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Springback Analysis For Land Width Optimization In Cold Drawing Process Of Square Sectional Seamless Tubes

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Abstract

Seamless tubes manufacturing process by cold drawing process achieves outer diameter, inner diameter and thickness of the tubes as per requirement. This paper emphasizes on the problem of springback effect on square cross sectional seamless steel tubes faced in the production with different land widths. The experimental study is carried for the analysis and modification on land width or bearing length of the die in controlling the springback of square sectional seamless steel tubes. This study deals with the effect of land widths of 5, 10, 15 and 20 mm on springback by conducting experimentation and finite element analysis using ANSYS. The results of this study reveals that 10 mm is optimum land width to minimize springback in square sectional tubes. This research improved springback results with the aid of series of experimentation. The results of this study reduced the rejection of precision tubes by 3 % saving substantial and considerable amount of the cold drawing manufacturing industry.

Keywords:-*Cold drawing Process, Finite Element Analysis, Optimization Seamless tubes, Springback, Square cross sectional tubes.*

I. INTRODUCTION

Cold drawing process utilizes a technique by which a material is drawn through a die-plug combination at room temperature to reduce the cross sectional area of wire, bar or tube. Cold drawing process is preferred over hot forming processes due to inherent advantages such as better surface finish, closer dimensional tolerances and improved mechanical properties. This process is carried out for manufacturing seamless tubes in different cross sections like round, square, rectangular, hexagonal, ovule etc. The tendency by which a material partially returns to its original shape when it is cold-worked; after releasing the forming force is called as springback. Springback, an elastic recovery phenomenon is influenced by material properties like tensile and yield strengths as well as geometrical properties like thickness, land width, die semi angle etc. Though there are many defects like eccentricity, bending, internal and external crack, ovality, scores on inner and outer diameter, springback is severe one. The reason is springback varies with composition, material properties, dimensional range and can't estimate exactly beforehand. The springback depends upon the land width of the die [1] and the design of the plug used for cold drawing. The aim of this study is to arrive for optimized land width of the drawing die to achieve dimensional stability and least springback, which will be following the permitted dimensional specifications.

Land width or bearing land is an important parameter in designing a square die, however the square tubes are preferred over circular tubing because of their advantages like ease of fitting in direction. However it produces high torque in twist along with reduced weight. Many researchers have focussed on this parameter for optimized performance. Li *et al*. [2] studied springback behaviour for bent tubes under different bending specifications. Non-linear springback analysis for medium strength thin-walled 6061-T4 Al-alloy tubes was studied. The authors explored many techniques like deformation theory of plasticity, explicit/implicit finite element method along with experimental approaches. The study was related to rotary draw bending process. It reflects changes in angular springback and radius growth with respect to changes in the tube diameter *D* and wall thickness *t*. Nagamachi *et al.* [3] studied the effect on circular seamless tube reshaped to square shapes. The authors found the relationship between hollow depth and high incremental reduction for

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different pass schedules. Zhu *et al.* [4] studied the influence of different process parameters on section deformation as well as springback. Authors used method of multi-parameter sensitivity analysis along with springback/section deformation prediction finite element model to find most sensitive process parameters. The study concluded that the pressure of pressure die and boost speed affects springback angle adversely. Thorat *et al*. [5] conducted FEA and mathematical calculation of springback for the rotary draw tube bending process. The authors found considerable in-plane distortion and thickness variation during the process. This research deals with rotary draw tube bending process, the finite element analysis technique and simulation of rotary draw tube bending of a seamless metal tube for the analysis of springback effect. Mathematical and experimental analysis of springback are carried out and results are compared.

By applying the theory on pure beam bending deformation, the mathematical model of spring back for pipe bending deformation is established. The Simpson's rule is applied for solving the radius in springback. Liu *et al*. [6] carried out the finite element analysis of metal flow as well as weld seam formation. This study is related to a porthole die where extrusion process of a square tube was considered. Finite element simulation was conducted in distinctive stages to find the changes in extrusion pressure. Du *et al.* [7] described the applications of the 3D elastic plastic finite element technique depending upon U.L. method for tube forming. The transforming matrix between world coordinates and local coordinates is given in the wave front area. The program EPFEP3 as well as its pre-process and post-process programs were developed. The simulating model controlling product quality was set up. Dong *et al*. [8] explained the importance of prediction model in energy consumption for seamless tubes production. Optimum process parameters were achieved through process simulation and optimization method of energy consumption. Leu [9] studied the squaring processes of reshaping the circular tube into a symmetric square-tube using an incremental elasto-plastic finite-element method. It used an updated Lagrangian formulation considering non-linearity of the problems. The modelling and simulation demonstrate the squaring processes until unloading and ensures shaping of a symmetric square-tube successfully. Watson *et al*.[10] studied the behaviour of simply supported tubes of aluminium and mild steel for three modes of deformation. The experimental results were presented based on plastic work considerations.

Johnson *et al*.[11] investigated lateral compression behaviour of aluminium and mild steel tubes. Firstly aluminium system's examination was carried for two principal categories and then observations related to mild steel systems were produced. DeRuntz and Hodge [12] studied the load-deformation curve for a thin tube which is crushed between two parallel, rigid plates. They quantitatively explained the influence of geometry changes and the direct shear and stress effects on the yield condition. Leu *et al.* [13] simulated a hole-flanging operation using an incremental elasto-plastic finite-element method. The simulation demonstrates how deformation shape generates until unloading. The experimental and simulation results shows better agreement. Kitazawa [14] studied the phenomenon of outward curling of circular metal tubes both experimentally and theoretically. It was found that there is a geometrical similarity law of the ρc which increases with increase in the die angle and does not depends upon the tube materials and lubrication. Fodse and Vyankatesh [15] did experiments for calculating the springback in sectional seamless tube by using finite element analysis for different land widths.

As per literature survey, it is observed that there is ample of literature available related to cold drawing of square cross sectional tubes. It is found that, most of the work is done related to distortion defect. In this work, it is emphasized that springback is also a severe phenomenon which is less studied as far as the cold drawing of square seamless tubes is concerned. To investigate the springback during cold drawing of seamless tube of square cross section which have wide use in construction field, medical field, industries etc., dies of 5, 10, 15 and 20 mm with constant die semi angle are considered as per industrial guidelines. The results of experimentation are also validated using FEM tool ANSYS.

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II.MATERIALS AND METHODS

AISI D3 air hardened, high-chromium, high-carbon tool steel is used as a die and plug material. Tool steel is specified according to ASTM A681 (D-3), DIN 1.2080, SAE 437, SAE J438, UNS T30403. It has excellent abrasion/wear resistance. However, it shows high compressive strength and good dimensional stability having following chemical composition as shown in table 1.

Table 1: Chemical Composition of AISI D3 Steel

Carbon, (C)	Silicon, (Si)	Chromium, (Cr)	Manganese, (Mn)	Nickel, (Ni)	Phosphorous, (P)	Sulphur, (S)	Vanadium, (V)
2.10 %	0.30 %	11.50 %	0.40 %	0.31 %	0.02 %	0.5 %	0.5 %

As, the requirements for a material to be cold worked are: Yield stress curve of gentle slope, early yield point and then large percentage elongation, with pronounced necking before fracture. Hence, ST 52 steel is taken as a tube material having density 7.87 g/cc, hardness RC 64, elastic modulus of 207 GPa and poisson’s ratio 0.29. Passes are designed as per available tooling and final size required. The process of seamless tube manufacturing for square tube 101.6 X 101.6 X 9.52 mm starts with mother tube 137.5 x 11.5 mm. Surface is prepared by pickling, phosphating and soaping to remove residues of grease, oil, cutting oils, marking inks etc. after fabrication operations. It is drawn to size of 129.72 x 9.52 mm. After normalizing for one hour surface preparation is done to draw in size 101.6 x 9.52 mm. Finally stresses are relieved through annealing and then tubes are cut to length and rust prevention oil is applied before bundling them.

III. DESIGN OF DIE

Using standard design procedure of die design as explained in annexure, various dimensional parameters are calculated and tabulated in table 2 as well as depicted in figure 1.

Table 2: Dimensions of the Die

Nomenclature	**Notation**	**Dimension**
Die exit	d (or)w (or) h	101.6 mm
Entry Diameter of Die	D1	138.5 mm
Diameter of Die at exit after 3º slope	D2	274.65 mm
Diameter of Die	D3	300.42 mm
Die angle	θ1	10°
Entrance die angle	θ2	15°
Corner radii of the die	R1,R2,R3	2 mm
Corner radii of the die	R4	5 mm
Length of die from exit to land start	L1	10 mm
Bearing length or Land of die	L2	10 mm
Length of die from land point to die angle end	L3	11.2 mm
Length of die from entry to die angle start	L4	63.8 mm
Total width of the die	L5	105 mm

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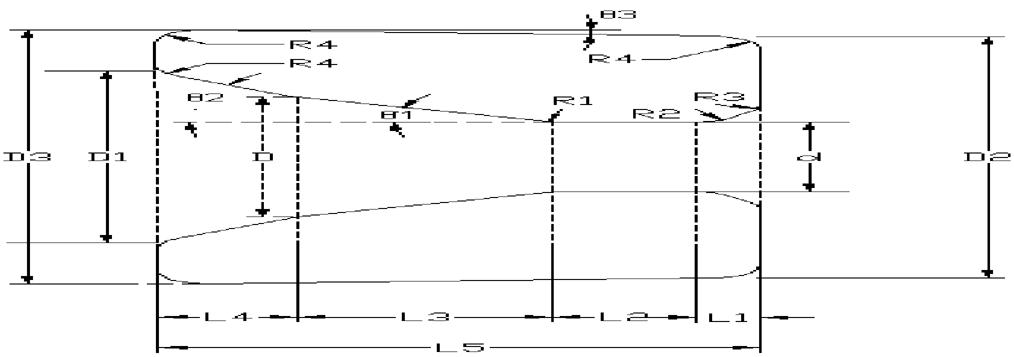
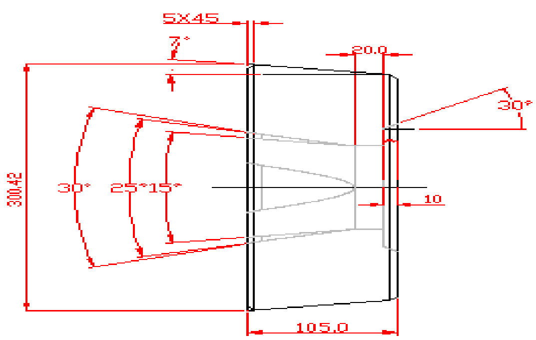
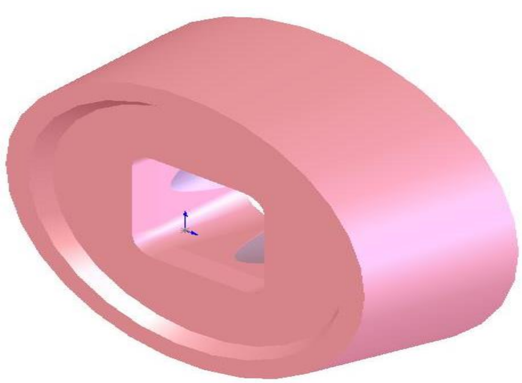


Figure 1: Die geometry

The die can be designed as per the dimensions from the reference data and old design of die. Bearing length or land of die can be varied from 5, 10, 15 to 20 mm. The dimensions of die are as shown in table 2, the drawings in figure 2 and actual photograph as shown in figure 3.





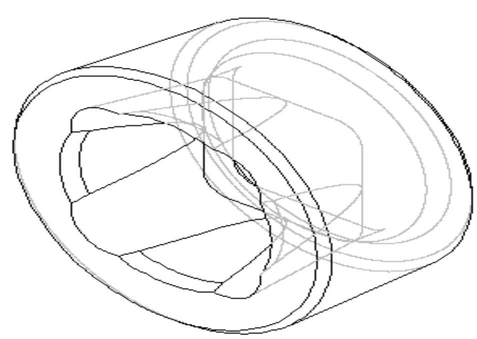


Figure 2: Die isometric view **Figure 3: 101.6 x 101.6 x 9.52 die photograph**

IV.EXPERIMENTATION

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Actual experimentation on draw bench is carried out to analyse the role of land width on springback. The variation in the drawn tube from the targeted size for various land widths are measured. Maruti make draw bench is used having specifications tabulated as shown in table 3.

Table 3: Specifications of Draw Bench

Parameter	Value
Strength	50 ton
Width of drawn tube	170 mm max
Thickness of tube	3-30 mm
Drawing speed	1-10 m/min
Return speed	10-48 m/min
Power supply	3 Phase 380 V/50 Hz ,90 KW
Machine size	Length: 26.8 m Width :4.5 m Height: 2.2 m Weight :30 ton

Less the variation from targeted value, less is the springback. Actual dimensions are measured with the help of Mitutoyo digital micrometer having 1 micron accuracy at 10 places along the periphery of the tube and their average is taken at 5 different locations. Note that all dimensions are in mm. Tables 4, 5 and 6 shows experimental results obtained. The variation from targeted value is recorded as springback. Dimensional report of square tube 101.6 x 101.6 x 9.52 with 10 mm land width where width dimension= 101.6mm, height dimension=101.6 mm and wall thickness dimension=9.52 mm are reported. Springback depends upon the various parameters out of which the most important one is die and plug bearing length (land).In this research it is decided to check the effect of springback on the square tube of size 101.6 x 101.6 x 9.52 mm. The new sets of die and plug suitable for above selected tube sections with 5, 10, 15 and 20 mm land width are manufactured.

Table 4: Width dimensions of square tube 101.6 X 101.6 X 9.52 mm

Tube No.	Average readings at location 1(mm)	Average readings at location 2(mm)	Average at centre (mm)	Average readings at location 3(mm)	Average readings at location 4(mm)	Grand average readings (mm)	Springback (mm)
1	101.679	101.789	101.711	101.653	101.689	101.7042	0.1042
2	101.712	101.698	101.585	101.703	101.703	101.6802	0.0802
3	101.706	102.031	101.598	101.675	101.656	101.7332	0.1332
4	101.701	102.022	101.612	101.635	101.713	101.7366	0.1366
5	101.712	101.663	101.779	101.722	101.578	101.6908	0.0908

Table 5: Height dimensions of square tube 101.6 X 101.6 X 9.52 mm

Tube No.	Average readings at location 1(mm)	Average readings at location 2(mm)	Average readings at centre (mm)	Average readings at location 3 (mm)	Average readings at location 4 (mm)	Grand average reading (mm)	Springback (mm)
1	101.632	101.578	101.612	101.696	101.656	101.6348	0.0348
2	101.702	101.565	101.711	101.703	101.706	101.6774	0.0774

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3	101.631	101.632	101.632	101.545	101.709	101.6298	0.0298
4	101.586	101.656	101.703	101.712	101.693	101.67	0.070
5	101.589	101.665	101.689	101.585	101.634	101.6324	0.0324

Table 6: Wall Thickness dimensions of square tube 101.6 X 101.6 X 9.52 mm

Tube No.	Width (B) side location readings (mm)				Height (H) side location readings (mm)				Average (mm)	Springback (mm)
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**		
1	9.521	9.519	9.524	9.531	9.523	9.530	9.529	9.521	9.524	0.004
2	9.526	9.517	9.528	9.530	9.521	9.524	9.524	9.523	9.525	0.005
3	9.524	9.528	9.516	9.526	9.519	9.526	9.520	9.522	9.523	0.003
4	9.527	9.524	9.518	9.531	9.525	9.528	9.521	9.526	9.525	0.005
5	9.530	9.516	9.521	9.523	9.531	9.524	9.515	9.523	9.523	0.003

Table 7: Springback readings of square tubes 101.6 X 101.6 X 9.52 with 10 mm land width

Parameter	Reading set 1(mm)	Reading set 2(mm)	Reading set 3(mm)	Reading set 4(mm)	Reading set 5(mm)	Average springback (mm)
Along width 101.6 mm side	0.042	0.0802	0.1332	0.1366	0.0908	0.0965
Along height 101.6 mm side	0.0348	0.0774	0.0298	0.070	0.0324	0.04888
Along thickness 9.52 mm side	0.004	0.005	0.003	0.005	0.003	0.004

Similar readings are taken for other land widths viz. 5 mm, 15 mm and 20 mm.

V.MODELING AND SIMULATION ANALYSIS

Solid modeling is done by using PRO-E software developed by PTC. This helps to model dies and plugs used in cold drawing process. 3 D model consists of parts, drawings and assemblies. The finite element analysis is done by ANSYS software which involves solving many simultaneous algebraic equations.
While running simulation, the die is considered to be rigid and the tube as a rigid-plastic. However the interface between the tube and die is considered with a constant friction coefficient. The model prepared clearly indicates all features of existing engineering system with the elements, nodes, real constants, material properties, boundary conditions etc. The model is imported from PRO-E software in ANSYS for analysis. (figure 4).

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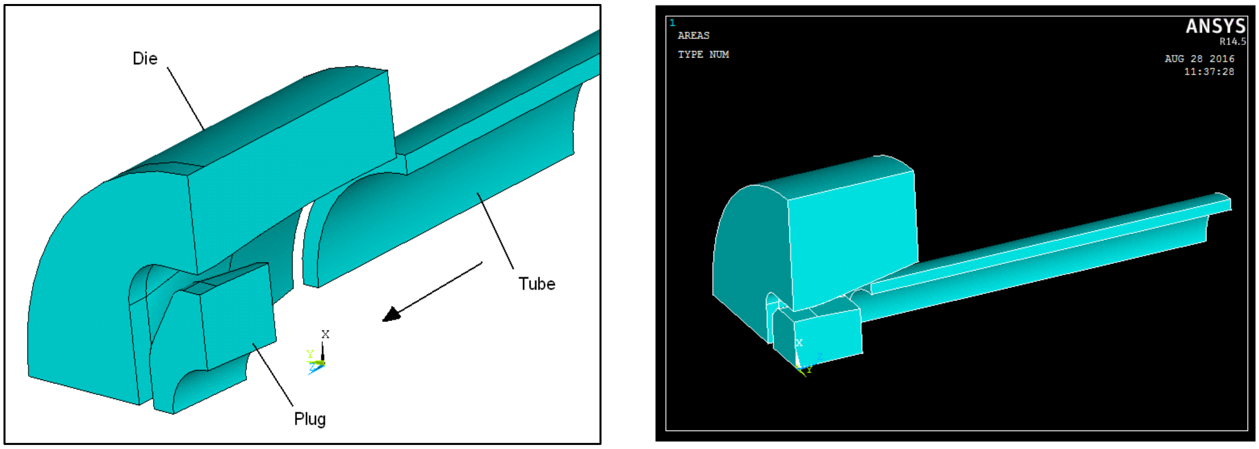

Figure 4: Imported quarter section 3D model

After building an axisymmetric model, material behaviour, geometry as well as loading conditions are considered as axially symmetric. Figure 5 shows meshing done with the smart size option in the mesh tool. Solid 45 is the eight noded-hexahedral brick defined by eight nodes which has three degrees of freedom for every node. This element used for solid structure 3-D modeling has inbuilt capabilities like creep, swelling, plasticity, large deflection, stress stiffening, large strain etc. The number of elements are 63172 and number of nodes are 69645.

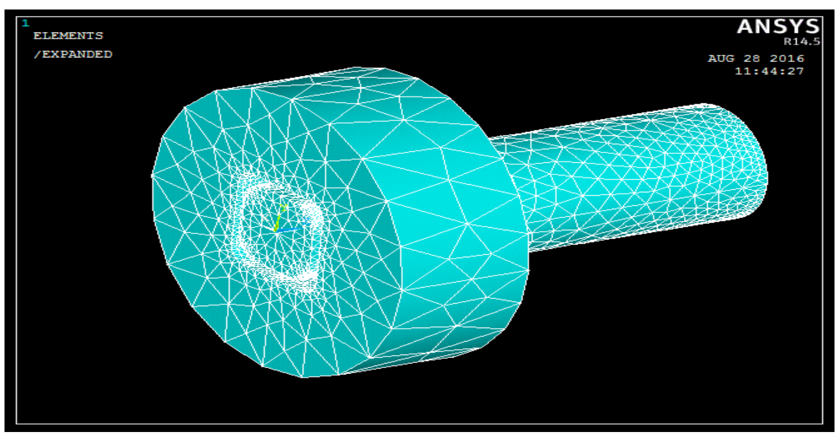

Figure 5: 3D mesh of tube and die

The FEA method produces many simultaneous algebraic equations, generated and solved by computer softwares further. ANSYS is most suitable software based on Finite element method for analysis and stress-strain calculations. ANSYS is used for seamless tube cold drawing process simulation. The material properties considered for tube material (ST 52) are: modulus of elasticity 210,000 N/mm^2 and poisson's ratio 0.29.The non-linear contact analysis is considered for the contacts existing between die inner and tube outer surfaces as well as tube inner surface and plug outer surface. It is assumed that die have very high Young's modulus of 2.1 x 10^9 N/mm^2.The pre-solver exhibits model properties created in pre-processor. It also represents the concerned model mathematically. The post-solver exhibits outcomes like stresses, strains, heat fluxes, velocities, etc. for each node within the component or continuum. The post-processor reads the result file where all results are accumulated.

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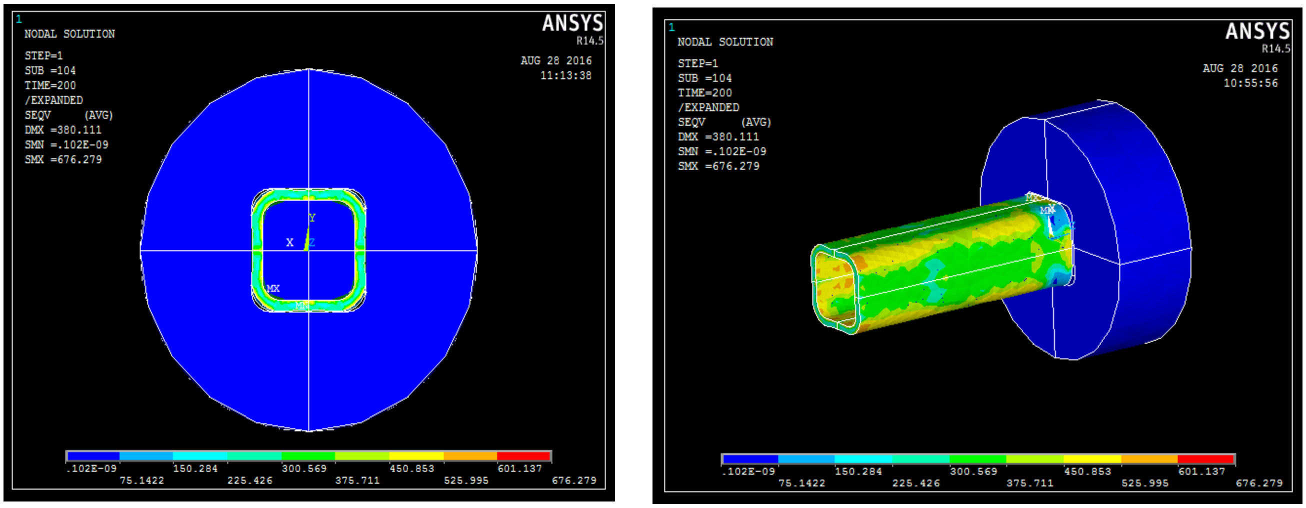

Figure 6: Equivalent Von-Mises stress

This research need to calculate the equivalent Von-Mises stress as shown in figure 6. From this we can observe that the least stress value is observed at the die surface. However, the maximum stress value is observed at the end of the square tube with numerical value of 676.279 N/mm^2

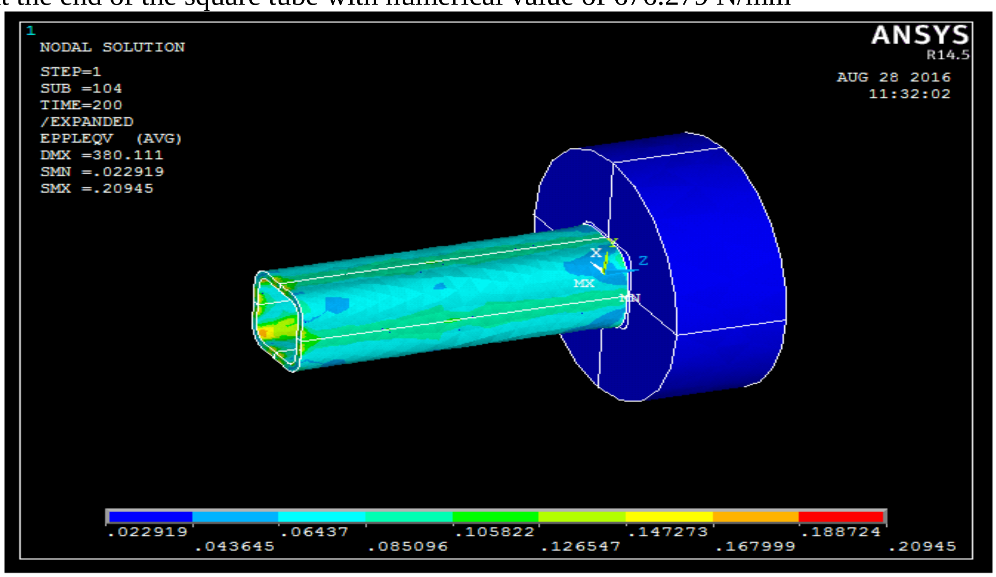

Figure 7: Equivalent plastic strain

The equivalent plastic strain which is a permanent strain is the measure degree of work hardening in the material. As shown in figure 7, the maximum value of strain observed is 0.20945 whereas minimum value of strain found is 0.022919.

VI RESULTS AND DISCUSSIONS

Draw bench machine is used for cold drawing of seamless tubes of square cross section. The variations from targeted sizes are measured using digital micrometer and called as springback. An experimentation is conducted for four different size land widths viz. 5 mm, 10 mm, 15 mm and 20 mm. Table 8 shows corresponding results.

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Table 8: Comparison among springback values for different land widths

Parameter	5 (mm)	10 (mm)	15 (mm)	20 (mm)
Along width	0.0966	0.0965	0.0968	0.0967
Along height	0.06833	0.04888	0.06125	0.05675
along thickness	0.005	0.004	0.005	0.006

Table 8 shows that the springback is least in 10 mm land width which can be showed graphically as shown in figure 8. In depth analysis shows that springback is more at 5 mm land, reduces at 10 mm and further increases after that.

Figure 8: Graphs of springback vs. Land width

There is an agreement between the experimental and FEA results as shown in tables 9 and 10 and graphically as shown in figure 9. Average springback values along height, width and wall thickness are measured.

Table 9: Experimental springback results

Parameter	Average readings at location 1 (mm)	Average readings at location 2 (mm)	Average readings (mm)	Springback (mm)
height	101.253	101.254	101.2535	0.0535
width	101.293	101.3112	101.3021	0.1021
wall thickness	9.528	9.512	9.525	0.005

Table 10: FEA springback results

Parameter	Average readings at location 1 (mm)	Average readings at location 2 (mm)	Average readings(mm)	Springback (mm)
height	101.253	101.254	101.2535	0.0535
width	101.293	101.3112	101.3021	0.1021
wall thickness	9.528	9.512	9.525	0.005

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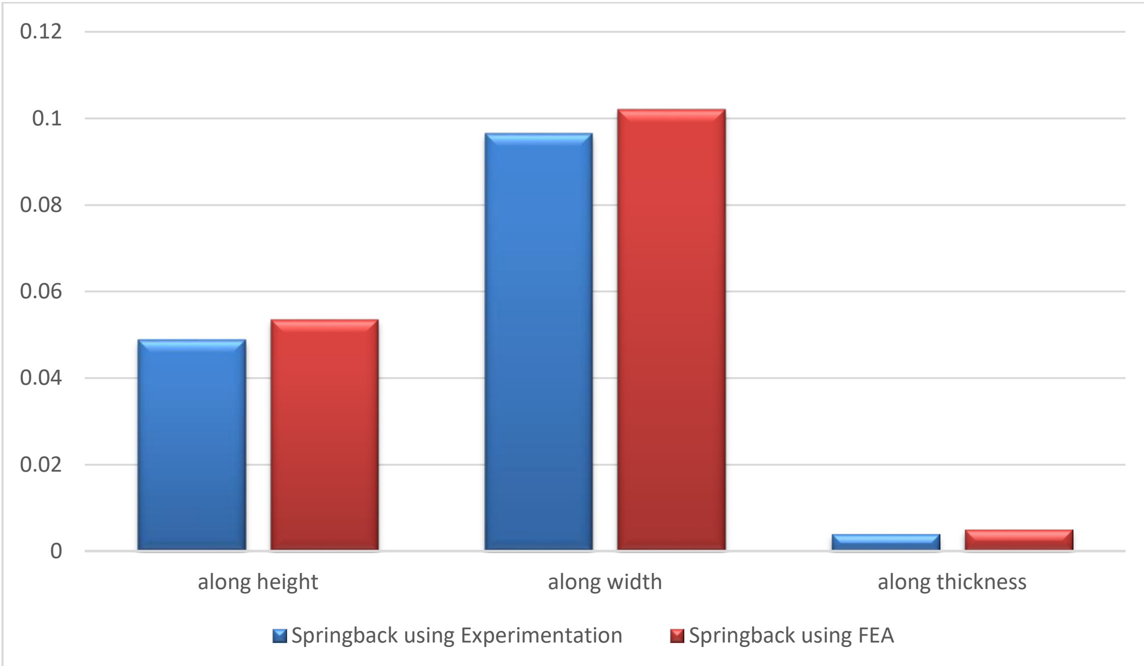

Figure 9: Comparison between experimental and FEA springback

VII. CONCLUSIONS

This research study is associated with simulation of cold drawing process for square tubes. The prime objective of an experimentation was to minimize the springback in land width. The outcomes of this study concludes that

1) The springback is least in 10 mm land width as compared to those values in 5 mm, 15 mm and 20 mm land widths.

2) The springback values during simulation shows good agreement with the experimental findings. This FEM analysis can also be used for predicting the dimensions of the actual process ensuring minimum number of failures and ensuring that the tubes will not crack during drawing process.

3) This simulations techniques is also helpful for validating the design of die and plug in sectional tubes such as rectangular, hexagonal, ovule, elliptical etc.

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ANNEXURE

The necessary formulae of design are

Let

a = Side dimension of Square

t = Nominal Thickness
R = Corner radius (Outer)
r = Corner radius (Inner) = R-t
Now

De = Equivalent Diameter = $\dfrac{4a-8R+2\pi R}{\pi}$

Ds = Square diagonal = $\sqrt{2}a-2R(\sqrt{2}-1)$

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As = Cross Sectional area of the Tube = $\pi(De-t)t$

Sp = Density of Steel = 7.85 gm/cm3

Material weight (kg/m) = $As \times \frac{7.85}{1000}$

Perimeter of tube = πDeq

Perimeter of Hollow = πD_H

Difference in Perimeter = $\pi(D_H - D_{eq})$

Diameter of Hollow = D_H ---- Variable

Thickness of Hollow = T_H ---- Variable

Diameter of Hollow = D_H = dp + C + 2t

C = Clearance between the Hollow and Plug (Variable)

Area of Cross Section of the hollow = A_H = $\pi(D_H - T_H)T_H$

% Cross Sectional Area reduction = $\frac{A_H - A_S}{A_H} \times 100$

x = Truncation length on the plug, Variable x ≥ r (r = R-t)

dp = Diagonal of the Plug = $\sqrt{2\left[x^2 + (a - 2t - x^2)\right]}$

δ = Thickness variation

r_1 = Plug Corner radius = $\frac{\delta}{(\cos ec\phi/2-1)}$

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