Bending Analysis of SS NL Plates on 3-Roller Pyramidal Configuration Bending Machine and Its Experimental Validation

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ABSTRACT

Three roll pyramidal bending is an effective and efficient metal forming technique, where plates are bend to a desire curvature using forming rolls. Three roller sheet forming process is the most widely used techniques for manufacturing asymmetric hollow shapes, basic component of cylindrical vessels and structures used for different engineering applications. This roll bending process is to be useful consideration by manufacturing industries for producing large, thick parts such as the conical shaped of a turbine runner and of a wind turbine tower, bending of leaf spring. It is necessary to bend the metal sheet smoothly and safely, without cracks and damage working for long life. During bending the sheet metal, stress and strain is developed in the sheet. It is important that the stress and strain are within the limits of the material properties such as S.S. and the factor of safety desired by the engineering applications. Also, there must be maximum vertical displacement of top roller allowed without endangering crack formation in work piece obtained. Three-roll pyramidal roll bending process primarily related with calculating the top roller positions and the stress and strain developed during displacement of top roller for different thickness of the sheet metal. By using the ANSYS software in this study three dimensional dynamic Finite Element (FE) model of a pyramidal three roller bending process is developed. The simulation results are compared with experimental result with three roll pyramidal bending machine. Maximum vertical displacement of top roller allowed without crack in SS plate is observed as 10 mm from FEA results. From FEA and experimental results comparison strain values are in conformance matches with each other with maximum variation of 8.4 % which validates the FEA results. The limit of maximum vertical displacement of top roller is 10 mm, within which the Von mises stress is less than the stress value of material of SS NL plate.

Keyword: - *ANSYS, Bending, Finite Element, Roller, Stress, Strain.*

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1. INTRODUCTION

3-roller pyramidal configuration bending machine is widely used in heavy engineering applications for the manufacturing of cylindrical tanks, bending of spring, shell of boiler and heat exchangers, turbines, pressure vessel, towers, reactors, etc.Top roller load required to bend the sheet is the function of various parameters such as, thickness of plate, width, diameter of the shell to be rolled, properties of plate material and gap between the bottom rollers etc. Machine capacity has limitation by size and shape of motor of 3-roll bending machine motor. Machine consists of two bottom rollers and a one top roller as shown in Fig.1. Sheet metal plates are rolled without reduction in thickness to get the desired cylindrical shape. The plate undergoes plastic deformation and this is cold forming process due to that it has higher dimensional accuracy. The elements used in the construction 3-roll bending machine are as shaft, bearings, lead screw, gear, levers and frame.

3-roller pyramidal configuration bending process has four stages are as follows,

(A) Static bending (B) Forward rolling (C) Backward rolling and (D) Unloading of the work piece.

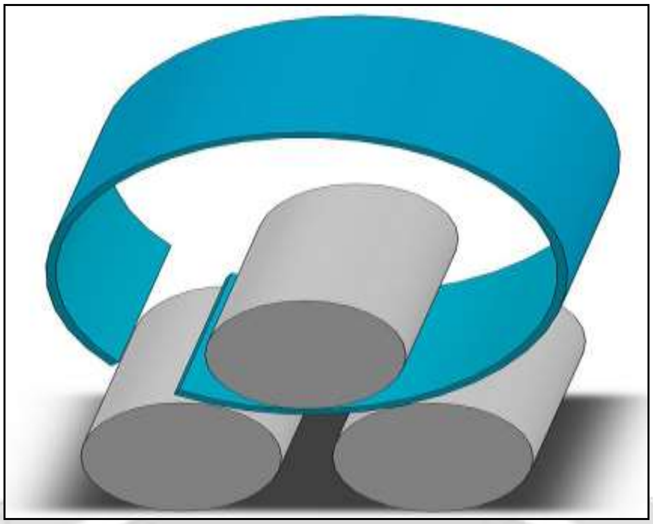

Fig.1: 3-roll pyramidal configuration bending machine

Firstly, the metal sheet is kept between top roller and bottom rollers and gives the vertical displacement to the top roller to get the required bending. In second stage the bottom rollers are driven by hand lever in forward direction to get the roll bending of the plate. We also use motor for the rotating of bottom rollers. Similarly for getting better dimensional accuracy of the final shape the rollers are driven in backward direction. The bent sheet is unloaded by raising the top roller. The process is performed using many materials such like aluminium alloys, carbon and alloy steels. In Rolling bending machines with three rolls are important for the manufacturing of cylindrical shapes having different radiuses of curvatures without endangering crack formation in work piece. The machine is useful for bending plates of various materials viz. Aluminium alloy steel, Carbon alloy steel etc.

2. LITERATURE SURVEY

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. In this conical bending process, the blank is given static bending by placing the blank over the bottom rollers and lowering the top roller. The rollers are rotated than to get roll bending action. Static bending of the plate requires larger force and it is done in multiple stages to lower down the value of required force [Gajjar et. al., 2008]. The total deflection of the top roller required is divided in steps to get the Multipass bending. **Zen Zemin Fu et al (2013) [3],** in which they stated that the 3-roll bend forming is an important manufacturing process in sheet metal industry due to its simple construction. This process is suitable for making large sheet parts with complicated, curved faces. Most researches on roll bending forming of large work piece are mainly based on experiments and explain the process through macroscopic metal deformation. An analytical model and ABAQUS finite element model are proposed in this paper for investigating the 3-roll bending forming process.

Himanshu Vet al, published a paper named “Bendability analysis for bending of C-Mn steel plates on heavy duty 3-roller bending machine” in 2007 which states, Bendability is constrained by max top roller load imparting capacity of the bending machine. Maximum load is faces during the stage of edge pre-bending. Capacity of three-roller bending machine is specified by maximum thickness and minimum shell diameter combinations that can be pre-bend for given plate material of max width. **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 3-roller cylindrical bending of plates, considering the contact point shift at the bottom roller plate interfaces.

3. FINITE ELEMENT ANALYSIS

3.1 Results of conventional steel shaft

Three dimensional solid models for the three roller bending machine assembly are modeled using CATIA V5. Fig.2. shows the assembly of 3-roll pyramidal bending machine.

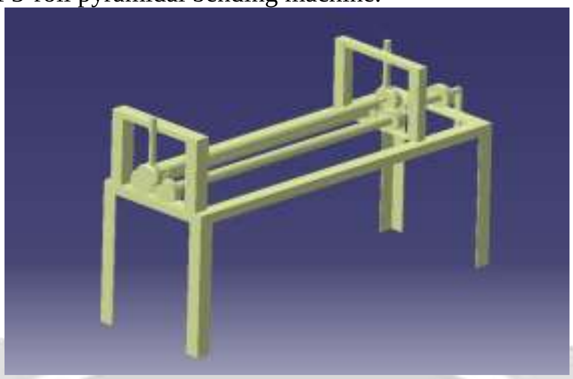

Fig.2: CAD model for Propeller Shaft Assembly

By using the Finite element (FE) analysis we calculate the stress during the vertical displacement of the top roller. By using plane stress method Bending of sheet process is simulated. Dynamic analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A dynamic analysis can be either linear or non-linear. All types of non-linearity allowed such like that large deformations, stress stiffening, contact elements, plasticity, creep, stress stiffening etc. A dynamic analysis is used to find out the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects.

A dynamic analysis can however include steady inertia loads such as gravity, spinning and time varying loads. The static analysis loading and response conditions assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time.

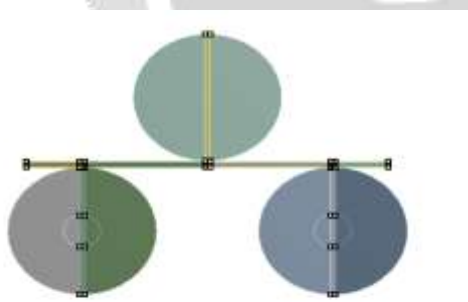

Fig. 3: Plane stress model for rolling process 1.5 mm sheet.

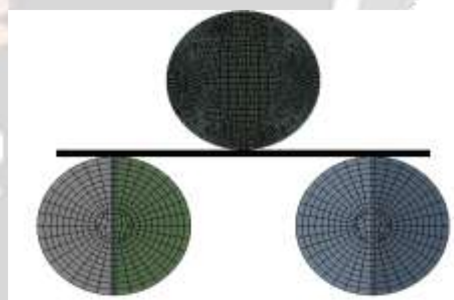

Fig. 4: Meshing for 3 roller bending process.

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 steel properties from ANSYS library are used for plate. It uses bilinear hardening plasticity to define stress strain curve beyond yield limit.

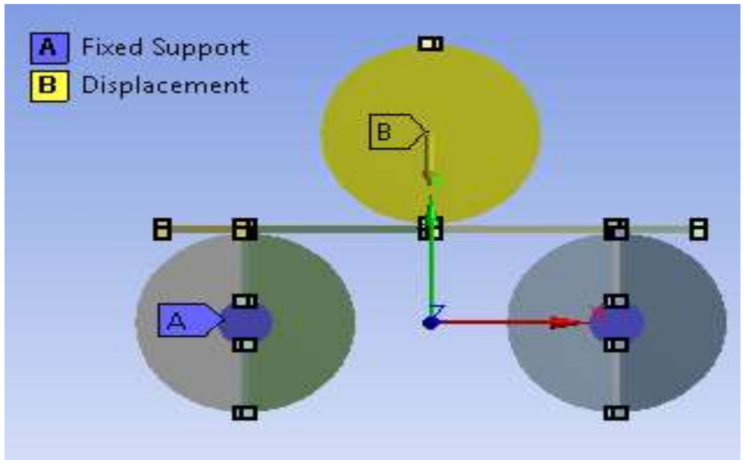

Fig. 5: Boundary condition and Loading

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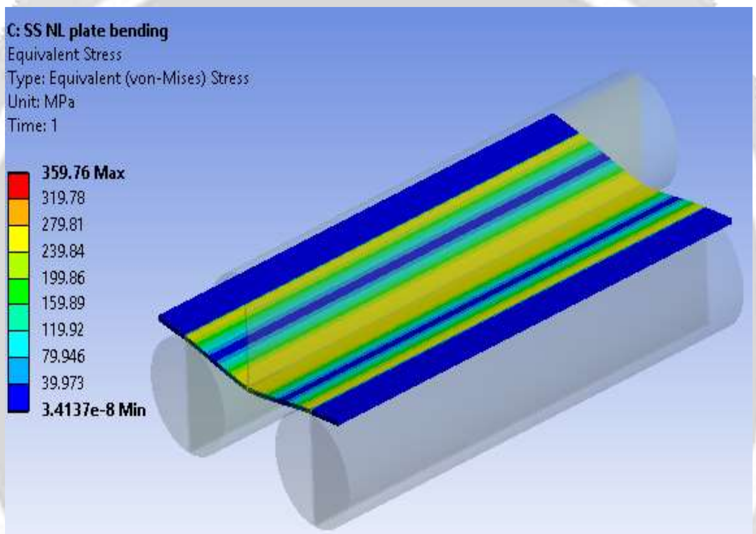

Fig. 6: Equivalent Stress plot at 1 mm roller displacement.

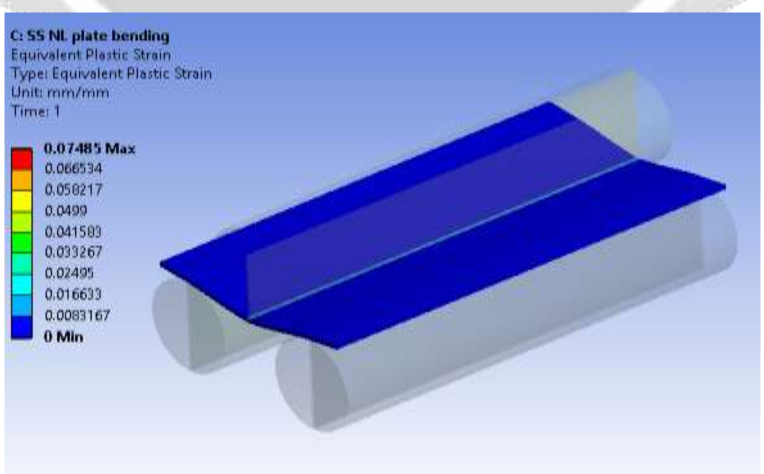

Fig. 7: Equivalent Total Strain plot.

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

Spring Back Effect = 0.90145-0.55038

Spring Back =0. 35107 mm

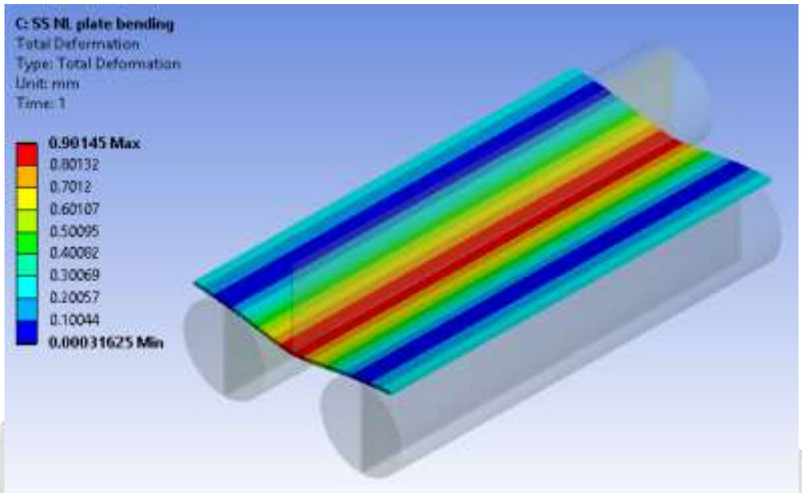

Fig. 8: Total Deformation plot for maximum displacement of roller.

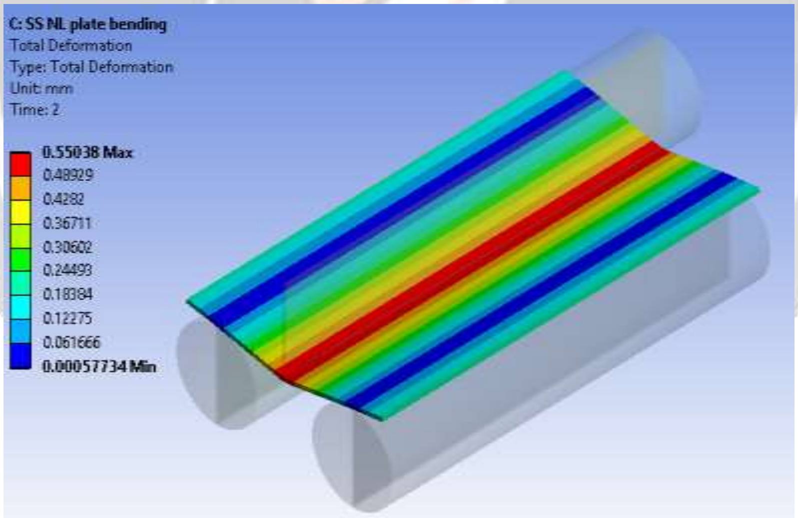

Fig. 9: Total Deformation plot after roller retrieved back.

Displacement (mm)	**Equivalent Stress (MPa)**	**Strain**	**Spring Back Effect (mm)**
1.00	359.76	0.07500	0.35107
2.00	503.00	0.16221	0.28060
3.00	733.00	0.31856	0.29180
4.00	1026.70	0.50579	0.29730
6.00	1421.00	0.75637	0.25730
8.00	1622.00	0.88413	0.21640
10.00	1815.00	1.0052	0.19620

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

4. EXPERIMENTAL ANALYSIS

4.1 Three Roller bending set up

In the experiment the metal sheet is kept between top roller and bottom rollers and the top roller is given vertical displacement as within the range of 1 to 10 mm to get the required bending and the bottom rollers are driven using 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. 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.11. 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 table II.

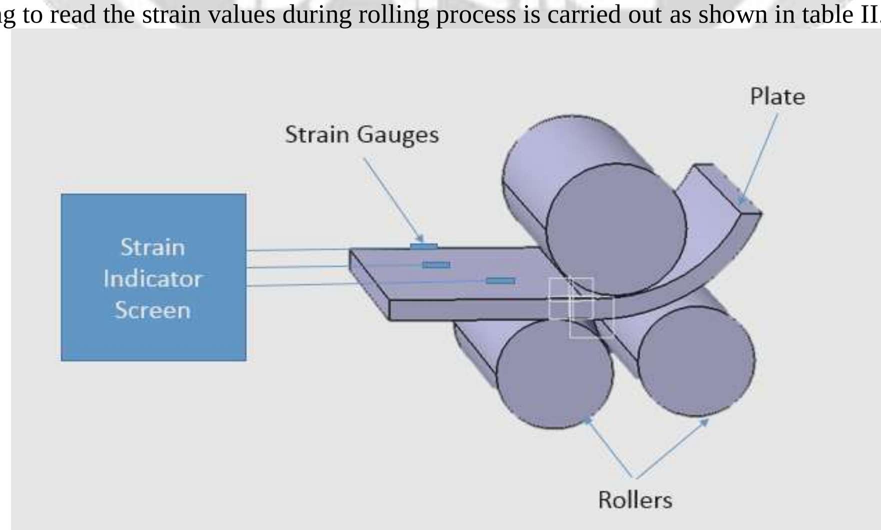

Fig. 10: Schematic Block diagram for testing on three roller bending machine.

Fig.11: Experimental set up for testing on three roller bending machine.

4.2 Experimental Result

Top Roller Displacement (mm)	Strain Observed
1.00	0.071
2.00	0.153
3.00	0.302
4.00	0.491
6.00	0.741
8.00	0.824
10.00	0.921

Table II: Results of testing.

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

5. RESULTS AND DISCUSSIONS

Maximum displacement of top roller allowed without endangering crack formation in work piece is observed as 10 mm from FEA results. From FEA and practical results comparison strain values are in conformance with each other with maximum variation of 8.4 % which validates the FEA results. Maximum von Mises Stress found in work piece while above 10 mm displacement of top roller is 1815 MPa which is up to the ultimate tensile strength of the SS plate. Variation of maximum von Misses Stress in the plate with respect to change in top roller position as shown in figure below from table I.

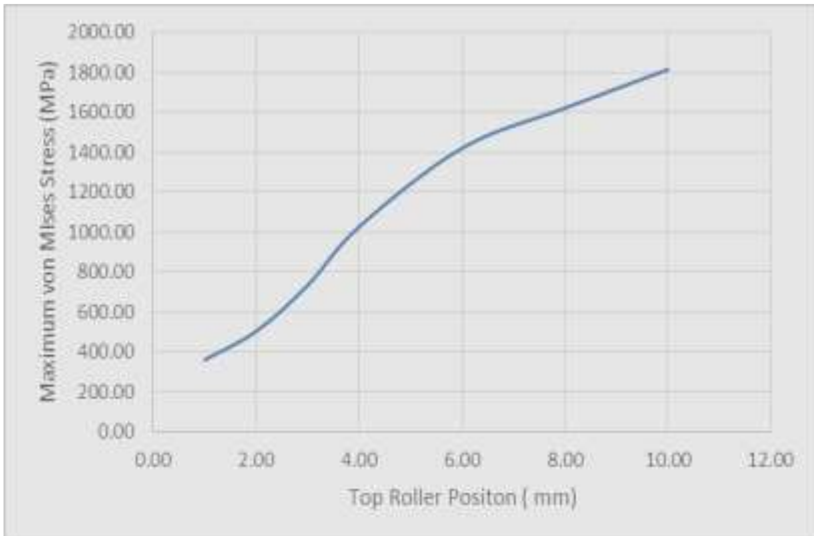

Chart 1: Displacement of top roller position V/s Maximum von Mises Stress.

Graph below from table I 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.

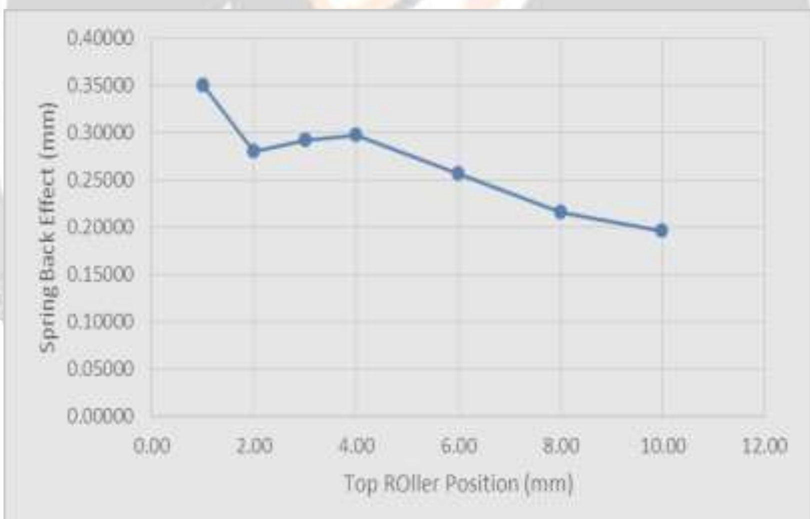

Chart 2: Displacement of top roller position V/s spring back effect.

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.

Displacement (mm)	**Strain**		**% Error**
	Analysis	**Testing**	
1.00	0.07500	0.071	5.33%
2.00	0.16221	0.153	5.68%
3.00	0.31856	0.302	5.20%
4.00	0.50579	0.491	2.92%
6.00	0.75637	0.741	2.03%
8.00	0.88413	0.824	6.80%
10.00	1.0052	0.921	8.38%

Table III: Comparison of analysis result and experimental result.

In the above table III 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 10 mm from experimental and FEA results. From FEA and practical results comparison comparison strain values are in conformance with each other.

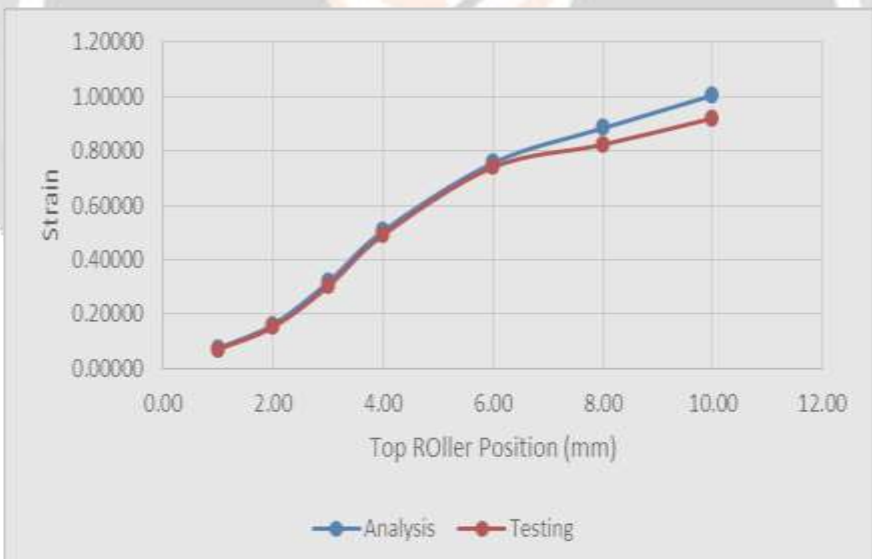

Chart 3: Comparison of FEA result V/s Experimental result.

6. CONCLUSIONS

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 SS plate up to roller position of 10 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 SS plate using this three roller bending machine.

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