal products in the present study, a commercial legitimate finite element package was used to analyse the three-roller bending of a Steel sheet. Observation with desired curvature radii were established by varying the distance between the two bottom rollers and with respect to the position of the upper one. The developed maps made the rolling process easier and less time consuming. In order to overcome some imperfections of the earlier numerical models of the process and based on the experience gathered with them. The developed system encompasses both sheet metal rolling and pipe bending. An industrial experiment (In Bishno and co. Rabale, Navimumbai) using heightenedapparatus was carried out to validate the numerical model. Residual stress and equivalent plastic strain distributions were also studied. The numerical spring back phenomenon was compared with analytical results.

Keywords: Encompassing, FEM, Bending process

INTRODUCTION

Bent metal tubes is widely applied in many industrial sectors. A fabricated tube, either welded orExtruded in straight tube sections, usually has to undergo post-fabrication treatments. In order to be transformed into a usable product, it is mainly manufactured by special handcraft tools or by CNC machines

The tool-dependent tube bending technologies, like for example the rotary draw bending process, have reached a high degree of reliability and robustness but suffer from a lack of flexibility, since each tool only be used to bent one constant radius for one outer diameter of the tube. The process of tube bending and sheet rolling appear to be

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different, but, the difference is meagre as both are built on same fundamental process of forming. In this report I would like to present the way of encompassing both in single creation. The identification, selection, design desirability, andpromotion of locally modified tools is made possible through the strengthening and redesigning of machine vital components A critical appraisal of locally available metal rolling machines indicated a necessity of improving on economically viable design, system complexity and cost. Many times The complexity of the crank mechanism, the numerous and intricate component parts of the machine defeated the aim of simple technology tool development and manufacture. Considering high cost of tools and products in sheet rolling processes, detection and controlling factors for producing precise product are important. In most processes, geometry and configuration of rolling components could be obtained from the geometry of product at the end of loading. Therefore elastic recovery (known as spring back) formed part of the unloading process, and it is the most important factor in deviation of final products from desired geometry. Spring back is influenced by a combination of various process parameters such as tool shape and dimension, contact friction condition, material properties, thickness, etc.

Three Roll Push Bending Process

In the first stage the plate is kept between top roller and bottom rollers and the top roller is given vertical displacement to get the required bend. In next stage the bottom rollers are driven using motors in forward direction to get the roll bending of the plate. Similarly the rollers are driven in reverse direction to get better dimensional accuracy of the final product. The bent plate is than unloaded by raising the top roller. For continuous single-pass four roll thin plate bending a model was proposed considering the equilibrium of the internal and external bending moment at and about the plate-top roll contact. The process remains intact for the tube bending, but, the set of tools varies according to the diameter.

Factors Influencing Three Roll Push Bending Process

The process based on three holding rolls, one bending roll and other two are setting roll, is driven by axes which are numerical controlled. Among these the C-axis designates the feed of the tube. The setting roll is moved in the bending plane by either rotating around the centre of the bending roll (Y-axis) or translating in radial direction (P-axis). An arc is formed depending on the position of the setting roll defined by P- and Y-axis and the feeding rate of the C-Axis. As the setting roll can be moved while the tube is being pushed forward and since the machine has an additional A-axis allowing for rotation of the tube around the C-axis during the bending process, arbitrary 3D geometries can be bent. However, this paper will be limited to bending constant radii in the plane. In the tree-roll-push-bending process the

Figure 1: Factors Influencing Three Roll Push Bending Process

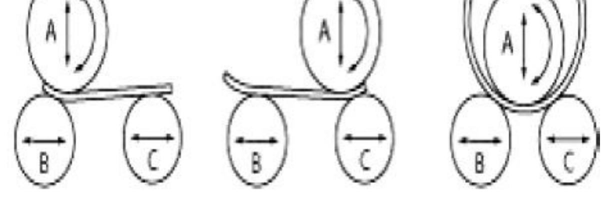


Table 1: Factors and Influencing Parameters

	Factors	Cofactors	Result
Machine	Process parameters P-axis Y-axis C-axis	Machine deflection Friction deflection	Bending radius R(mm)
	Geometry parameters Inner diameter d Outer diameter D Tube length l Material parameter Poison's ratio ¬ Young's modulus E Hardening curve ±(£)	Batch variations of material Spring back	

bending radius is the result of the kinematic-dynamic conditions that occur during the bending process. The bending radius is affected by many influences that can either be attributed to the tube or to the machine. Some of them are known before the process and can be controlled (factors) while others are beyond control (cofactors).

The process parameters have the biggest effect on the bending radius and are controlled by the machine. Geometry and material parameters are defined as tube properties by elastic and plastic properties and can vary due to batch Variations of the material. The variability in material batches is neglected and assumed is to be constant for every job under consideration.

The Process Design (Tube Bending)

The bending plane, as shown in figure bellow, can be introduced as a polar coordinate system with a dislocated centre of rotation in the bending roll. Each position of the setting roll in the bending plane represents one combination of the values for the P- and Y-axis with corresponding bending radius R.

Figure 2: FEA Analysis of Bend

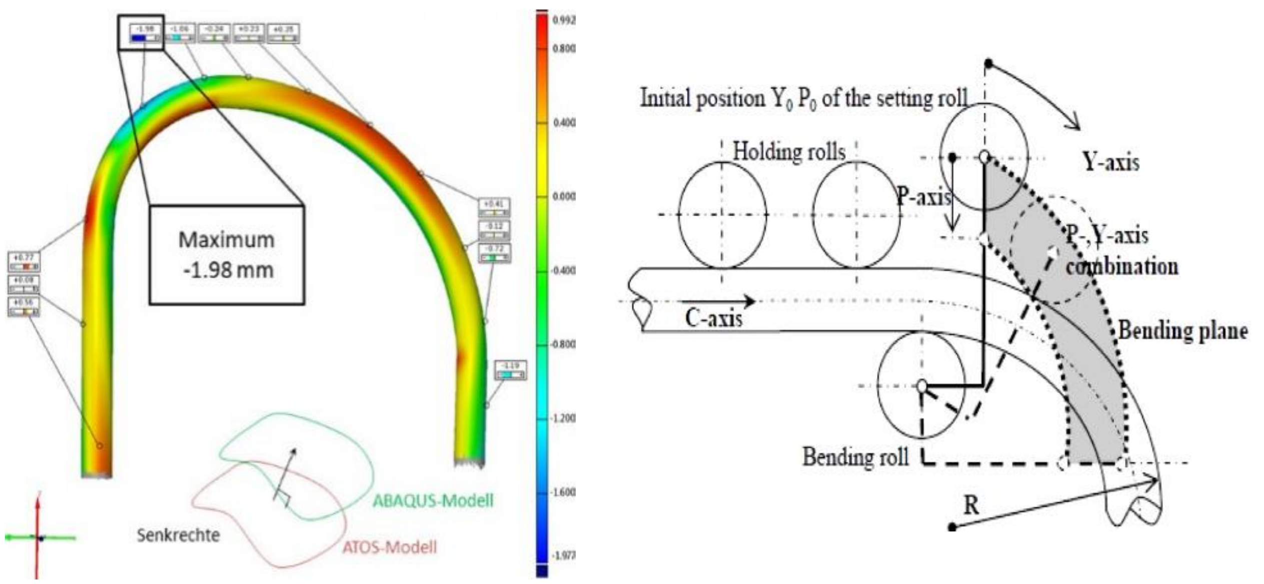
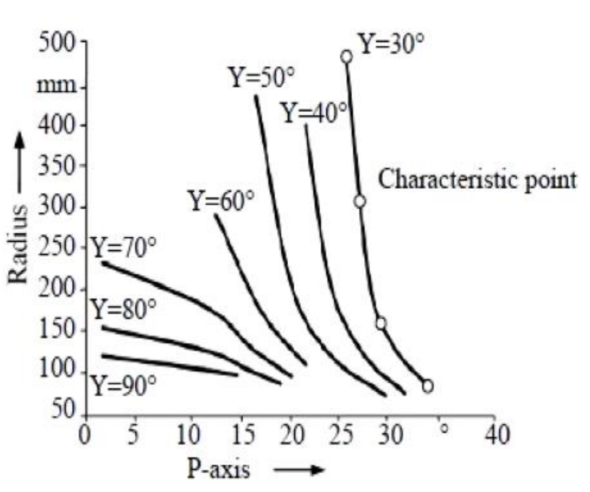


Figure 3: Ratio of Bend



In order to determine the P/Y-combination to be used to manufacture a desired radius, the bending plane, whichConsists of an infinitive number of P- and Y-axis combinations, is approximated by a set of characteristic lines(Figure as follow). These are then used to control the bending machine Wafios BMZ 61, which represents in this case the Three-roll-push-bending process. Each characteristic line of the set is interpolated on the basis of experimentally. Determined bending radii at a number of characteristic points the set of characteristic lines is valid for one specific tube material and specific tube geometry given by the outer diameter and the wall thickness. If only one of these parameters is changed the whole procedure of characteristic line determination has to be repeated.

The Development of the Improved FE-Model

Considering the three-roll-push-bending process characteristics the improved FE-model was developed in the FE-software ABAQUS 6.8. The model was set up by importing and meshing the tool's geometry from available CAD-models of the tools. In order to adapt the numerical model to real process behaviour, the roll positions were

Defined by digitizing the closed tool positions using an optical measurement system. Experimental investigations were conducted for tubes made of carbon steel St 43 with an outer diameter of 60mm and a wall thickness of 6 mm. The same tube was modelled in CAD-software and used for the numerical experiments. The tube discretization was performed by four node shell elements (S4R) with seven integration points and an hourglass control. The size of the elements was 1.2 mm x 1.2 mm. In order to model tube's with a length of 680mm a step time of 0.5 s was set and solved using Abacus/Explicit. An isotropic elastic material model defining the Young's Modulus as 210 000 N/mm^2 and the Poisson number to be 0.3 was used. Further input data for the description of the plastic isotropic behaviour of the material, like hardening curve and anisotropy values, were evaluated by appropriate testing procedures. The tensile test was employed to determine the hardening curve.

The guiding mechanism has the shape of an *L* and is built by three elements. The first element, which is fixed atthe first point placed in the centre P_0 of the global coordinate system $\{x_0, y_0\}$ *v v* and extends for the length l_1 ending in point P_1, can be rotated. This rotation in the global coordinate system simulates the Y-axis as variable ~. Point P_2 is defined starting at P_1 and using the local coordinate system 1 1 $\{x, y\}$ *v v*. The element, which connects P_1 with P2, is the guiding of the P-axis. The setting of the P-axis is modelled as variable p. The element is split in two parts, where l_2 is fixed and p is variable in length. The connection angle between the first and the second element is 90°. The final element of this model is a variable representing the deflection of the setting roll. The element which extends under the influence of the force for a defined length u_1, is connected to P_2, defined using the local coordinate system $\{x_2, y_2\}$ v v and P_3 in the local coordinate system 3 3 $\{x, y\}$ v v. The centre of the setting roll is P_3. The roll's mass m is concentrated in this point. P_3 can thus be defined as a forward kinematical position using the homogenous transformation matrix T_n.

$$P_3 = \begin{pmatrix} X_3 \\ X_3 \\ 1 \end{pmatrix} = T_n \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

The T_n are homogenous transformation matrices defined for each of the four local coordinate systems as, where T_1 is the rotation and T_2, T_3 and T_4 represent the different translations:

$$\begin{pmatrix} X_3 \\ Y_3 \\ 1 \end{pmatrix} = T_1 T_2 T_3 T_4 \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} X_3 \\ Y_3 \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\sim & \sin\sim & 0 \\ -\sin\sim & \cos\sim & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & -1 & L_1 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

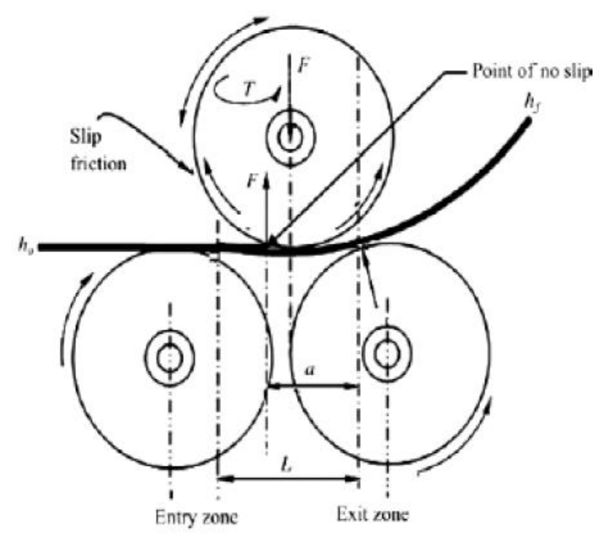
$$\begin{pmatrix} 1 & 0 & L_2 + P \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & U_1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} X_3 \\ Y_3 \\ 1 \end{pmatrix} = \begin{pmatrix} L_1 \cos\sim + (L_2 + p + U_1)\sin\sim \\ L_1 \sin\sim + (L_2 + p + U_1)\cos\sim \end{pmatrix}$$

Design Consideration for Sheet Metal Rolling

Following basic shearing operation on a sheet metal, components can be rolled to give it a definite shape.Bending of parts depends upon material properties at the location of the bend. To achieve bending, the work material must be subjected to two major forces; frictional force which causes a no-slip action when metal and roller came in contact and a bending force acting against the forward speed and the torque applied to move the material.

Figure 4: Three Point Bar Bending



At least two rollers were involved in flat rolling depending on the thickness and properties of material while three or multiple roller system is required in shape rolling. A work material under bending load is subjected to some form of residual stress and deformation as it bends. Materials at the outer bend radius undergo tensile plastic deformation while the material at the inner bend radius undergoes compressive plastic deformation. The width along the bend radius will reduce in length based on Poisson's ratio and if the bend radius is too small, the plastic deformation at the outside of the bend results in fracture

$$L_b = {}^{-}\left(r + \text{©}T\right)$$

where, L_b = bend allowance; ¯ = bend angle; r = bend radius to neutral axis; © = constant for material, for $r < 2T$; $k = 0.33$; for $r > 2T$, $k = 0.5$, T = thickness of material.

The strain on the outermost fibres of the bend is evaluated by Equation

$$\text{£} = \frac{1}{\frac{2r}{T} + 1}$$

Maximum bending force is calculated by Equation is given below

$$\frac{\pm_{yield} LT^2}{W} = \frac{\pm_{ultimate} LT^2}{W}$$

where, P = maximum bending load; k = constant for particular die from 0.3 to 0.7; $\pm_{yield}$ = yield stress for material; $\pm_{UTS}$ = ultimate tensile stress for the material; L = length of bend (along bend axis); W = distance between reaction supports. When the rollers are in contact with the load, there is a frictional force existing, and an applied force, F and aslip between rollers and the load, which is not constant over the entire surface area of contact. An assumption of no reduction in size of material thickness during rolling makes, the thickness uniform, i.e., and for small diameter bending, $a = L$. For large diameter bending $L > a$.

$$\text{«}^2 r = h_f - h_0 = Maximum\ draft$$

where, « = frictional force 0.4 Nm^{-1}; h_0, h_f = thickness of the sheet before and after time t. Analytical solutions of bending process have been presented by several researchers however, for inverse analysis of spring back in free bending process, a state of plain strain and negligible shear deformation is assumed. Strain components; the elastic strain (£_e) and plastic strain (£_p), the total axial strain (£_x) can be written as Equation

$$\text{£}_x = \text{£}_e + \text{£}_p = \frac{\left(1 - \text{¬}^2\right) \pm x}{E} + \text{£}_p$$

where, £_x = total axial strain; £_e = elastic strain; £_p = plastic strain; E = Young's modulus, V = Poisson's ratio.

Required bending moment (M) can be calculated as Equation

$$M = \int_A \pm_x y dA$$

where, A = area of shaft; $\pm_x$ = axial stress; y = radial arm in mm.

Bend radius after spring back can be written as Equation

$$\text{°}' = \frac{1}{\frac{1}{\text{°}} - \frac{12M\left(1 - v^2\right)}{bt^3 E}}$$

where, ° and °' are bending radius before and after spring back respectively. Knowing the thickness and width of sheet plate and considering material's behaviour, analysis of V-bending for various bending angle and radius become possible. The power required to roll the material is given by Equation

$$P = force \times velocity = \left(LW_{\text{¥}ave}\right) \times \left(2\text{®}\ rn\right)$$

where, P = power in watts required to roll the sheet and n = speed in $rmin^{-1}$.

The spring back effect in bending is compensated by the following Equation

$$\frac{\pm_{before}}{\pm_{after}} = 4\frac{\text{¥}_{before} \pm_{yield}}{ET} - 3\frac{\text{¥}_{before} \pm_{yield}}{ET} + 1$$

where, $\pm_{before} = \pm_{after} = 1$ for flat sheet; £== Bending strain.

Performance Evaluation

Performance evaluation of the fabricated machine was carried out in the Bishno and company. The field test was performed with four randomly sampled welders and tinsmiths selected within the local government area. The capacity of the machine was evaluated based on the maximum width of strips of metal that can be rolled without exceeding the designed maximum bearing load and the numbers of operators required to conveniently operate the machine without overbearing efforts. Maximum length capacity of the machine is determined by the width of material that can conveniently be passed through the aperture without difficulty. The roller aperture is determined by the maximum size opening between the three rollers when aligned axially. The percentage acceptance is determined from the analysis or respondents acceptability of the adapted technology.

Table 2: For Sheet

Material	Thickness (mm)	Width of Work (mm)	Length (mm)
Mild steel	12	1020	1200
Stainless steal	8	1050	1200
Aluminium	5	1200	1200
Mild steel	7	1280	600

Table 3: For Tube

Material	Thickness (mm)	Radius (mm)	Length (mm)
Mild steel	2	80.5	1020
Stainless steel	1	65	1200
Aluminium	2	65	1680
Mild steel	3	85	1280

RESULTS AND DISCUSSION

Figure shows the different steps in the rolling process obtained via numerical computation. Clearly, the distribution of the curvature was asymmetric at about the top contact point (between the top roller and sheet). This finding, which can be explained by the asymmetrical deformation about the maximum bending moment point, the work piece thickness also remained constant after the bending and rolling processes. The goal of the paper was to introduce an improved model of the three-roll-push-bending process. Special effort was to be put on the modeling of the machines deflection. The presented FE-model provides the means to determine the required characteristic lines for a wide range of bending radii at acceptable computational cost and without the need for experiments or machine downtime at satisfying accuracy. Some effort will be put in the definition of the objective function. At the moment the influence of all three rolls to the resulting bending radius is considered equal in so far, as all have the same influence on the objective function. But experiments show, that the influence of the setting roll is much more significant than that of the others. This should be addressed in the model and considered during optimization and might lead to a further improve in accuracy. Moreover it will be interesting to use the optimized FE-model for the simulation of tubes with different geometries and different material properties. At first it has to be seen if the FE-model is providing the same accuracy for different semi-finished products. If there is an influence of the material or the tubes geometry on the simulations accuracy, this might provide a starting point to research the effects of spring back on the three-roll-push-bending process and the resulting bending radii.

REFERENCES

1. Bouhêlier C (1982), "*Formage des tôles fortes*", *Techniques ingénieurs*, B 7630, pp. 5-19 (in French).
2. Cojutti M, Vipavc D, Hagenah H and Merklein M (2009), "An Innovative Approach for the Process Design for Three-Roll Bending of Plain Tubular Components", Proceedings of the International Congress on Efficient Rollforming, pp. 133-139, Bilbao, Spain.
3. Gantner P, Bauer H, Harrison D K and De Silva A K M (2005), "Free-Bending—A New Bending Technique in the Hydroforming Process Chain", *Journal of Materials Processing Technology*, Vol. 167, pp. 302-308.
4. Hagenah H, Vipavc D, Vatter P H, Cojutti M and Plettke R (2010), "Creation of the Data Base for the Process Design of the Three-Roll-Push Bending Process", 7th CIRP International Conference on Intelligent Computation in Manufacturing Engineering, Capri.
5. Han X and Hua L (2009), "3D FE Modeling of Cold Rotary Forging of a Ring Workpiece", *Journal of Materials Processing Technology*, Vol. 209, pp. 5353-5362.
6. Karlsson H (2007), "Abaqus/CAE User's Manuel", Version 6.4, Abaqus, Inc.
7. Merklein M, Hagenah H and Cojutti M (2009), "Investigation on Three-Roll Bending of Plain Tubular Components", *Key Engineering Materials*, Vols. 410-411, pp. 325-334.
8. Plettke R, Vatter P H, Vipavc D, Cojutti M and Hagenah H (2010), "Investigation on the Process Parameters and Process Window of Three-Roll-Push-Bending", Paper No. 1662-36th MATADOR Conference, Manchester.
9. Yang M, Shima S and Watanabe T (1990), "Model Base Control for Three Roller Bending Process of Channel Bar", *Eng. Ind. Trans. ASME*, Vol. 112, pp. 346-351.
10. Zhao G Y, Liu Y L, Yang H, Lu C H and Gu R J (2009), "Three-Dimensional Finite-Elements Modeling and Simulation of Rotary-Draw Bending Process for Thin-Walled Rectangular Tube", *Materials Science and Engineering A*, Vol. 499, pp. 257-261.