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Experimental Investigation of Springback in Rectangular Cross Sectional Seamless Tubes during Cold Drawing Process

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Abstract— **Seamless tubes are manufactured by hollowing out solid heated billets in a Piercing mill and then cold drawing process is continued. Cold drawing is the process of reducing the dimensions of seamless tubes as per required size. This paper emphasizes on the problem of springback effect in rectangular sectional seamless steel tubes faced in production with different land widths. The study will perform the analysis and modification to be done on land width of die in controlling the springback of rectangular sectional seamless steel tubes. In the present study, experiments are carried to study the effect of land widths of 5, 10, 15 and 20 mm on springback.The result of this study shows that for a ST 52 tube material and D3 die-plug material, 10 mm land width gives least spring back. The outcomes of this research is useful for the seamless tube manufacturing industries in designing the tooling.**

Keywords—**Cold drawing, Optimization, Rectangular cross sectional tubes, Seamless tubes, Springback.**

I. Introduction

The cold drawing process is the process of reducing the cross sectional area of wire, bar or tube by drawing the material through a die without any preheating. Cold drawing process is used for the production of bright steel bar in round, square, rectangular, hexagonal and flat section. Seamless tubes have most diversified applications like domestic and export applications, e.g. automobile axles, structural systems, commercial vehicles, two-three wheelers, bearings, oil industry, petrochemical industry, refineries, fertilizer plants, boilers, heat exchangers, pressure vessels, hydraulic and pneumatic cylinders etc.

When the sectional tube is drawn through a die of average nominal dimensions, it is generally observed some dimensional variation due to elastic springback. The spring back depends upon the land width (bearing length) of the die and the design of the plug used for cold drawing. The bearing length and cross section size determine the size and surface finish of the drawn material. Too high a bearing length will spoil the surface finish and too low a bearing length will cause excessive die wear.

To arrive at the best possible land width, it is necessary to achieve dimensional stability and least springback, which will be well within the permitted dimensional specifications.

II. Background And Review

Condition that occurs when a seamless tube is cold-worked; upon release of the forming force, the material has a tendency to partially return to its original shape because of the elastic recovery of the material. This is called Springback and influenced not only by the tensile and yield strengths, but also by thickness, die angle, land width etc. The permanent deformation will usually be less than the designer intended deformation. The springback will be equal to the amount of elastic strain recovered. It is also important to note that the stress is highest at the top and bottom surfaces of the thickness and falls to zero at the neutral axis. A material with higher yield strength will have a greater ratio of elastic to plastic strain, and will exhibit more spring-back than a material with lower yield strength. On the other hand, a material with a higher elastic modulus will show less spring-back than a material with a lower elastic modulus.

III. Literature Review

Land width or bearing land is an important parameter in die design. It determines the size and surface finish of the drawn tube in cold drawing. It is now common practice to use rectangular cross sectional tubes for many industrial applications. The advantage of these tubes over circular tubing include that they are easy to fit in direction, increase to produce high torque in twist and with the feature of weight reduction. Many researchers have done work on rectangular cross section design. Zhao *et al.* [1] explained the cross-sectional distortion appeared during rotary-draw bending process of thin-walled rectangular tube with small bending radius. To study the cross-sectional distortion of the tube, a three-dimensional finite-element model of the process was developed based on ABAQUS/Explicit code and its reliability was validated by experiment.

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The results show that a zone of larger circumferential stress appears on the tube when bending angle reaches 30°.The maximum cross-sectional distortion is located in the larger circumferential stress zone and the angle between the plane of maximum cross-sectional distortion and the bending reference plane is about 50°.Zhu *et a*l. [2] studied the effects of the process parameters on springback and section deformation. A sensitivity analysis model was established based on the combination use of the multi-parameter sensitivity analysis method and the springback/section deformation prediction finite element model, and by using this model the sensitivities of the springback and the section deformation to process parameters were analysed and compared. The results showed that the most sensitive process conditions for springback angle are the boost speed and the pressure of pressure die, and the most sensitive process condition for section deformation is the number of cores. Zhao *et al*. [3] studied the characteristics of the rotary-draw bending process of a thin-walled rectangular tube, a three-dimensional finite-elements model of this process is built under the ABAQUS/explicit environment based on the solution of several key techniques, such as contact boundary condition treating, material properties definition, meshing technology, etc. The actions of pressure die, wiper die, clamp die and mandrel were considered in the modelling process. Then the reliability of the model is validated by comparison with experiments in the literature. Furthermore, numerical simulation and analysis of the thin-walled rectangular tube bending process of 3A21 aluminum alloy have been carried out by using the model. The distribution laws of tangential stress in the process have been analysed. The results show that the maximum tangential stress increases sharply in the initial stage and then keeps nearly constant with the progress of the bending process. The circumferential compressive stress zone is basically unchanged when the bending process becomes stable. The cross-section distortion produced in rotary draw bending process of thin-walled rectangular 3A21 aluminum alloy tube was studied by Liu *et al*. [4] which severely affects the forming quality of the tube. To predict and control cross-section distortion, the experiments with different process parameters were carried out. It is indicated that the effects of bending angle, core number and clearance between the pressure die and tube on the cross-section distortion are significant, but the effects of clearance between wiper die and tube and the boost velocity of the pressure die can be neglected.

The maximum cross-section distortion is produced in the section of the angle 50°, and the position does not change with the variation of the process parameters. The results are of significance in the determination of the process parameters for the rotary draw bending process of rectangular tube.Liu *et al.* [5], revealed that the collapsing deformation of an outer flange is the key factor affecting the forming quality of a thin-walled rectangular tube during the rotary draw bending process. The simplified model for loads and deformation of the outer flange, the force acted by the core die and the bending moment acted by the clamp die are obtained analytically and then, the analytical formula of collapsing deformation is deduced based on the theory of plate and shell, and finally, the analytical model is validated by comparison with simulated and experimental results. The study is of great significance to elevate the forming quality of a thin-walled rectangular tube during the rotary draw bending process. Shen *et al.* [6] proved cross-sectional distortion is one of the major problems in the bending of thin-walled rectangular waveguide tube. The cross-sectional distortion characteristics are investigated using a three-dimensional finite element (FE) model. Results showed that the maximum flange distortion locates at the symmetric line; meanwhile, the maximum web distortion locates at the extrados ridge of the tube. Hwang and Chem [7] proposed a simple analytical expression, which can be used easily in a manufacturing plant to estimate the forming pressure, and to explore the plastic deformation behavior of the tubes during the hydraulic expansion process in a rectangular cross-sectional die. At first analytical expressions using the thin-walled and thick-walled theorems are proposed to determine the forming pressures needed to hydroform a circular tube into a rectangular cross-section with a desired corner radius and then a series of finite element simulations of tube expansion are carried out to compare the simulation results of forming pressures with those from the proposed analytical expressions.

Going through ample of literature related to cold drawing of rectangular cross sectional tubes, it is found that most of the work is done related to distortion. The authors found that springback is also severe phenomenon which is untouched as far as the cold drawing of rectangular seamless tubes is concerned. The present study is organized as new design of die, plug and nut-bolts, experimentation for different land widths viz. 5 mm, 10 mm, 15 mm and 20 mm to arrive at an optimized land width to minimize springback.

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IV. Objectives Of The Research

One of the most troublesome problems facing the tubing production industry is springback in the tube making process. With the ongoing miniaturization of products, springback is a dominant effect because material behaviour greatly varies in this process. The experimentation is carried to formulate following objectives:

- To design dies and plugs for rectangular cross sections.
- To manufacture dies of various die land (land widths).
- To check the springback in dies of different land widths.

V. Methodology

The seamless tubes manufactured must satisfy the different norms and standards, hence proper material selection to achieve better product quality is utmost important. The materials used for study of seamless tubes, die and plug are given below:

A Chemical Composition of Die and Plug material (D3)

The material for die and plug is D3 (high carbon high chromium cold-work tool steels) having chemical composition is as shown in table 1.

Table 1
Chemical Composition Of D3

Component	Carbon C	Chromium Cr	Manganese Mn	Silicon Si	Phosphorous P	Sulphur S	Tungsten W	Vanadium V
Minimum %	2	11	0	0	0	0	0	0
Maximum%	2.35	13.5	0.6	0.6	0.03	1	1	1

B Properties of material

The physical and mechanical properties are tabulated as shown in table 2.

Table 2
Properties

Density g/cc	Hardness, Rockwell C	Modulus of Elasticity GPa	Poisson's ratio
7.87	64	207	0.29

C Die and Plug Design Modification Calculations

The tube under study is rectangular tube of Size 120 x 80 x 8 mm with corner radius (CR) = R = 20 mm

Let
a = 120 mm, b = 80 mm
Equivalent diameter of the Rectangular tube

$$= Deq = \frac{2(a+b)-8R+2\pi R}{\pi}$$

$$= \frac{2(120+80)-(8\times 20)+(2\pi\times 20)}{\pi} = 116.39 \text{ mm}$$

Area of the cross-section = $\pi(De-t)t$

$$= \pi\,(116.39 - 8)8$$

$$= 2724.14 \text{mm}^2$$

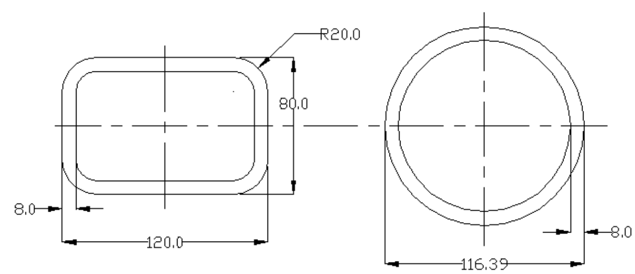

Fig: 1 Comparison of areas for rectangular tube

Above equivalent diameter of the tube area is equal to the area of rectangular tube as shown in figure 1.

Area of the fillet = 0.2146 R^2
Outside area of the fillet = 0.2146 x $(20)^2$
= 85.84 mm^2
Inside area of the fillet = 0.2146 x $(12)^2$
= 30.9024 mm^2
Outside area of the rectangular tube
= 120 x 80 – 4 x 85.84
= 9256.64
Inside area of the rectangular tube
= 104 x 64 – 4x 30.9024
=6532.3904
Area of the hollow rectangular
= 9256.64 – 6532.3904
=2724.14 mm^2

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First pass diameter of hollow required is 139.7 x 9, it can be drawn into size 129.62 x 8

Area of the reduction in first pass:

Area of the hollow before first pass = $\pi(D-t)t$

= π (139.7 – 9) 9= 3695.455 mm^2

Area of the hollow after first pass

= π (129.62 – 8) 8

= 3056.64 mm^2

Area of the reduction

= 3695.455 – 3056.64

= 638.815 mm^2

% Cross sectional area reduction

$$= \frac{A_H - A_S}{A_H} \times 100$$

$$= \frac{3695.455 - 3056.64}{3695.455}$$

Area of the reduction = 17.286 %

Second pass hollow tube 129.62 x 8 drawn to size 120 x 80 x 8

= 3056.64 – 2724.14

= 332.5 mm^2

% Cross sectional area reduction

$$= \frac{3056.64 - 2724.14}{3056.64}$$

= 10.877 %

Square plug corner radius= 20 – 8 = 12

Truncation on the plug smaller side= x

= 18.741

Ratio the sides of the tube 120: 80= 1.5: 1

Truncation on the plug larger side = x = 28.11

Larger diagonal of the plug = 107.266 mm

Smaller diagonal of the plug = 78.8953 mm

The above calculations can be summarized as shown in table 3.

Table 3
Summary Of Calculations

Sizes of products (mm)	Corner radius (mm)	Perimeter (mm)	Equivalent diameter (mm)	Area of cross section (mm^2)	Weight (kg/m)	Length (m/ton)
120 x 80 x 8	20	365.66	116.39	2724.25	21.385	46.762

VI. Die And Plug Geometry

Springback depends upon the various parameters out of which the most important one is die and plug bearing length (land). Due to time limitations, it was decided to study the effect of springback on the rectangular tube of size 120 x 80 x 8 mm with different land widths viz. 5, 10, 15 and 20 mm.The new sets of die and plug suitable for above selected tube sections are manufactured. The new design of dies and plugs is are as shown in figures 2, 3 and 4.

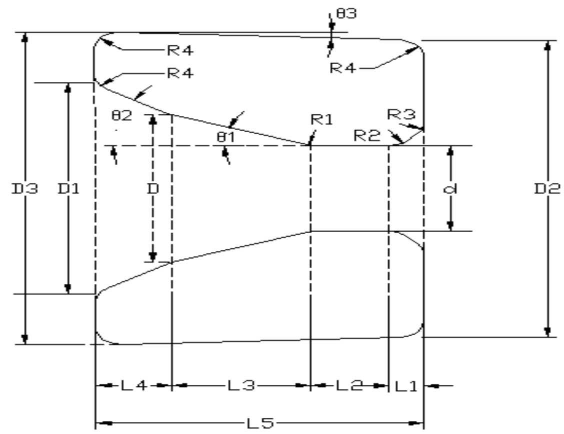

Fig.2: Rectangular die

Where

D1 Entry diameter of die
D2 Diameter of die at exit after 3º slope
D3 Diameter of die
d (or) w (or) Die exit angle end
L1 Length of die from exit to land start
L2 Bearing length or land of die
L3 Length of die from land point to die
L4 Length of die from entry to die angle start
L5 Total width of the die
θ1 Die angle
θ2 Entrance die angle
R1, R2, R3, and R corner radii of the die

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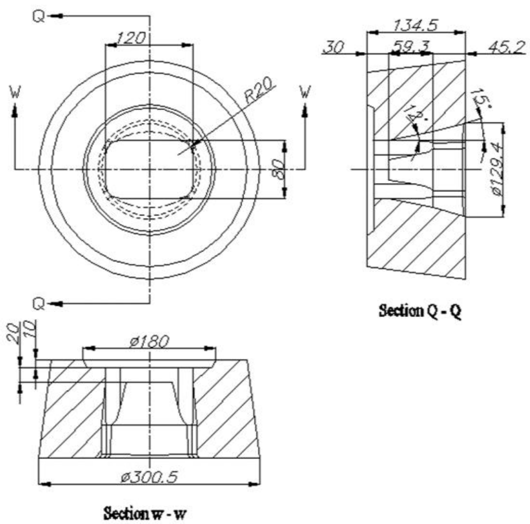


Fig. 3: 120 x 80 Rectangular tube die

The dimensions of die are as shown in table 4.

TABLE 4
DIMENSIONS OF THE DIE

Notation	Unit	Dimension
W	mm	120
H	mm	80
D	mm	125
D1	mm	129.4
D2	mm	267.47
D3	mm	300.5
θ1	degree	10
θ2	degree	15
R1,R2,R3	mm	2
R4	mm	5
L1,L2	mm	10
L3	mm	59.3
L4	mm	45.2
L5	mm	134.5

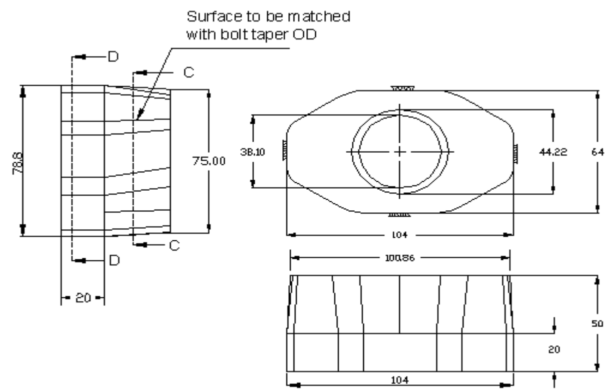
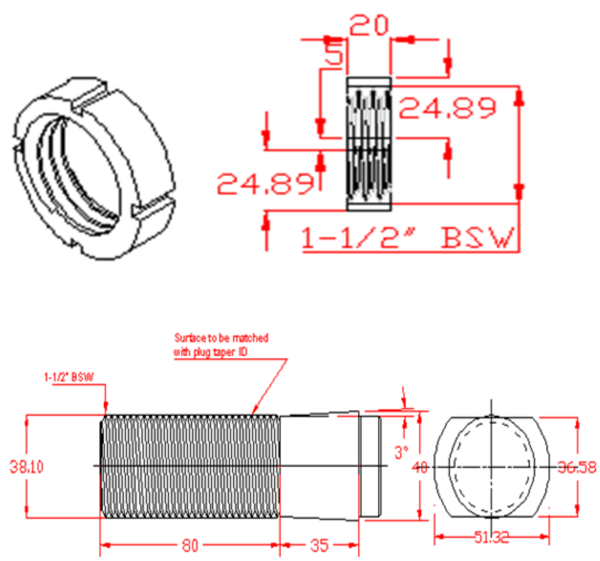


Fig.4: 120 x 80 x 8 Rectangular tube plug

A Nut and Bolt Design

Nut and bolt used for rectangular tubes are BSW 1-1/2 thread. 4 slots are given in the nut for tightening purpose. Small taper was given in the bolt up to 35 mm from the head end of the bolt and same taper was given in the plug for better gripping. The assembly of plug, bolt and nut is as shown in figure 5.



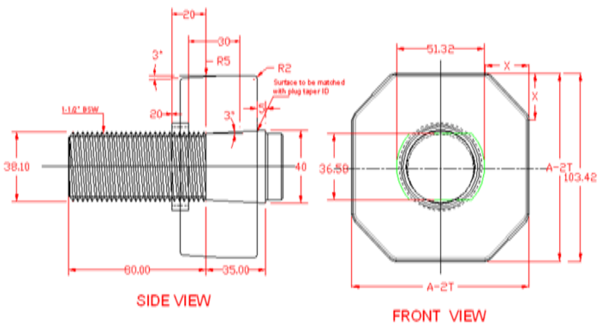


Fig.5: Nut and Bolt

The assembly is as shown in figure 6.

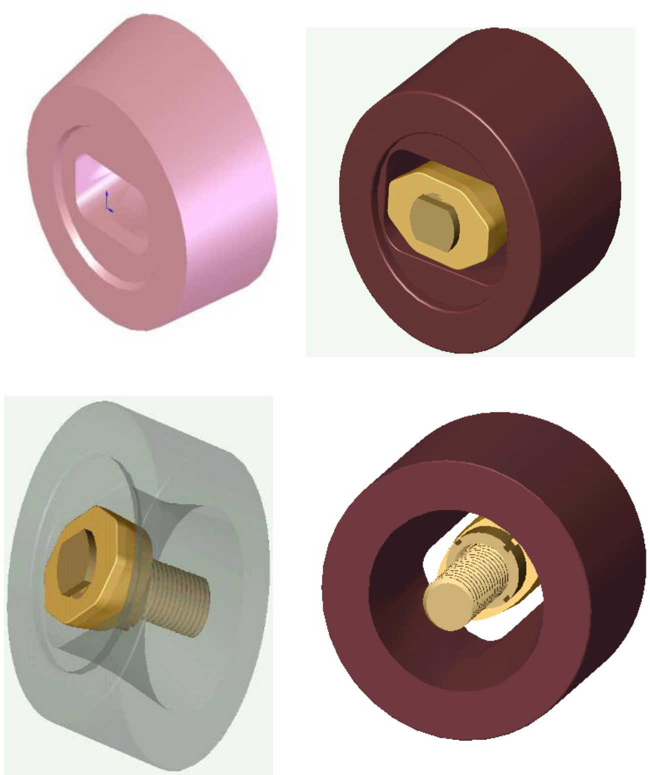


Fig. 6: Assembly

VII. EXPERIMENTATION

Actual dimensions are measured with the help of digital micrometer having 1 micron accuracy and the results are tabulated in tables 5, 6 and 7.The variation from targeted value is recorded as springback. Dimensional report of rectangular tubes 120 x 80 x 8 drawn on cold draw bench with width dimension of 80 mm, height dimension of 120 mm and wall thickness dimension of 8 mm is taken.

The dimensions are taken with digital micrometer at 10 places along the periphery of the tube and their average is taken at 5 different locations as shown in following tables.

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TABLE 5
WIDTH DIMENSIONS OF RECTANGULAR TUBE 120 X 80 X 8

Tube No.	Average at location 1	Average at location 2	Average at centre	Average at location 3	Average at location 4	Grand average readings	Springback
1	80.120	80.183	80.177	80.165	80.121	80.153	0.153
2	80.174	80.165	80.165	80.169	80.134	80.1614	0.161
3	80.185	80.157	80.142	80.158	80.120	80.152	0.152
4	80.155	80.196	80.137	80.137	80.151	80.155	0.155
5	80.152	80.111	80.156	80.157	80.158	80.147	0.147

TABLE 6
HEIGHT DIMENSIONS OF RECTANGULAR TUBE 120 X 80 X 8

Tube No.	Average at location 1	Average at location 2	Average at centre	Average at location 3	Average at location 4	Grand average readings	Springback
1	120.200	120.166	119.980	120.020	120.125	120.098	0.098
2	120.000	120.135	120.111	120.050	120.134	120.086	0.086
3	120.180	120.139	120.123	120.070	120.139	120.130	0.130
4	120.197	120.111	120.137	120.075	120.165	120.137	0.137
5	120.162	120.129	120.139	120.072	120.129	120.126	0.126

TABLE 7
WALL THICKNESS DIMENSIONS OF RECTANGULAR TUBE 120 X 80 X 8

Tube No.	Width (B) side locations				Height (H) side locations				Grand average readings	Springback
	1	2	3	4	1	2	3	4		
1	8.050	8.068	8.035	8.058	8.012	8.023	8.022	7.997	8.033	0.033
2	8.010	8.069	8.039	8.037	8.022	8.014	8.025	8.016	8.029	0.029
3	8.042	7.990	8.038	8.047	7.992	8.051	7.990	8.020	8.021	0.021
4	8.045	7.995	8.037	8.048	8.053	8.047	7.999	8.024	8.031	0.031
5	8.065	8.025	7.940	7.989	8.063	8.018	8.057	8.032	8.023	0.023

Springback values for 10 mm land width are as shown in table 8.

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TABLE 8
SPRING-BACK READINGS OF RECTANGULAR TUBES 120 X 80 X 8 WITH 10 MM LAND WIDTH

Tube no.	1	2	3	4	5	Average springback
Along width 80 mm side	0.153	0.161	0.152	0.155	0.147	0.1536
Along height 120 mm side	0.098	0.086	0.130	0.137	0.126	0.1154
Along thickness 8 mm side	0.033	0.029	0.021	0.031	0.023	0.0274

Similar readings are taken for land widths of 5 mm, 15 mm and 20 mm and the results are tabulated as shown in table 9.

TABLE 9
COMPARISON OF SPRINGBACK IN DIFFERENT LAND WIDTHS

Land width	5 mm	10 mm	15 mm	20 mm
Along width	0.1634	0.1536	0.1698	0.1620
Along height	0.1730	0.1154	0.1455	0.1470
Along thickness	0.0375	0.0274	0.0388	0.0360

The springback along width and thickness is least for 10 mm land width. It increases for 15 mm and then decreases for 20 mm.Simillarly the springback along height is least for 10 mm land width.It increases for 15 mm and then stables as shown in figure 7.

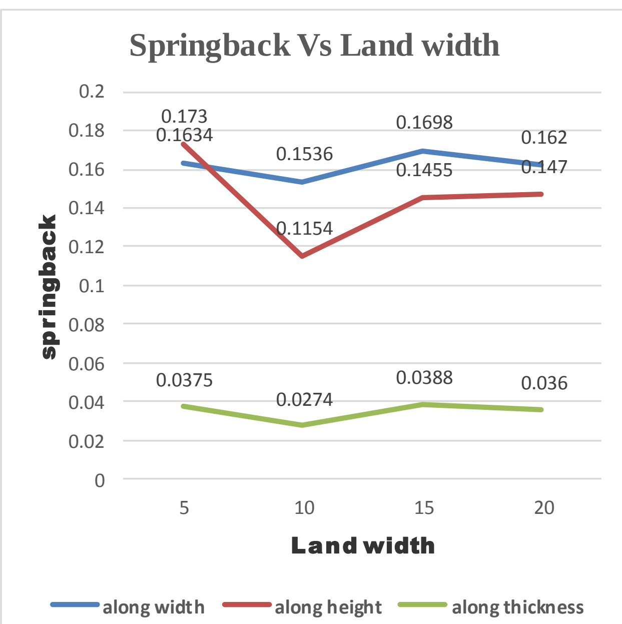

Fig.7: Graph of Springback vs. Land width

VIII. CONCLUSIONS

The experimental studies are to be limited to a minimum, because the use of each die set is very costly. The comparison of theoretical and experimental studies will lead us to a further direction for die and plug design for cold drawing the sectional seamless tubes. From the results of this study following conclusions can be drawn:

1. The results shows that land width of 10 mm gives least springback among all available options of 5,10,15 and 20 mm land width dies.
2. The values of springback are least for 10 mm and then increases and get stabilized for 15 mm and 20 mm land width.
3. The FEM analysis can also be used for predicting the dimension of the actual process, Hence results in minimizing failures.
4. The simulation model is a useful tool for the optimization of the process and can be used in future for the control of the quality product.
5. Modification in the plug geometry (truncation of the plug and plug angles) of the sectional tubes will result in minimization of the springback.
6. The simulations techniques can also be used for validation of die and plug design when used for sectional tube formation such as square, hexagonal, elliptical etc.

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