

Dynamic Analysis and Experimental Verification of Three-roll pyramidal configuration Roll Bending Process

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Abstract— Three Roll bending is an efficient metal forming technique, where plates are bent to a desired curvature using forming rolls. Three rolling sheet forming process is one of the most widely used techniques for manufacturing asymmetric hollow shapes, basic component of cylindrical vessels and structures used for different engineering applications. Three-roll pyramidal roll bending process is beginning to be taken into serious consideration by industries for producing big, thick parts such as the conically shaped crown of a Francis turbine runner and of a wind turbine tower. It is important to bend the sheet smoothly and safely, without cracks and working for longer life. While bending the sheet metal, stress and strain is developed in the sheet. It is highly essential that the stress and strain are within the limits of the material properties such as mild steel and the factor of safety desired by the engineering applications. Also, there must be maximum displacement of top roller allowed without endangering crack formation in work piece obtained. Three-roll pyramidal roll bending process primarily deals with calculating the relation of the top roller positions and the stress and strain developed during displacement of top roller for different thickness of the sheet metal. In this study three dimensional dynamic Finite Element (FE) model of a pyramidal three roller bending process is developed using the ANSYS software. The simulation results are compared with experiments performed with three roll bending machine. Maximum displacement of top roller allowed without endangering crack formation in work piece is observed as 12 mm from FEA results. From FEA and practical results comparison strain values are in conformance with each other with maximum variation of 10.6 % which validates the FEA results. The limit for maximum displacement of top roller is 12 mm, within which the von mises stress is less than the stress value of material of construction i.e. mild steel of the roller.

Keywords: ANSYS, Bending, Finite Element, Roller, Stress, Strain.

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I. INTRODUCTION

Three roller bending machines are widely used in heavy engineering applications for the manufacturing of skeleton of the construction of tunnels, cylindrical tanks, shell of boiler and heat exchangers, fuel tanks for launch vehicles in space applications, pressure vessels, tall towers, reactors, etc. Top roller the load required to bend the sheet is the function of various parameters viz. plate thickness, width, shell diameter

to be rolled, plate material property and gap between the bottom rollers etc. Machine capacity is limited by size and shape of motor of three roll bending machine motor. It consists of two bottom rollers and a one top roller as shown in Fig.1. Sheet metal plates with specified contours are rolled without decrease in thickness to get the desired cylindrical shape. The plate undergoes plastic deformation and it is cold forming process and hence it has higher dimensional accuracy. The various machine elements used in the construction three roll bending machine are as shaft, bearings, gear, lead screw, lever and frame.

Three roller pyramidal bending process has four stages as described under,

- (a) static bending (b) forward rolling
- (c) backward rolling and (d) unloading of the work piece.



Fig.1. Three roll pyramidal bending machine.

In the first stage the metal sheet is kept between top roller and bottom rollers and the top roller is given vertical displacement to get the required bending. In next stage the bottom rollers are driven using motors or by hand lever in forward direction to get the roll bending of the plate. Similarly the rollers are driven in backward direction to get better dimensional accuracy of the final shape. The bent sheet is then unloaded by raising the top roller. The process is performed using many materials such like carbon and alloy steels, aluminium alloys. Rolling bending machines with three rolls are indispensable to the production of cylindrical shapes with different radiuses of curvatures without endangering crack formation in work piece. The machine can be used for bending plates of various materials viz. carbon alloy steel, aluminium alloy steel etc.

Various researchers have worked for the development of mathematical models for three roll pyramidal bending process, M. K. Chudasama and H. K. Raval (2012) [1], conducted a study of analytical model for prediction of force

during three roller multi-pass conical bending and Its experimental verification. They found that Conical sections and shells are produced using three roller conical bending machine. M. K. Chudasama and H. K. Raval (2013) [2], they fomalated an analytical model is developed to predict bending force which will be acting during three roller conical bending process. Analytical results and experimental results were compared. Force predicted by analytical model is in close proximity of the experimental results. The error in the prediction was $\pm 10\%$. Hence the model gives quite satisfactory results. Zen Zemin Fu et al (2013) [3],] in which they stated that the three-roll bending forming of sheet metal is an important and flexible manufacturing process due to simple configuration. and explain the process through macroscopic metal deformation. An analytical model and ABAQUS finite element model (FEM) are proposed Then, the three-roll bending forming process of a semi-circle-shaped work piece with 3,105 mm (length) \times 714 mm (width) \times 545 mm (height) is simulated with FEM established by the optimum tool and process parameters. A. H. Gandhi et al (2008) [5], .described the work proposed an analytical and empirical model to estimate the top roller position explicitly as a function of desired radius of curvature for three-roller cylindrical bending of plates, considering the contact point shift at the bottom roller plate interfaces. Effect of initial strain and change of material properties during deformation is neglected. Top roller positions for loaded radius of curvature are plotted for a certain set of data for centre distance between bottom rollers and bottom roller radius. From above literature it is fond that we can bend a sheet metal of required shape by changing the roller position of top and lateral rollers.

II. FINITE ELEMENT ANALYSIS

A. Results of conventional steel shaft

Three dimensional solid models for the three roller bending machine assembly is modeled using CATIA V5. Fig.2. shows the assembly of three roll pyramidal bending machine.

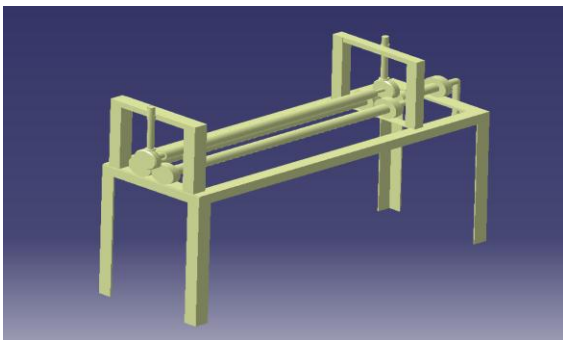


Fig. 2. CAD model for Propeller Shaft Assembly.

By using the FE analysis we calculate the stress during the displacement of the top roller. Bending of sheet is process that can be simulated using plane stress method. As results will be similar throughout the length. In order to save analysis time we have modeled 2 D ANSYS plane stress analysis.

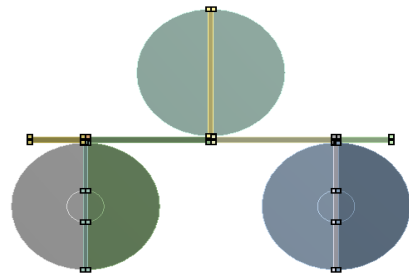


Fig. 3. Plane stress model for rolling process 1.5 mm sheet .

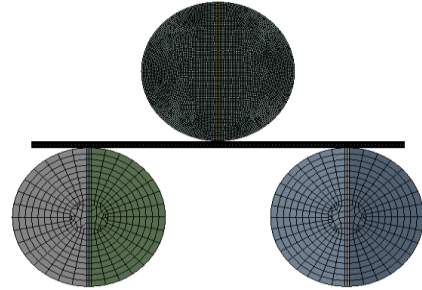


Fig. 4. Meshing for 3 roller bending process.

Top roller is modeled 0.1 mm away from the plate, and frictional contact is used between top roller and plate surface. Other two rollers are assumed to have bonded contact with plate surface. Finer meshing size is used at top roller for contact region and plate as it is our area of interest. Bottom two rollers are fixed at inside circle of 10 mm diameter. Displacement to the top roller will be used as boundary condition. Non- Linear mild steel properties from ANSYS library are used for plate. It uses bilinear hardening plasticity to define stress strain curve beyond yield limit.

Two steps are performed in analysis in first step displacement is used as input to push the plate using top roller and then in the next step roller is moved back. So that spring back effect can be observed in the sheet. Strain data is recorded for both the cases. Also spring back displacement also observed at different thickness plates and different displacement values. We will find maximum displacement for the top roller before crack generation starts on the sheet due to bending. As we have selected mild steel as our plate material, ultimate tensile strength for mild steel 1018 will be our acceptable limit for von-Mises stress. Table for material properties of mild carbon steel 1018 is given below.

Table I. Material properties for mild steel [11].

Property	Value	Unit
Modulus of Elasticity	205 E3	M Pa
Poisson's Ration	0.29	-
Yield Strength	180	M Pa
Ultimate Tensile Strength	440	M Pa

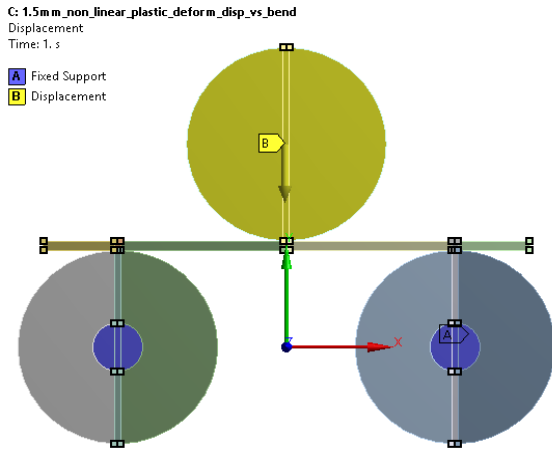


Fig. 5. Boundary condition and Loading.

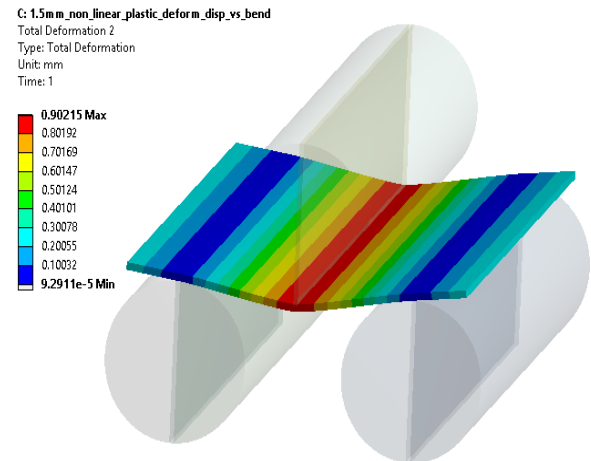


Fig. 8. Total Deformation plot for maximum displacement of roller.

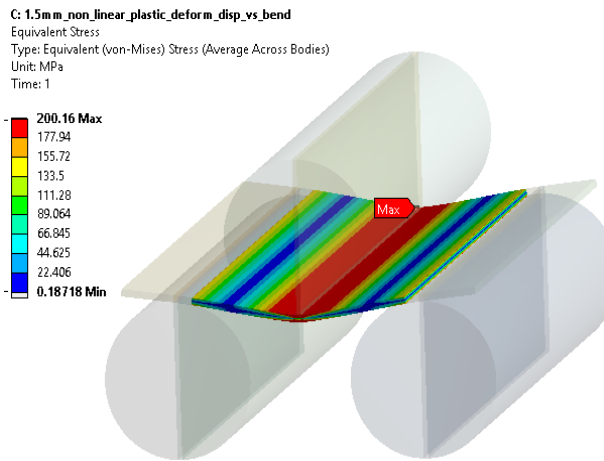


Fig. 6. Von Mises Stress plot at 1 mm roller displacement.

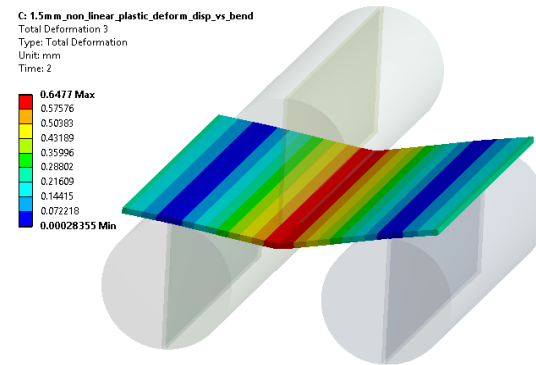


Fig. 9. Total Deformation plot after roller retrieved back.

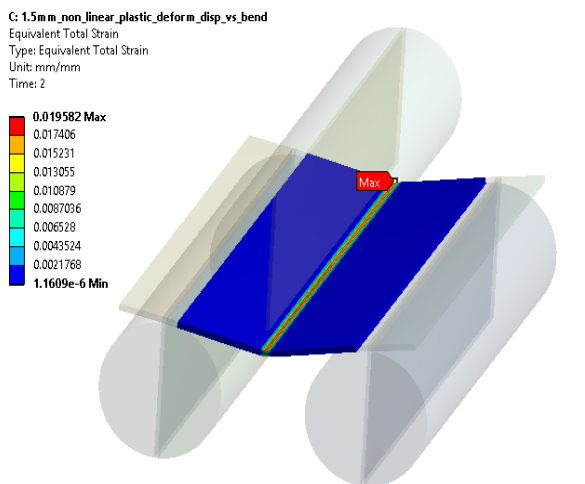


Fig. 7. Equivalent Total Strain plot.

Spring Back effect can be measured in ANSYS as the difference between maximum deformations of the sheet at the top roller displaced and maximum deformation at the end of the cycle.

$$\text{Spring Back Effect} = 0.90 - 0.6477$$

$$\text{Spring Back} = 0.2533 \text{ mm}$$

Table II. FE Analysis result - stress and strain for sheet thickness of 1.5 mm.

Displacement (mm)	Equivalent Stress (MPa)	Strain	Spring Back Effect (mm)
1.00	200.16	0.01900	0.25260
2.00	209.88	0.03967	0.19710
4.00	241.29	0.10268	0.19300
6.00	280.58	0.18120	0.17120
8.00	322.69	0.26520	0.14770
10.00	371.97	0.36344	0.12800
12.00	422.56	0.46438	0.11700
14.00	465.13	0.54958	0.11

III. EXPERIMENTAL VERIFICATION

A. Three Roller bending set up

In the experiment, the metal sheet is kept between the top roller and bottom rollers, and the top roller is given vertical displacement within the range of 1 to 12 mm to get the required bending. The bottom rollers are driven using a hand lever in the forward direction to get the roll bending of the plate. Similarly, the rollers are driven in the backward direction to get better dimensional accuracy of the final shape. The bent

sheet is then unloaded by raising the top roller. Generally plane rollers will be used to roll the plate to the shape. Maximum possible deflection of the roller is simulated using FEA. Same needs the validation as a proof of correctness of the results as one cannot rely on only FEA to predict the accurate results. Experimental set up as shown in Fig.1. consists of 3 roller pyramidal bending machine with helical groove on the rollers, groove ensure that the path is provided for strain gauges mounted on the plate to pass without being rolled and results of the strain observation on plate while rolling are not strangled. Set up requires thus rolling machine with groove on the rollers, Strain gauges to be placed on the plate at the time of testing to read the strain values during rolling process is carried out as shown in Fig.10.

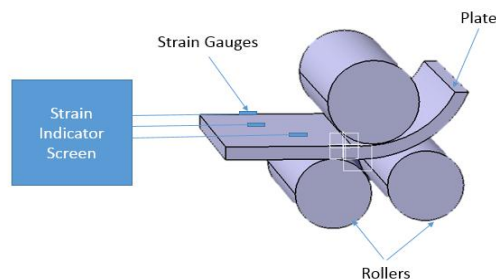


Fig. 10. Schematic Block diagram for testing on three roller bending machine.

B. Experimental Result

Table III. Results of testing.

Top Roller Displacement (mm)	Strain Observed
2	0.036
4	0.098
6	0.162
8	0.245
10	0.335
12	0.426
14	0.533

From the above table III, we have proved that the strain values observed in experimental result with FEA result with marginal acceptable error.

IV. RESULTS AND DISCUSSIONS

Maximum displacement of top roller allowed without endangering crack formation in work piece is observed as 12 mm from FEA results. From FEA and practical results comparison strain values are in conformance with each other with maximum variation of 10.6 % which validates the FEA results. Maximum von Mises Stress found in work piece while 14 mm displacement of top roller is 465 MPa which is more than the ultimate tensile strength of the mild steel. Variation of maximum von Misses Stress in the plate with respect to change in top roller position as shown in figure below from table II.

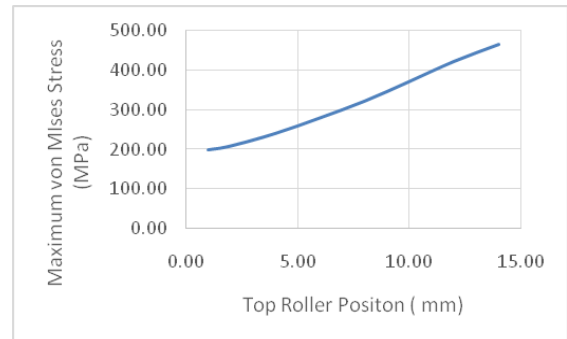


Fig. 11. Displacement of top roller position V/s Maximum von Mises Stress.

Graph below from table II shows the relation between spring back effect of the plate and top roller position while rolling. Spring back effect reduces as top roller position is advanced downward.

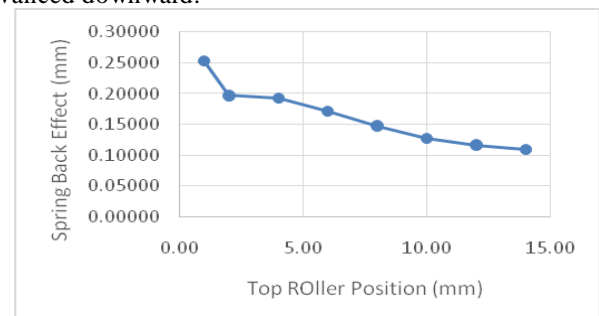


Fig. 12. Displacement of top roller position V/s spring back effect.

Strain values observed from analysis and testing strain values are compared to find the error % or deviation of the strain from testing values. Maximum of 15 % deviation from the actual values is considered good correlation with FEA.

Table IV. Comparison of analysis result and experimental result.

Displacement (mm)	Strain		% Error
	Analysis	Testing	
1.00	0.01900	0.017	10.53%
2.00	0.03967	0.036	9.25%
4.00	0.10268	0.096	6.51%
6.00	0.18120	0.162	10.60%
8.00	0.26520	0.245	7.62%
10.00	0.36344	0.335	7.83%
12.00	0.46438	0.426	8.26%
14.00	0.54958	0.533	3.02%

In the above table IV the simulation results are compared with experiments performed with three roll bending machine. Maximum displacement of top roller allowed without endangering crack formation in the range of 1 mm to 12 mm from experimental and FEA results. From FEA and practical results comparison strain values are in conformance with each other.

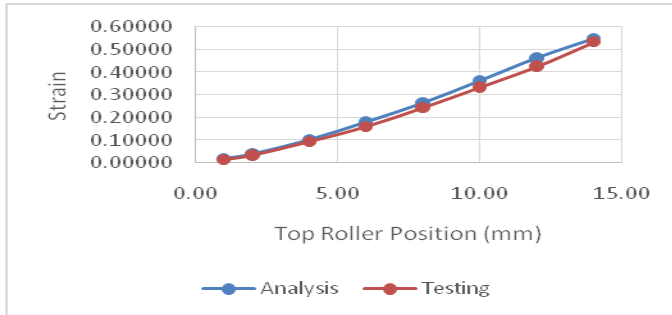


Fig. 13. Comparison of FEA result V/s Experimental result.

V. CONCLUSION

We have calculated the diameter of the roller required for bending maximum of 2 mm thickness sheet is 30 mm. With given configuration of 30 mm roller diameter with 54 mm roller distance we can bend 1.5 mm mild steel plate up to roller position of 12 mm without any cracks on the sheet metal. Strain values observed in FEA and testing are pretty much in conformance which validates the FEA model. Valuable prediction of maximum stress, spring back effect and strain values is generated for different top rollers positions while bending 1.5 mm thick mild steel plate using this three roller bending machine.

A. Future Scope

- Different thickness varying below 2 mm can be modeled and similar data can be generated for all possible gauge thicknesses of sheet.
- Different material can be tested and validated in FEA and testing and data for them can be generated.
- Data generated can be used to graphically predicting the minimum radius of curvature each type of material and thickness of sheet can achieve on particular bending machine without generating cracks on the work piece.
- MATLAB program can be used to predict mathematical values of radius of curvature for different sheet thickness and different roller positions.

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