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Comprehensive review on three roller bending operation

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ABSTRACT

This paper describes a comprehensive review of major published research work performed on three roller cylindrical bending process. Based on the literature, further research scope is identified. The present literature reveals that there is a further scope to model the three roller bending process in a generalized and simplest form includes various parameters viz geometrical, process, and material parameters, which will help to produce sheet metal parts to precise shape with smooth surface finish and good dimensional accuracy.

Keywords: *Bending, mathematical model, material properties, steel, rolling, alloys, cylindrical*

1. INTRODUCTION

Roll forming is one of the metals forming processes in which a long, straight metal strip is passed through a set of rollers to transform it into desired curved cross-sectional profile [9]. The plates to be bent are cut for required shape and size. Roll bending is a continuous forming process, produces higher dimensional accuracy of the finished products without loss of material [10]. Cylindrical, conical, elliptical, oval shells are widely used in process industries like power plants, food processing, dairy equipment manufacturing, etc. [11]. Various products like cylindrical tanks, drums, boilers, pressure vessels, tunnels, containers, chimneys, towers, structural components are manufactured using roller bending process. Many different types of roller bending machines have been developed over the past few decades. The existing roller bending machines are mainly classified as three-roller and four-roller bending machines. Two types of three-roller bending machines, pinch-type (Asymmetrical) and pyramidal (Symmetrical) were initially developed for forming the boiler shells.

Though roller bending is widely used in metal forming industries, its process is quite complex to understand. Normal practice of the roller bending still heavily depends upon experience and skill of operators. There have been several efforts made so far to develop mathematical models to understand the mechanics of bending process.

2. COMPREHENSIVE LITERATURE REVIEW

Literature review is undertaken to know the research work executed by researchers in the concern area of research. The reported information of research work is available in books, research papers published in National and International Journals, papers presented in conferences, the Post Graduate and Doctoral research work. The aim of this paper is to share exhaustive work carried out by various researchers in the area of three roller bending operation and methodologies applied for the analysis of the operation. The detailed review related the specified area is discussed herein as below.

N. E. Hansen and O. Jannerup[1] focused on the geometric understanding of three roller beam bending process by assuming triangular moment distribution between rollers. The main aim of the research was to obtain more accurate geometrical model to control the bending process. The model was formulated to find the position of top roller corresponding to desired curvature function. Sensitivity of geometrical model to variations in machine geometry and material characteristics was also investigated. The work was limited to bending of beams based on simple theory of bending of beams.

D. E. Hardt et al[2] described real time, close loop shape control for a three roller bending process. Objective of the research was to impart a desired curvature to a work piece at each point along the length of the part. The methodology presented here

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accomplishes shape control by measuring the loaded shape, loaded moment, and the effective beam rigidity of the material in real time. A series of constant curvature bending experiments were performed to evaluate both the steady state accuracy of the curvature control system and to test the ability of the system to compensate for different material properties and geometries.

Michael Hale, David E. Hardt[3] made an attempt to automate the roll bending process using closed-loop control. Dynamic models were developed for individual components of roll bending apparatus and the whole rolling process. An experimental roll bending apparatus was used to evaluate the developed system models and to verify the control design.

Ming Yang and Susumu Shima[4] performed a simulation of the deformation of a work piece with a U-shaped cross section in a three-roll bending process. The distribution of curvature and bending moment were discussed in accordance with the displacement and the rotation of the rolls. The relationship between the position of the rolls and the final curvature of the work piece was reported. Some experiments of the roll bending process were performed on a three-roller bending machine and the simulated results were compared with experimental results to conform the accuracy of the simulation.

V. Ramamurti et al[5] studied the fabricated stands of a three roller heavy duty plate bending machine under various loads and parametric study had been performed. Two machines were analyzed for the same. The FEM was used to study the static response of the stands when machine was in operation. The response was calculated for the worst case of loading. Parametric study was carried out to evaluate the performance of the machine stands for various designs.

Jong Gye Shin et al[6] developed a logical procedure to determine the center roller displacement in the three roll bending process. The mechanics of the process was studied through an analytical approach and finite element method. The results of both analytical and finite element approaches were investigated and compared with each other. Relationship between center roller displacement and residual curvature was proposed. In this paper, one dimensional beam theory for analytical model and 2-Dimensional finite element method was adopted.

Ahmed Ktari et al[7] studied various parameters of three roller bending process. The parameters include position of top roller, distance between bottom rollers and thickness of sheet metal. A two dimensional finite element model was built under ABAQUS/Explicit environment. An industrial experiment using optimized numerical results was carried out to validate the numerical model. Residual stress and plastic strain through work piece thickness were estimated. The evolution of initial curvature radius versus the obtained radius was established by numerical simulation of the rolling process to obtain spring back. The obtained spring back was compared with an analytical solution.

H. V. Gajjar et al[8] described the methodology for the analysis of bendability within machine capacity considering input variables as plate thickness, shell diameter and material properties. Analytical models of equivalent thickness, equivalent width and maximum width based on the power law material model were derived to study the bendability. Equivalent thickness model was compared for four different material grades of C- Mn steel plates in order to predict the bendability. Effect of top roller offset on the bendability at maximum top roller load imparting capacity was also reported. Top roller load for pre bending was derived by equating external and internal bending moments induced in the plate.

A. H. Gandhi and Dr. H. K. Raval[9] developed an analytical model for estimation of top roller position as a function of desired radius of curvature for multiple pass 3-roller forming of cylinders, considering real material behavior. Model was developed based on the Ludwic-Nadal pre-strain power law material. It can be observed from the analytical model that top roller position is the function of bottom roller radius, center distance between bottom rollers, material property parameters, plate thickness, desired radius and initial strain. Model was developed with constant Young's modulus of elasticity. Developed model was modified to include the effect of change of Young's modulus of elasticity during deformation on spring back radius and top roller position. Developed multiple pass analytical models were compared with single pass analytical model. Experiments were performed on pyramid type 3-roller bending machine using mild steel plates to validate developed models. Reported work revealed that predicted top roller position for multiple pass model is higher in comparison to the single pass model for the same desired radius of curvature. Results obtained from analytical models were compared with experimental results and it was found that loaded radius of curvature reduces with increase in top roller position and tends to stabilized with increase of top roller position. From the reported work, author viewed that developed model can be used as a simple tool for the accurate prediction of machine setting parameters for required product dimensions.

A. H. Gandhi et al[10] developed mathematical model for prediction of top roller load required for pre-bending of a plate on three roller bending machine. Analytical top roller offsets were calculated based on practical top roller bending load data for different grades of C-Mn steel plates. Finite element analysis of pre-bending stage was performed in Hyperform LS-Dyna. Two dimensional Finite Element model with symmetrical boundary conditions of plate roller bending process was considered to reduce the solution time. C-Mn steel plates of material grade SA-387Gr11C12 were used for simulation. To study the effect of coefficient of friction on pre-bending load, FE analysis were performed for five different values of coefficient of friction at roller plate interfaces. It was found that pre-bending load increases with increase of coefficient of friction.

P. S. Thakare et al[11] developed a mathematical model to predict top roller displacement of three roller bending machine during cylindrical operation. Geometrical, operational, and material parameters were considered for the modeling. Methodology of dimensional analysis was used for the same. Percentage variation between experimental results and predicted values were also determined. It is found from the results that developed model is accurate and reliable as percentage variation was less than 5 %.

V. K. Tailor et al[12] simulated FE model of three-roller plate bending process to study the influence of various parameters on the bending quality of the deformed plate. Geometric model of roller plate system was developed in Solid Edge v16 and simulation was performed based on elastic-plastic explicit dynamic finite element method under Hyperform LS-DYNA environment. The C-Mn steel plates of different material grades and dimensions were used to assess the three roller bending process. FE simulation results were verified with experimental results. Parametric studies were conducted through experimentations performed on three-roller bending machine by varying each input parameter keeping other parameters constant to investigate the effect of different parameters, such as roller position, rolling speed, plate material and friction on the desired radius.

J. Hao et al[13] presented a three dimensional simulation model to study the dynamic process of three roll plate bending. The presented model was based on the elastic-plastic explicit dynamic FEM under ANSYS/LS-DYNA environment. Continuous three roll bending configuration with cylindrical rolls was used to bend a thick plate into a cylindrical shape. Effect of initial strain and change of material properties during deformation was neglected. Influence of process parameters, top roller position, friction between rolls and plate, and temperature on optimum shape was investigated. Author advised to use FEM simulation which is feasible and economical method to study the influence of aforementioned parameters in less time.

Zhengkun Feng and Henri Champliaud[14] investigated asymmetrical three-roll bending process by numerical simulation. The position of the lateral roll was predicted by numerical simulation. Tensile tests were carried out to determine the stress-strain relationship of the elasto-plastic material of the plate. The nonlinear equations were resolved through a fully integrated Belytschko-Tsay shell formulation under ANSYS/LS-DYNA environment. A series of simulations and experiments with different radii of bent cylinders were performed. Numerical and experimental results were compared and deviation was found below 6%.

P. S. Thakare et al[15] reported the methodology of dimensional analysis to develop a mathematical model for three roller bending operation. Geometrical, operational, and material parameters were considered for the modeling. Percentage variation between experimental results and predicted values were also determined. It is found from the results that developed model is accurate and reliable as percentage variation was less than 10 %.

Zemin Fu et al[16] proposed an analytical model and finite element model to investigate the three-roll bending forming process. A method for numerical simulation of sheet metal three-roll bending forming to produce high accuracy parts was developed. Bilinear elasto-plastic constitutive model was applied for simulation. Relationship between the downward inner roller displacement and unloaded radius of curvature was yielded by both models. Process parameters of three-roll bending forming of a semi-cylindrical work piece were optimized using simulation method. The proposed simulation method was confirmed by experiments performed on three-roll bending machine. It is shown that proposed experimental investigation and theoretical analysis can be used to predict the center roller displacement with higher precision.

Dachao Hu et al[17] established a mathematical model of spring back radius during sheet metal roll bending forming based on orthogonal test and regression analysis. The established model predicted relationship between spring back radius of sheet metal and vertical movement of upper roller, sheet thickness, yield strength and young's modulus of elasticity in the forming process. Influence of various parameters like machine geometry, plate geometry, plate material properties and downward movement of upper roller was analyzed. It is found that downward amount of upper roller has a greater impact on spring-back radius. Spring-back can be reduced by selecting lower values of yield strength, elastic modulus and larger thickness.

Quan Hoang Tran et al[18] developed a three dimensional dynamic finite element model of an asymmetrical roll bending process using ANSYS/LS-DYNA software. Primary processing parameters, such as plate thickness, position of the lateral roll, radius of rolls, final shape radius and width of the final shape were identified and influence of these process parameters on the forming forces and quality of the final shape were investigated through 3D FE model. Numerical results were validated with experiments performed on instrumented roll bending machine. Furthermore, a new experimental approach for measuring strains with strain gauges to obtain the strain variation left in the formed plate was also proposed.

Yogesh Srivastav & Suyog Shinde[19] developed a simulation methodology and simulation tool to study the dynamic process of plate roll bending using finite element method. The continuous three roll pyramid bending configuration with cylindrical rolls was used to form thick plate into cylindrical shell. Plate details, roll bending process parameters and machine data were used as inputs. Parameters like deformation, plastic strain and von-misses stress distribution were calculated from the simulation. Reaction forces, occurred on the rollers were also determined through the simulation. Suggested methodology was validated by performing experiment on the pyramid type three-roll bending machine. It was fond that deformation of formed shape in simulation was very close to the actual deformation.

Shakil A Kagzi, H. K. Raval[20] developed a three dimensional simulation model for three rollers bending process to bend the plates into cylindrical shell using FEM and model was solved in ABAQUS-Explicit solver. Effect of variation in operational and material parameters such as top roller displacement, span of bottom rollers, thickness of plates, and strength coefficient of plate material on bending forces during static and dynamic bending using Taguchi L_9 array was investigated. An ANOVA was performed to determine the contribution of each input parameter on the spring back and power consumption of rollers during process.

Shakil A Kagzi and H. K. Raval[21] performed simulation for multiple pass conical bending operation using FEA software. A variation in radius of the plate as plate passes through the rollers was noted. The increase in curvature and the spring back occurring in each pass was simultaneously obtained. The results of final radius were compared with mathematical formulation

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reported in available literature. The simulation performed in FEA software reveals that bending force increases and radius decreases in each pass.

3. FINDINGS OF LITERATURE REVIEW

Based on the available literature on roller bending operation, following observations can be made.

a) Roller bending operation is mainly performed on three roller symmetrical bending machine because of its simple configuration and easy operation.
b) Amount of displacement of top roller in downward direction is responsible for accuracy in profiles.
c) Bending operations are done through approximation and with skill and experience of the worker.
d) Multiple pass bending is superior to single pass bending to bend thick plates, which reduces bending force and power consumption.

From the literature review, various parameters are identified affecting the performance of bending operation as follows:

1. Top roller radius (r_1)
2. Bottom roller radius (r_2)
3. Distance between bottom rollers (x)
4. Plate thickness (t)
5. Plate width (b)
6. Plate material property (E, n, k, ϑ)
7. Shell diameter to be rolled (d)
8. Top roller position (U)
9. Bending force (F)
10. Number of Passes (N)
11. Total power consumption

4. CONCLUSION

The reported paper presents detailed review of three roller bending operation and various methodology used for the analysis. Various authors developed analytical and empirical models. Finite element analysis (FEM) is also used for dynamic analysis. Findings of literature review are discussed in the paper. From the review, it is revealed that various parameters including machine parameters, material parameters, and operational parameters affect the overall performance of the machine. It is also observed that developing single mathematical model considering all above-mentioned parameters is difficult, and hence researchers have wide scope to analyze the process with better and simplified results, which can help the entrepreneurs to increase the productivity by reducing power consumption, time during operation with consistent dimensional accuracy.

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