J. Appl. Comput. Mech., 4(4) (2018) 275-285
DOI: 10.22055/jacm.2018.24156.1174

ISSN: 2383-4536
jacm.scu.ac.ir

Shahid Chamran University of Ahvaz

Journal of Applied and Computational Mechanics

Research Article

Determination of the Optimal Reduction Ratio for Least Springback during Cold Drawing of Seamless Tubes

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Received November 20 2017; Revised January 29 2018; Accepted for publication February 08 2018.
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Abstract. Cold drawing process is one of the most used metals forming processes in industries for forming seamless tubes. This process of plastic deformation of metals occurs below the recrystallization temperature and is generally performed at room temperature. When metal is cold worked, upon the release of forming force, the springback occurs. In this paper, the springback effect of the seamless tube that has undergone cold drawing is studied for three different reduction ratios viz.10-15 %,15-20 %, and 20-25 % having the aim to reduce it. Experiments are conducted under different reduction ratios with working conditions of die semi angles of 10 and 15 degrees, die land width of 5 mm and 10 mm as well as drawing speed of 4, 6, and 8 m/min for C-45 tube material. Optimum reduction ratio is finalized using Statistical Package for Social Science (SPSS) software of data analysis using statistical tests like Kruskal-Wallis, ANOVA, Post-hoc, etc. Metallurgical analysis through microstructural investigation, XRD and mechanical testing via cold draw load, and hardness testing for different reduction ratios are also studied for validation purposes. The results of this research show that 10-15 % reduction ratio yields the minimum springback. This can be used to help designing tools in the metal forming industry to minimize springback and improve the quality of the product.

Keywords: Cold drawing, Seamless tubes, Springback, Optimization, Statistical Package for social sciences.

1. Introduction

Cold drawing is one of the most important semi-finished processes used in the steel industry. Cold drawing of the seamless tube is therefore an important engineering discipline within the area of manufacturing technology. The major problem associated with cold drawing of seamless tubes is the springback. Dimensional variation, scores on tubes, chattering, and bending of tubes are other defects found in the cold drawing process: Dimensional variation can be solved by ensuring the position of the plug and the die face, scores can be removed by grinding operation, and chattering can be reduced by proper lubrication like soaping and phosphating. Bending of the tube during drawing operation is avoided by proper positioning of the die in the frame of drawing bench. The cold drawing defects can be attained easily, but springback is severe one as it varies with different parameters and is difficult to predict beforehand.

Basically, springback is the geometric difference between the loaded and unloaded configuration which is affected by various factors such as die semi angle, land width, drawing speed, tube material, etc. It also depends on tribological parameters

Published Online: September 20 2018

like coefficient of friction, lubrication, heat treatment methods, etc. This study aims at minimizing the influence of various operating parameters on springback in cold drawing of C-45 seamless tubes. Since all materials have limited elastic modulus, when load acting on plastic deformation is relieved from the material, it is followed by several elastic improving. Elastic limits of materials are exceeded, but flow limit thereof cannot be exceeded, therefore, the material still keeps a portion of its original flexibility character. When the load is released, the material on forcing compress side tries to enlarge, whereas the material on tensile side tries to shrink. As a result, the material tries to springback. This nature of material is known as springback (Wagoner *et al*. [1]). Springback is a phenomenon that occurs in many cold working processes. In a deformed stage of the metal into the plastic region, the total strain is composed of two parts namely an elastic and the plastic part. After removal of the deformation load, a stress reduction will occur and accordingly the total strain will decrease by the amount of the elastic part, which results in springback (Anderson [2]).

2. Literature Review

The important parameters affecting drawing load are mechanical properties like yield stress, ultimate strength, percentage of reduction, die semi angle, friction coefficient, and peak load during start up. The application of the slab method to the drawing process was first investigated by Hoffman and Sachs [3]. The use of slab method for analyzing the drawing process has found widespread acceptance due to its simplicity and accuracy, whose procedure is based on principles of mechanics. It reveals that there is relation between the forming load and the material flow stress in the form. Pioneering work on tube sinking theory is accredited to Bishop and Hill [4]. Boer and Webster [5] investigated the application of the upper bound solution and the finite element method for round to square drawing. The study presents a direct comparison between two modeling techniques of metal forming processes, one method is a direct analytical solution based on the kinematically admissible velocity field; the other method uses a finite element approach based on the calculation of velocities at the nodes of the mesh. Collins [6] obtained the slip line field solution for the axisymmetric tube drawing process.

The finite element analysis is a proven method to simulate and optimize various manufacturing processes. FEM solutions for the tube drawing have been done by many authors. Validation of finite element modeling of the tube sinking process was done by Pietrzyk and Sadok [7]. Sawamiphakdi et.al [8] investigated the tube drawing process using finite element method. Karnezis and Farugia [9] used workability criterion to determine failure in the cold drawing process. Rasty and Chapman [10] investigated the effect of process variables on the tube drawing process and product integrity using the finite element package ABAQUS. This study concentrated on the effect of die and plug angles on the performance of the drawing operation. The high starting load phenomenon is common in most of the forming processes, mainly due to frictional forces. The effect of friction and lubricant on the peak load in the tube drawing process was investigated by Neves and Button [11]. Typical lubricants used in the tube drawing are soap with or without conversion coatings and emulsions. The peaks are more intense in the tests with the most viscous lubricants (Reno form and Extrudoil). In many tests with the less viscous lubricant (SAE), the peaks are not well defined. The peak load during starting of the extrusion process was also observed in the experimental data of Beland *et.al* [12].

Noonai *et al.* [13] studied the influences of reduction ratio on mechanical properties and transformation temperature of Ni Ti drawn wires. Vega *et al.* [14] studied the effect of process variables such as semi die angle and reduction in area coefficient of friction on the drawing force. The influence of main process parameters (wire yield stress, cross sectional area reduction, and die half angle) on shape quality and area fraction in round to hexagonal composite wire drawing were investigated by Norasethasopon and Yoshida [15]. The effects of degrees of deformations, ranging from 5 to 30% reductions on the mechanical properties of cold drawn mild steel rods were experimentally investigated by Alawode and Adeyemi [16]. Centinarslan [17] studied the influence of reduction ratio and drawing speed on the cold drawing of ferrous wires. Suliga *et al* [18-19] studied the influence of drawing speed on fatigue strength TRIP steel wires. Liu *et al.* [20] studied the variation of axial stress within the contacting region change of the drawing stress with several factors in terms of the longitudinal amplitude and frequency of the applied ultrasonic vibration, the diameter reduction ratio, and the drawing force. The result indicated that the drawing force increases with the growth of the drawing velocity and the reduction ratio.

Literature review reveals that the investigation carried by various research studies with respect to minimization of springback while cold drawing the seamless tubes is scarce. Therefore, the present work aims at identifying the optimal reduction ratio to minimize the springback. Seamless tubes are drawn at different reduction ratios under different process parameter conditions. To obtain the optimal reduction ratio, it is proposed to carry out experimental work followed by data analysis. Data analysis of experimental findings is carried out using available statistical tools to infer the meaning with respect to the aim of study. The microstructure characterization of the drawn tubes for various reduction ratios viz. microstructure, grain elongation, mechanical properties, hardness, and XRD analysis is also carried out. The optimized reduction ratio is also found in the patent 4646/MUM/2015 in [21].

3. Experimental Work

The ultimate aim of the experimental work is to decide the best reduction ratio for a particular tube and die material combination**.** The experimental work is carried out for three different reduction ratios in order to check the minimum variation in the drawn tube. The less is the variation from targeted value, the less is the springback**.** The cold drawing process sequence is as shown in Fig.1. In push pointing, 200 mm length of the tube end is decreased in diameter so that it can easily enter in the drawing die. Rotary swaging and squeeze pointing are also similar employed techniques. Sometimes, phosphate coating or soap film is applied before drawing. Surface preparation starts with pickling process to remove scale and rust where H_2SO_4 is maintained at 50-60° C temperature. Then, the tubes inserted in water bath for rinsing and subsequently the neutralization is done. Finally, the tubes are dipped in oil bath containing Reacto 9080 oil for 15-20 minutes at 50-60° C temperature. The tubes are drawn using the draw bench till required dimensions are achieved using multipasses. Intermediate heat treatment is carried out to relieve stresses. Straightening is usually performed using a six- or 10-roll rotary straightener with a combination of flex and pressure. Eddy current testing is one of the non-destructive testing employed for testing the seamless tube defects. Finally, the tubes are cut to required length and finishing operations may include polishing, pickling, or sandblasting to improve the surface appearance and remove minor imperfections. Final inspection techniques are determined by the customers' order requirements.

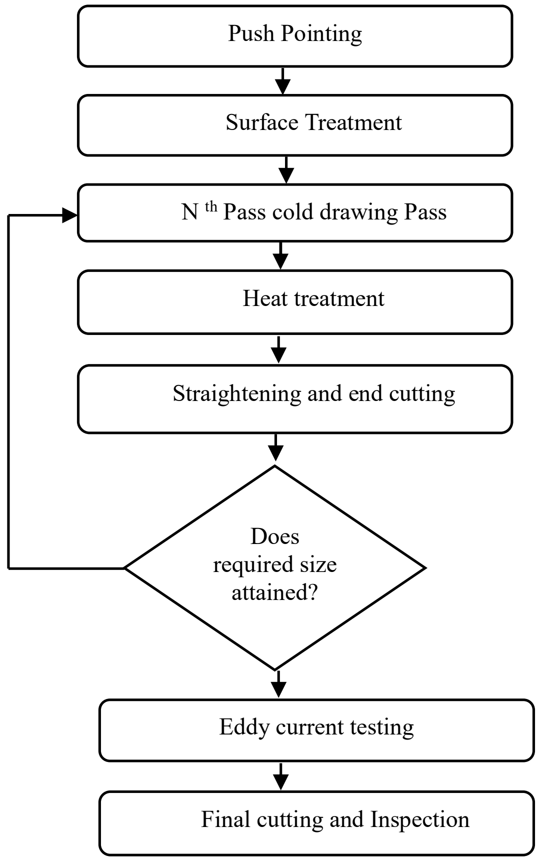


Fig. 1. Flow chart of cold drawing process sequence

3.1 Materials

During experimental work, mother or hollow seamless tubes of C-45 material with 4.00 mm wall thickness are cold drawn from size of 33.40 mm outer diameter for three different reduction ratios as given in Table 1. The reduction ratios are decided as per size of standard hollow tube size available or custom size prepared for cold drawing. The required thickness and shaping also plays an important role in deciding reduction ratio.

Table 1. Reduction ratios

Reduction ratio (%)	Hollow Tube Dimensions (mm)			Final Tube Dimensions (mm)			Reductions (%)		
	OD	TH	ID	OD	TH	ID	OD	TH	C/S
A (10-15)	33.4	4.00	25.4	30.0	3.85	22.30	10.18	3.75	14.39
B (15-20)	33.4	4.00	25.4	30.0	3.60	22.80	10.18	10.0	19.18
C (20-25)	33.4	4.00	25.4	30.0	3.40	23.20	10.18	15.0	23.10

Two principal limitations to cold working of a material are the permissible stress applied on the tool material and the ductility of the material to make cold worked cost effectively. The chemical composition for tube material of C-45(EN-8 D) is as shown in Table 2. The properties and composition of different shipments of the same size and the same steel grade may vary because of original melt and cast process as well as the amount of cold work.

Table 2. Chemical composition of tube material of C-45(EN-8D)

Element	C	O	Si	P	Fe
Weight %	17.68	11.04	0.68	2.09	68.50
Atomic %	42.29	19.83	0.70	1.94	35.24

The mechanical properties for the tube material are yield stress of 490 N/mm^2, ultimate strength of 670 N/mm^2, hardness of 87 HRB, and 28 % elongation. The die and plug (as shown in Figs. 2 and 3) are made up of AISI D3 air hardened, high-carbon, and high-chromium tool steel. Commonly dies are made up of D3 steel material with 42-48 RC hardness and plug with D1 or D2 or D3 steel with hardness 30-38 RC. They are machined and applied heat treatment process is tempering at 1000^0 C, which display excellent abrasion/wear resistance and show good dimensional stability and high compressive strength having chemical composition as shown in Table 3. The chemical analysis is done on the spectrometer in Ahmednagar Auto & Engineering Association as per IS 8811: 1998.The die of size 30.0 mm and plugs of various sizes are selected for achieving different reduction ratios as tabulated in Table 4.

Table 3. Chemical Composition of AISI D3 Steel

Carbon (C)	Silicon (Si)	Chromium (Cr)	Manganese (Mn)	Nickel (Ni)
2.10 %	0.30 %	11.50 %	0.40 %	0.31 %

Reduction ratios play an important role in deciding the desired properties. Based on the literature survey, the discussions with industrial experts, and the availability of tooling, three reduction ratios are determined.

Table 4. Die and Plug sizes

Reduction ratio	Die size (mm)	Plug size (mm)
A (10-15 %)	30.0	22.30
B (15-20 %)	30.0	22.80
C (20-25 %)	30.0	23.20

3.2 Experimentation on Draw Bench

The experimentation is carried out on draw bench having 50-ton strength, 1-10 m/min drawing speed, and 10-48 m/min return speed capacity. Three sets of experiments for each reduction ratio group are conducted for various die semi angle, land width, and drawing speed combinations. The resultant springback is measured. The springback is the difference between the measured dimension after drawing and the desired size, which is measured with the help of digital micrometer (Mitutoyo make with 1micron accuracy).

3.3 Design of Experiments

Experiments are designed as per design of experiments (DoE) technique. L12 orthogonal array is used to conduct experimental tests. Three reduction ratios A (10- 15 %) with actual value of 14.39 %, B (15-20 %) with actual value of 19.18 %, and C (20-25 %) with actual value of 23.10 % are considered for experimental work. The levels of experimentation are found by conducting pilot trials and their range is sorted by discussions with industry experts and with the review of concerned literature in the cold drawing process.

Fig. 2. Die of size 30.0 mm OD, 15 degree die semi angle and 5 mm land width

The die semi angle is an entrance angle section which guides the tube during drawing process in the die. Land width is the portion which facilitates the drawing operation. Too high value of die semi angle tends to thin the wall thickness of the drawn tube and too low value tends to thicken. Similarly, the die land width affects accuracy and surface finish of the drawn product. Too high bearing length will spoil the surface finish and too low bearing length will cause excessive die wear. Generally, the length of bearing is kept longer for drawing material with high tensile strength and shorter for low strength materials. Two levels of die semi angle viz.10 and 15 degrees, two levels of land width viz. 5 mm and 10 mm, three levels of drawing speed viz. 4, 6 and 8 m/min are considered for experimentation, as shown in Table 5.

Fig. 3. Plug of sizes 22.30 mm, 22.80 mm, and 23.20 mm

Table 5. Levels of Experimentation

Sr. No.	Process Parameter Factor	Unit	Factor Level		
			Level 1	Level 2	Level 3
1	Die semi angle	Deg.	10	------	15
2	Land width	mm	5	------	10
3	Drawing speed	m/min	4	6	8

Experimental plan is laid for the various combinations of die semi angle, land width, and drawing speed to measure the springback for three reduction ratios. Seamless tubes are cold drawn for 3 different reduction ratios. The tubes are allowed to cool down to room temperature. The variation from targeted size is measured using digital micrometer of 1micron accuracy. Actual outer diameter is measured with the help of digital micrometer having 1micron accuracy and the results are tabulated in Table 6. The variation from targeted value of 30.0 mm is recorded as springback. Springback is an elastic recovery. After cold drawing, the tubes are allowed to cool down to room temperature and the stresses are allowed to relieve. The dimensions then set to a particular value. The less this variation is, the less the springback will be.

Table 6. Measured Readings

Die semi angle (degree)	Land width (mm)	Drawing speed (m/min)	Average OD for A(mm)	Springback A (mm)	Average OD for B (mm)	Springback B (mm)	Average OD for C (mm)	Springback C (mm)
10	5	4	30.065	0.065	30.052	0.052	30.067	0.067
10	5	6	30.064	0.064	30.102	0.102	30.169	0.169
10	5	8	30.098	0.098	30.046	0.046	30.111	0.111
10	10	4	30.08	0.08	30.156	0.156	30.096	0.096
10	10	6	30.081	0.081	30.036	0.036	30.083	0.083
10	10	8	30.046	0.046	30.087	0.087	30.105	0.105
15	5	4	30.063	0.063	30.127	0.127	30.198	0.198
15	5	6	30.284	0.284	30.089	0.089	30.107	0.107
15	5	8	30.266	0.266	30.01	0.01	30.115	0.115
15	10	4	30.308	0.308	30.13	0.13	30.112	0.112
15	10	6	30.104	0.104	30.147	0.147	30.1	0.1
15	10	8	30.048	0.048	30.145	0.145	30.123	0.123

4. Data Analysis

After getting experimental data, it is attempted to draw inference using statistical tools. Different statistical tests are available with their own merits in the software Statistical Package for Social Sciences (SPSS).

4.1 Test 1: Kruskal-Wallis Test

The Kruskal-Wallis test [21] is a nonparametric (distribution free) test which is used when the assumptions of ANOVA are not met. This test is used to assess the significant differences of a continuous dependent variable from a grouping of independent variable (with three or more groups). It is considered the nonparametric alternative to the one way ANOVA and an extension of the Mann-Whitney U test to allow the comparison of more than two independent groups. The assumptions include H_0: There is no significant difference among three different groups of reduction ratios and H_1: There is significant difference among three different groups of reduction ratios.

The objective of the test is to study whether A, B, and C differs with respect to springback values for the level of significance, α: 0.05. The independent variables are reduction ratio with 3 categories A, B, C and dependent variable is springback values measured in mm. The output of test statistic is as shown in Tables 7 and 8.

Table 7. Test Statistic Ranks

Group	N	Mean Rank
Reduction ratio 10-15%	1080	2005.31
Reduction ratio 15-20%	1080	1481.25
Reduction ratio 20-25 %	1080	1374.94
Total	3240	

Table 8. Test Statistics

	Outer Diameter
Chi-Square	281.126
Dof	2
Asymp. Sig.	0.000

The mean rank (i.e., the 'Mean Rank' column in the Ranks table) of the outer diameter for each reduction ratio group can be used to compare the effect of the springback in different reduction ratios. Whether these three reduction ratio groups have different springback values can be assessed using the Test Statistics table which presents the result of the Kruskal-Wallis H test including the chi-squared statistic (the 'Chi-Square' row), the degrees of freedom (the 'dof' row) of the test, and the statistical significance of the test (the 'Asymp. Sig' row).

Since P value (0.000) (Table 8) is less than level of significance (LOS: 0.05), the null hypothesis is rejected. The significance level is the probability of rejecting the null hypothesis, when it is true. For 5 % significance level, it indicates a 5% risk of concluding that a difference exists when there is no actual difference. Therefore, it is concluded that 3 reduction ratios are different with respect to springback values. In order to find out where the difference lies, we refer to the mean value. Hence, it can be concluded from Table 7 that the mean value is more for reduction ratio of 10-15%, therefore, it produces least springback value.

4.2 Test 2: One Sample Test

One sample t -test is a statistical procedure used to test the mean value of a distribution under the normal sampled distribution. However, this procedure performs well even for non-normal populations if the sample size is sufficient large [22]. The aim of the test is to study whether the springback values on an average is significantly different from the designed value of 30 mm for level of significance $\alpha = 0.05$**.** The results of test are shown in Table 9.

Table 9. One-Sample test results for 10-15%, 15-20 %, 20-25 % reduction ratio

Parameter setting ,Test Value = 30 95% Confidence Interval of the Difference	10-15 % reduction ratio	15-20 % reduction ratio	20-25 % reduction Ratio
Die semi angle 10, Land width 5, Speed 4	0.0696	0.0602	0.0880
Die semi angle 10, Land width 5, speed 6	0.0675	0.1136	0.2013
Die semi angle 10, Land width 5, speed 8	0.1076	0.0502	0.1131
Die semi angle 10, Land width 10, Speed 4	0.0849	0.2582	0.1035
Die semi angle 10,Land width 10, Speed 6	0.0857	0.0444	0.0858
Die semi angle 10, Land width 10, Speed 8	0.0510	0.1070	0.1220
Die semi angle 15, Land width 5, Speed 4	0.0776	0.1524	0.2030
Die semi angle 15, Land width 5, Speed 6	0.3114	0.1095	0.1091
Die semi angle 15, Land width 5, Speed 8	0.4495	0.1239	0.1159
Die semi angle 15, Land width 10, Speed 4	0.4501	0.1389	0.1129
Die semi angle 15, Land width 10, Speed 6	0.1069	0.1557	0.1187
Die semi angle 15, Land width 10 ,Speed 8	0.0556	0.1490	0.1364

4.3 Test 3: ANOVA Test

The ANOVA is a statistical method used to compare different sources of variance within a data set. The purpose of this comparison is to determine the existence of significant differences between two or more groups [23]. The aim of the test is to study if there is a significant difference in springback values of 12 combinations of reduction ratio 10-15% for level of significance $\alpha = 0.05$. The independent variables considered are die semi angle, land width, drawing speed combinations, and dependent variable is springback values of 10-15% reduction ratio measured in mm.

Table 10. ANOVA for all 3 reduction ratio

Reduction ratio		Sum of Squares	Dof	Mean Square	F	Sig.
10-15 %	Between Groups	1.212	11	0.110	26.774	0.000
	Within Groups	4.395	1068	0.004		
	Total	5.607	1079			
15-20 %	Between Groups	1.724	11	0.157	5.947	0.000
	Within Groups	28.145	1068	0.026		
	Total	29.869	1079			
20-25 %	Between Groups	8.662	11	0.787	13.943	0.000
	Within Groups	60.316	1068	0.056		
	Total	68.978	1079			

As shown in Table 10, as the P value is less than LOS, the null hypothesis is rejected. Hence, it can be concluded that, there is a significant difference in springback value of 10-15% reduction ratio across 12 combinations.

4.4 Test4: Post Hoc Tests

In the design and analysis of experiments, the post hoc analysis is an important procedure without which the multivariate hypothesis testing would greatly suffer, rendering the chances of discovering false positives unacceptably high. The post hoc analysis includes looking at the data after the experiment has concluded for patterns that were not specified a priori. Most results of post hoc analyses are reported as they are with unadjusted p-values. In practice, post hoc analyses are concerned with finding relationships between different subgroups of sampled populations that would otherwise remain undetected and undiscovered [24]. In order to find where the difference lies, we refer to homogeneous subset table. From Homogeneous subset table it can be seen that there is no difference in the mean values of the sets.

Table 11. Descriptive Outer Diameter

Reduction ratio	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean
					Lower Bound
10-15 %	1080	30.0883	0.91581	0.02787	30.0336
15 - 20%	1080	30.1008	0.16638	0.00506	30.0909
20 - 25%	1080	30.1252	0.27098	0.00825	30.1090
Total	3240	30.1048	0.55974	0.00983	30.0855

As shown in table 11, as mean values of all readings is close to target value of 30.0 , hence, 10-15 % reduction ratio is better among all. This can be illustrated in Fig. 4.

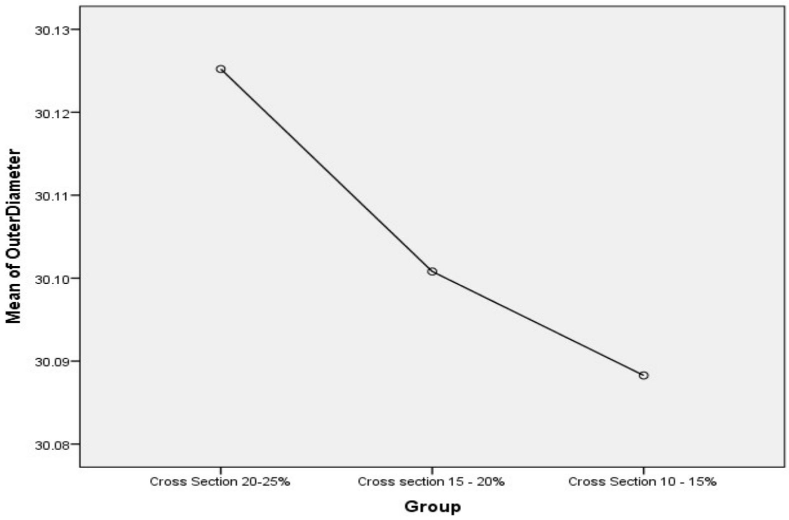


Fig. 4. Variation of Springback for various reduction ratios

In depth analysis of the results shown in Fig. 5 reveals that there is less variation in springback for 10-15 % reduction ratio as compared to 15-20 % and 20-25 % reduction ratios. Further, it is found that that die semi angle 10 degree, land width 5 mm, and speed 4m/min gives the least springback. Secondly, die semi angle 10 degree, land width 10 mm, and speed 6 m/min as well as die semi angle 10 degree, land width 10 mm, and speed 4 m/min are another process parameter combinations that can be used in minimizing springback during the cold drawing process.

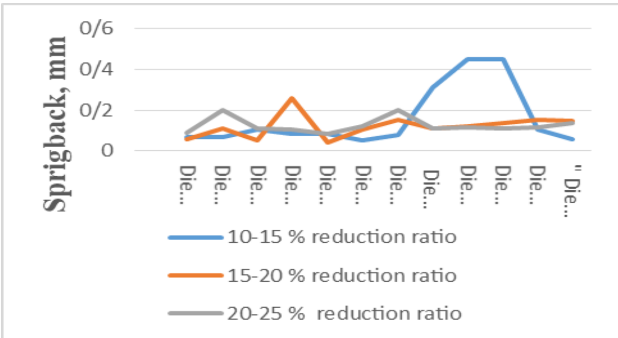


Fig. 5. Variation of Springback for various process parameters

5. Microstructure and Mechanical Properties

The purpose of this study is to quantify and understand the changes in microstructure and mechanical properties among the three reduction ratios. Due to the combination of good ductility and other useful mechanical properties considerable work has been performed to increase the tensile strength of high-carbon steel tubes. In order to increase the properties suitable for various working environments, one research direction on the drawn tubes is to figure out the microstructure and the texture evolution in the process of cold deformation [25]. Owing to the deformation of cementite occurred in the drawn process, this research direction has drawn considerable attraction both in science and technology. The present work aimed to investigate the mechanical properties of drawn seamless tubes by various tests like tensile test, hardness test, XRD etc. and examine its relevance to springback in different reduction ratios. It is necessary to study the composition, microstructure, mechanical properties, relationship between composition, structure and mechanical properties, residual stresses etc. The reason is all that is related to springback.

5.1 Micro Structural Changes

Micro structure revealed equiaxed grains of ferrite and perlite in samples of hollow tube. Whereas, grain flow was reported in a cold working direction in all three types as shown in Fig. 6. Micro structures checked in a longitudinal direction where gradual elongation of grains was reported as shown in Table 12. With reduction, the grains elongate and the microstructure shows twisted grains. At recrystallization, the temperature grains are replaced by the small equiaxed grains. The grain size was found to be reduced after reduction in cold drawing. The grain size ASTM No 5-6 of hollow tube changed to ASTM No 6-7 after reduction. The microstructure shows the grain structure with elongated grains as the reduction ratio increases. This occurs due to the cold working in a tensile nature to various reduction patterns. With the increasing cold working reduction pattern, the gradual rise was found in elongation of grains as shown in Table 12 and Fig. 7.

Table 12. Gradual elongation of grains

No of reading	Hollow Tube	Type A	Type B	Type C
1	30.21	32.46	54.87	76.16
2	25.62	32.30	63.13	62.41
3	27.61	30.11	70.76	62.45
4	20.23	57.52	32.99	80.23
5	18.42	81.85	64.60	100.64
6	25.26	24.93	70.64	58.98
7	20.20	32.93	31.55	92.61
8	22.23	32.46	45.31	62.62
9	28.26	30.10	40.20	70.64
Average	24.23	39.41	52.67	74.08

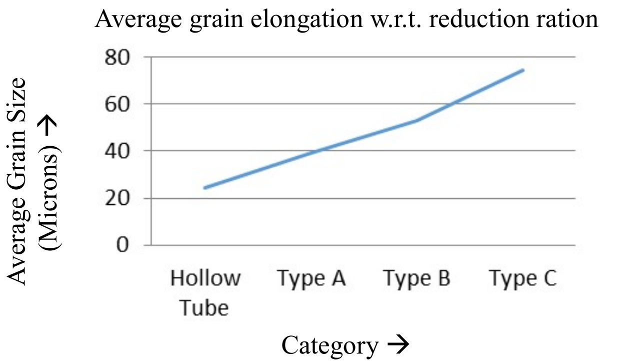
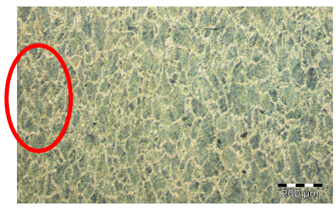


Fig. 6. Grain elongation for mother tube and all the 3 reduction ratios

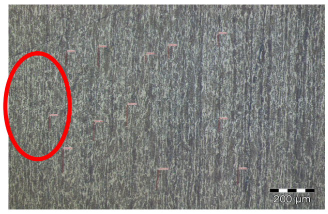
The microstructure, as shown in Fig. 6, indicates that β-Ti phase for 10-15 % reduction ratio is found stable. With the increase in reduction ratio from 10-15 % to 20-25 %, the microstructure of the alloys evolves from deformed dendrite structure to fiber-like structure. The microstructure with the reduction ratio of 10-15 % exhibits optimum mechanical properties and closely correlates to the dendrite structure of the alloy.



Hollow Tube - Section in a Longitudinal Direction
Magnification : 100X Nital Etch

Type A (10-15 %)– Section in a Longitudinal Direction
Magnification : 100X Nital Etch

Type B (15-20 %)– Section in a Longitudinal Direction
Magnification : 100X Nital Etch



Type C(20-25 %) – Section in a Longitudinal Direction
Magnification : 100X Nital Etch

Fig. 7. Microstructure of Mother tube, 10-15 % reduction, 15-20 % reduction and 20-25 % reduction ratio samples

The finer grains were newly formed at the boundaries of the original large grains and twin boundaries by dynamic recrystallization. The grain size distribution was changed from a bimodal distribution upon a small total reduction to a homogeneous distribution upon a large total reduction due to the formation of finer grains that continued at the grain boundaries of large grains. The size and distribution of the grains were affected by the reduction ratio.

5.2 XRD plots

X-ray Diffraction (XRD) helps to reach the science at the atomic scale in the analysis of crystal structure, chemical composition, and physical properties of bulk and thin film crystalline or polycrystalline materials. Commonly X-ray diffraction gives graph of Intensity versus 2θ. This scan result provides a signature peak of the phases present in the sample. By comparing this signature peak with standard reference patterns, the required properties can be identified of the subjected material. The unit cell crystal structure and its parameters can also be determined. XRD plots for 3 reduction ratios are obtained using PANalytical Make X-Ray Diffractomer X'PERT PRO, Kα Radiation: Chromium source, wavelength 2.289760 Å having Parallel beam geometry with a poly-capillary lens and the parallel plate collimator. The results are shown in Fig. 8. The results show that induced stresses are less in 10-15 % reduction ratio samples because of less deformation.

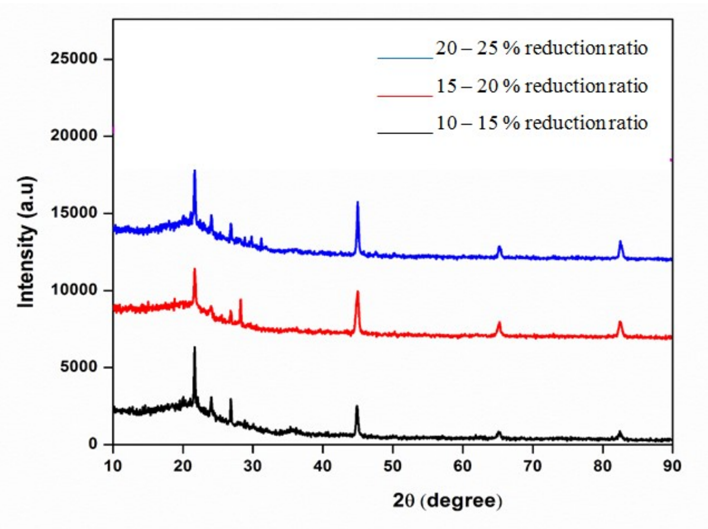


Fig. 8. XRD plots of residual stresses for three reduction ratios

6. Results and Discussions

6.1 Cold draw load

The required load to draw the seamless tubes is measured using load cell attached to the draw bench. The load is 6.65 MT for 10-15%, 8.86 MT for 15-20%, and 10.67 MT for 20-25% reduction ratio. With the rise in reduction pattern, the load is increased as well.

6.2 Elastic recovery

The elastic recovery is given by {% elastic recovery = (100*(die size – actual OD) / die size)} which is as shown in Table 13. Thus the elastic recovery or springback is found less for type A i.e. 10-15 % reduction ratio.

6.3 Mechanical properties

Mechanical properties viz. yield strength (YS) and ultimate tensile strength (UTS) are checked using tensile test after preparing the specimen according to ASTM standard (For tensile test ASTM E18, ASTM E23, ASTM E8 standards are used) and are tabulated below in Table 14.

Table 13. % Elastic recovery

Sample No	Type A (10-15%)		Type B (15-20 %)		TypeC (20-25%)	
	OD	% elastic recovery	OD	% elastic recovery	OD	% elastic recovery
1	30.065	0.173	30.052	0.217	30.067	0.223
2	30.064	0.340	30.102	0.213	30.169	0.563
3	30.098	0.153	30.046	0.327	30.111	0.370
4	30.08	0.520	30.156	0.267	30.096	0.320
5	30.081	0.120	30.036	0.270	30.083	0.277
6	30.046	0.290	30.087	0.153	30.105	0.350
7	30.063	0.423	30.127	0.210	30.198	0.660
8	30.284	0.297	30.089	0.947	30.107	0.357
9	30.266	0.033	30.01	0.887	30.115	0.383
10	30.308	0.433	30.13	1.027	30.112	0.373
11	30.104	0.490	30.147	0.347	30.100	0.333
12	30.048	0.483	30.145	0.160	30.123	0.410
Average		0.313		0.419		0.385

Table 14. Mechanical Properties

Sample No	YS (MPa)	UTS (MPa)
Type A (10-15 %)	480	615
Type B (15-20 %)	590	675
Type C (20-25 %)	685	750

6.4 Hardness Property

Hardness is measured at various locations along the tube using Brinell Hardness Tester. The ball indenter is pressed into the sample by an accurately controlled test force. The force is maintained for a 10 second dwell time, leaving a round indent in the sample. The size of the indent is determined optically by measuring two diagonals of the round indent using either a portable microscope or one that is integrated with the load application device. The Brinell hardness number is a function of the test force divided by the curved surface area of the indent. The measured hardness values are shown in Table 15.

Table 15. Hardness values

Sample No	Hollow Tube Average HRB	Final Tube Average HRB	% Change
Type A 10-15 % reduction ratio	86	90	4.65
	88	92	4.55
	86	90	4.65
Type B 15-20 % reduction ratio	87	92	5.75
	86	94	9.30
	86	92	6.98
Type C 20-25 % reduction ratio	87	96	10.34
	88	98	11.36
	88	102	15.91

The hardness was found increasing with the rise in reduction pattern. This was caused due to the increase in cold working amount. The findings showed 4.6 % average change in 10-15 % reduction ratio, 7.34% average change in 15-20 % reduction ratio, and 12.53 % average change in 20-25 % reduction ratio.

7. Conclusions

After data analysis for three reduction ratios viz, 10-15 %, 15-20 %, and 20-25%, it is found that the mean values of these 3 sets are significantly different and the springback is least for 10-15%. In depth analysis of this 10-15 % reduction ratio also gives following better combinations of die semi angle, land width, and drawing speed.

- Die semi angle 10 degree, land width 5 mm, and speed 4m/min (mean 30.07 mm)
- Die semi angle 10 degree, land width 10 mm, and speed 6 m/min (mean 30.08 mm)
- Die semi angle 10 degree, land width 10 mm, and speed 4 m/min (mean 30.096 mm)

Therefore, it can be concluded that these 3 combinations of die semi angle, land width, and speed are most suitable from minimization of springback point of view. The microstructural study and mechanical property evaluation among three reduction ratios indicates that 10-15 % reduction ratio is better as compared to other two reduction ratios. For higher reduction ratio, the stress–strain curves are characterized by a necking behavior and the end of the yielding or necking is reached when the amount of induced rigid phase attained 50%. The rigid phase then acted as the continuous phase and the stress increased very strongly. Thus, these induced stresses are found more in 20-25% and less in 10-15% reduction ratios.

Acknowledgment

Authors thanks to Yashashree Tubes Private Limited, F-48, Maharashtra Industrial Development Corporation, Ahmednagar, Maharashtra State, India for sponsorship and experimentation. This work was supported by efforts of Dr. S. H. Gawande, Professor in Mechanical Engineering, M.E.S. College of Engineering, Pune, India.

Nomenclature

D3:	Die and plug material	A:	10-15 % reduction ratio
OD:	Outer diameter	B:	15-20 % reduction ratio
ID:	Inner diameter	C:	20-25 % reduction ratio
TH:	Wall thickness	C/S:	Cross section

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