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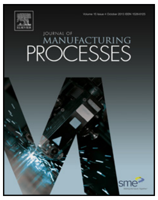

Bending force prediction for dynamic roll-bending during 3-roller conical bending process

M.K. Chudasama[a,*], H.K. Raval[b]

[a] Government Engineering College, Surat, Gujarat, India
[b] Mechanical Engineering Department, S.V. National Institute of Technology, Surat, Gujarat, India

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ABSTRACT

Cylindrical as well as conical cross-section structural parts are widely used in industrial applications worldwide. Such parts are produced from metal plates using many manufacturing methods. 3-roller conical bending process is one such process. In this process first the metal plates in specified blank shapes are given static bending in the rollers. Then the rollers are driven using motors for bending of the blanks under dynamic condition. During bending reaction forces will be there on the rollers. Forces acting on the rollers during the process are transmitted to the machine frame at the roller supports. In the paper an analytical model is developed for the prediction of force during the stage of dynamic bending. The model consists of various parameters like material parameters and geometrical parameters. Experimentation is carried out and the developed model is validated with the experimental results. Effects of various material and geometrical parameters are studied in the present paper. The present work can give insight in the process and can be helpful to the designers as well as to the researchers working in the area of metal forming.

1. Introduction

Metal forming process greatly influences the productivity of the manufacturing sector. Cylindrical and conical cross sectional structures are widely used in large construction as structural members. To get such cross sectional metal parts many manufacturing processes are used and 3-roller conical bending process is one such process. In this process metal plates with specified contours are processes to get the required geometry of the final product. Basically plastic deformation is achieved in the metal plate using three rollers in this roll bending process. The stresses induced during the process are greater than the yield strength, but less than the fracture strength of the material. Usually roll bending process is cold forming process and it usually produces higher dimensional accuracy of the finished products [8].

Whole process of 3-roller conical bending can be divided into four stages namely (i) static bending, (ii) forward rolling, (iii) backward rolling and (iv) unloading. First stage of static bending is performed by loading the blank between top roller and bottom rollers as shown in Fig. 1 and then pressing the top roller downwards. This process is similar to air bending process but is performed by the rollers instead of punch & die. In the subsequent stages bottom rollers are given rotation in forward and reverse direction to perform the rolling. After the rolling is completed the rolled plate is unloaded by moving the top roller upward in the vertical direction. At this stage plate undergoes springback due to the elastic recovery during the unloading of the deformed plate.

Cone frustum bending mechanics is complex to understand as compared to cylindrical shell bending. In case of cylindrical bending, neither top roller nor bottom rollers are inclined. Hence the line at which the reaction forces at the roller plate interface act, would be parallel to the axis of the rollers. Such force system would be easy to analyse. While in case of conical bending either top roller or bottom rollers or all the rollers are inclined simultaneously. In this condition the line at which the reaction forces at the roller plate interface act, would not be parallel to the axis of the rollers. The line, at which the reaction forces act, would be at some angle and hence it will be difficult to analyse such force system. When it comes to the roll-bending in forward or backward direction, it becomes more complex. So it becomes difficult to design the machine considering the bending load during the operation. Usually it is overdesigned for safety purposes. If some analytical model is available for the prediction of the force during the roll-bending process it will be useful to the designers as well as to original equipment manufacturers and small to large scale fabricators who are using the machine. Using such knowledge they can achieve economy, quality and competency in their products. It is also beneficial to simulate the forces acting on rollers, to get the friction coefficient, during the rolling process. In this paper, an attempt has been made to develop an analytical model for the prediction of bending load and to estimate

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* Corresponding author. Tel.: +91 9979074377.
E-mail address: mkcgecs@gmail.com (M.K. Chudasama).

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Nomenclature

B1, B2	Bearings for top roller
B3, B4, B5, B6	bearings for bottom rollers
w	width of the blank in mm
t	thickness of the plate in mm
L_B	length of the blank in mm
M	bending moment in N m
P	vertical load at the top roller and bending plate interface in N
a	horizontal distance of the bottom roller centers in mm
x	half the horizontal distance of the bottom roller centers in mm
Q	normal force exerted by the plate on the bottom roller at roller plate interface in N
θ	angle between frictional force and horizontal plane at the roller plate interface in radians
θ_B	angle between the end generators to prepare the blank in degrees
U	vertical distance travelled by the top roller for first stage of static bending in mm
E	Young's modulus in N/mm^2
C	strength coefficient in N/mm^2
n	strain hardening exponent
$r1$	radius of bottom roller in mm
R	radius of curvature of the bent plate in mm
R_B	smaller radius of the prepared blank in mm
R_{BL}	larger radius of the prepared blank in mm
y	distance of fiber from neutral plane in mm
I	second moment of area (For plate it is equal to bt^3/12), mm^4
μ	coefficient of friction at roller plate interface
ε	strain
σ	stress in N/mm^2
ν	Poisson's ratio
y_{ep}	distance of the fiber upto which elasticity E is constant in mm
χ	curvature of the bend plate between bottom rollers, mm^{-1}
ε^*	strain at yield point
E^*	the ratio of modulus of elasticity to σ_s
t_e	thickness of elastic layer in mm
ε_0	strain of the strip mid-line
$\bar{\varepsilon}$	effective strain
$\bar{\sigma}$	effective stress
$\dot{\varepsilon}$	strain rate
$\dot{m}$	strain rate sensitivity index
β	bottom roller inclination,
A_F, A_R	center distance between bottom rollers at front and rear end respectively
α	top roller inclination, in the present case it is zero
φ	cone angle
R_F, R_R	bending radius at the front end and rear end respectively

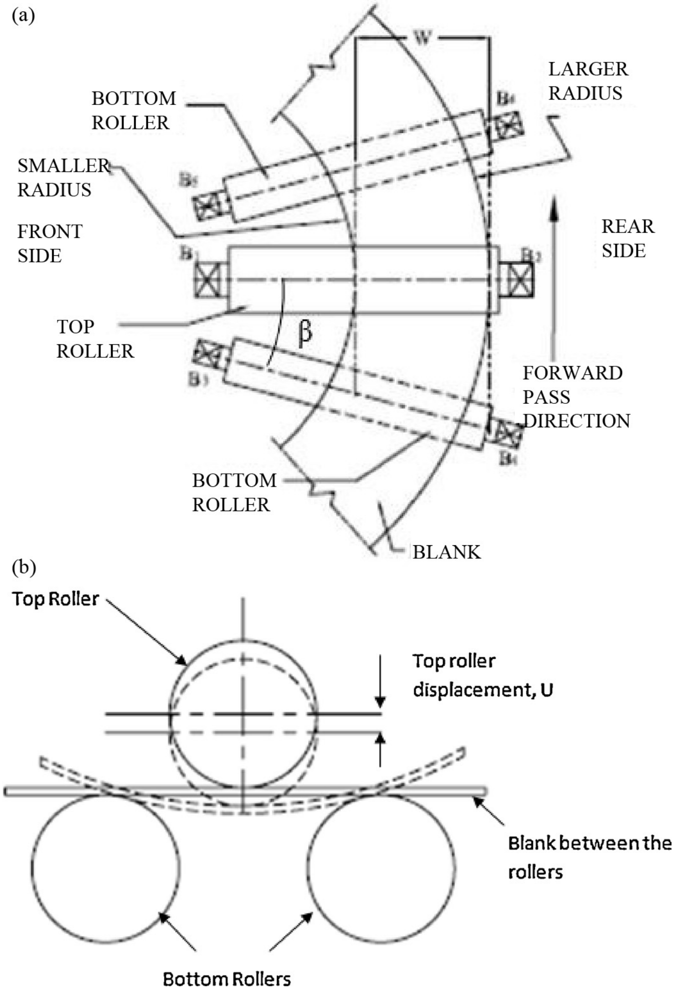

Fig. 1. Schematic arrangement of 3-roller conical bending setup.

the value of coefficient of friction at roller plate interface during dynamic roll-bending stage for 3-roller conical bending process.

A lot of work has been reported by researchers in the area of analytical modelling of bending process and its implication in FEA models. Mathematical models for plane-strain sheet bending have been established by Wang et al., to predict springback [19]. They used the true (non-linear) strain distribution across the sheet thickness. They had shown that the bending moment is greater for materials with higher strength and normal anisotropy. Hale has given concept for controlling the springback using dynamic control of the roll bending process [6].

Hua et al. have proposed a mathematical model for determining the plate internal bending resistance at the top roll contact for multi-pass four-roll thin-plate bending operations [9]. An analytical model for continuous single-pass four-roll thin plate bending was proposed by Baines et al., considering the equilibrium of the internal and external bending moment at and about the plate-top roll contact [10]. Lin et al. had given a mathematical model to simulate the mechanics in a steady continuous bending mode for four-roll thin plate bending process considering varying radius of curvature of the plate between the rollers [8]. Hua and Lin also investigated Influence of material strain hardening on the mechanics of steady continuous roll and edge-bending mode in the four-roll plate bending process [12].

Moreira and Ferron had investigated the influence of the plasticity model adopted in sheet metal forming simulations by means of a numerical study of experimental tests [15]. They concluded that the isotropic hardening assumption provides a good fit of experiments for the tests where the sheet is submitted to relatively linear loading paths. Firat had employed two rate-independent anisotropic plasticity models in the deformation modeling of a stamping part [2]. Kim et al. have developed an analytical model to predict springback and bend allowance simultaneously in air bending, and prepared computer program [11].