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Optimization of Reduction Ratio for Minimizing the Spring back during Cold Drawing of Seamless Tubes

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Abstract

Cold drawing is metal working process utilizing tensile forces to deform the metal. This paper reports the microstructure and mechanical properties correlation with each stage of multi-pass cold drawing of ST 35 steel in the process of seamless tubes manufacturing. The micro-structural evaluations showed that there is grain elongations as the number of passes increases. The same findings can be validated using Scan Electron Microscope (SEM). In addition, the mechanical testing values on UTM are examined with the number of passes. The results of this study shows that the mechanical properties, variation in grain size and hardness has correlation with the resulting microstructure of the material which are evaluated with the increase in number of passes. First pass before heat treatment shows better properties.

***Keywords**: Grain size, Microstructure, Springback, Retraction ability, Statistical Package for social sciences.*

1. Introduction

Cold drawn tubes are extensively used in automotive, petroleum, mining and bearing industries for manufacturing of various components, bearings, drill rods and line pipes. Dimensional accuracy has immense importance in the quality of end products and controlling rejection in manufacturing processes of these end products. However, springback causes geometrical inaccuracies in drawn tubes.

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 thedie 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. 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 ST 35 Steel. 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*.). 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.

2. Literature Review

A purely elastically bent sheet will return to its original configuration upon removal of the bending moment. After partially plastic bending, permanent deformation and residual stresses remain after unloading [3]. For the calculation of springback, springback ratio K and springback angle Δα have to be determined, the springback angle is easily determined to be: $\Delta\alpha = \emptyset_1 - \emptyset_2 = \left\{\frac{1}{K} - 1\right\}$ where s is the thickness of the bending material.

A variety of theoretical and experimental investigations of phenomenon of the Young's modulus alteration depending on plastic deformation in combination with differentkinds of elasto-plastic constitutive models have been investigated. Vin *et al.* [1]. 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 [2]. Boer and Webster [3] 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 [4] obtained the slip line field solution for the axisymmetric tube drawing process.

Young's modulus is a number that measures an object or substance's resistance to being deformed elastically. The effect of Young's modulus, material behaviour and microstructureon springback have investigated by many researchers in different manufacturing processes**.**The change of elastic modulus with increasing plastic strain was firstly investigated by Lems [5]. Sawamiphakdi et.al [6] investigated the tube drawing process using finite element method. Karnezis and Farugia [7] used workability criterion to determine failure in the cold drawing process. Rasty and Chapman [8] 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 [9]. 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* [10].

Noonai *et al.* [11] studied the influences of reduction ratio on mechanical properties and transformation temperature of Ni Ti drawn wires. Vega *et al.* [12] studied the effect of process variables such as semi die angle and reduction in area coefficient

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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 [13]. The effects of degrees of deformations, ranging from 5 to 30% reductions on the mechanicalproperties 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 theinfluence 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.

3. Experimental Work and Procedure

Cold drawing of seamless tubes on draw bench is carried out to check the minimum variation in the drawn tube. Less the variation from targeted value, less is the springback. The ultimate aimof this study is to decide best parameter setting for a particular tube and die material combination.

Materials:

The materials used for study of seamless tubes, die and plug are given below:

The material for die and plug is ST 35 which is an air hardening, high-carbon, high-chromium tool steel. It displays excellent abrasion/wear resistance and has good dimensional stability and high compressive strength. The chemical composition as shown in Table 1

Table 1. Chemical Composition of ST 35

Component	Maximum	Minimum
Manganese,	0.62	1
Mn Silicon,	0.036	1.75
Si Phosphorous,	0.62	1
P Sulphur,	0.36	1.25
S Tungsten,	0.56	
W Vanadium, V	1	
0.66	1.5	

The physical and Mechanical properties for ST 35 material are density of 6.87 g/cc, hardness of 64HRC, youngs modulus of 190GPa and Poisson's ratio of 0.39 respectively.

The material taken in this work is an uncoated cold rolled ST 35 steel .ST 35 is low carbon steel grade suitable for applications where elevated working temperatures are the norm and the material is used by fabricators throughout the oil, gas and petrochemical industry. It is normally supplied in stress relieved, annealed or normalized condition. The size taken is 32.4(OD) x16.64(ID) x 2.38(WT) (mm). The chemical composition of the tested tube sample is shown in table 2 and the mechanical properties of a hollow tube of 32.4 x 16.64 mm are listed below in table 3.

Table 2. Physical and mechanical properties of ST 35

Property	Value
Hardness, Rockwell C	16
Ultimate Tensile Strength, MPa	326.226
Yield Strength, MPa	200.774
Elongation at Break, %	21.80
Modulus of Elasticity, GPa	110
Bulk Modulus, GPa	240
Poisson's Ratio	0.35
Shear Modulus, GPa	40

Table 3.Actual chemical composition of ST35

Component	Composition
Carbon	0.21
Manganese	0.89
Silicon Phosphorous	0.402
Silicon Chromium	0.179
Ferrous	0.016

The tubes are cold drawn into different passes as shown in table 4.

Table 4. Reduction Passes during the working of ST 35 Steel sheet cold drawing.

Sr. No	Pass	Outer Dia.	Thicknes s	Inner Dia.	%Cross sect red
1	Hollow Tube	31.4	4.58	25.60	----
2	1st Pass	24	2.0	19	43.56

3	2nd Pass	19	2.2	14.6	29.38
4	3rd Pass	15	2	11.56	27.50

During the actual and traditional working on such material there are too much error at the time of applying different tensile and compressive forces that is why the material gets changes its shape and size during the removal of object from machine attachments so we can use optimization algorithm technique to reduce this adverse effects.

An optimization algorithm is a procedure which is executed iteratively by comparing various solutions to the optimum, or a satisfactory solution is found. Optimization algorithms begin with one or more design solutions supplied by the user and then iteratively check new solutions to achieve a truly optimum solution.

The objective function is formulated (equation 1) for applying different algorithms viz. Particle Swarm Optimization (PSO), Simulated Annealing (SA), Genetic Algorithm (GA).

4. Particle swarm optimization (PSO)

PSO is a multi-agent parallel search technique. Particles are conceptual entities, which flythrough the multi-dimensional search space. At any particular instant, each particle has a position and a velocity. The position vector of a particle concerning the origin of the search space represents a trial solution of the search problem.

Uniaxial tension specimens were cut from the as-received tube in the longitudinal direction. The dimensions of each specimen were in accordance with the gauge length 50 mm. In order to minimize the influence of machining forces linear cutting of the specimens was used. Uniaxial tension was carried out on UTM with a precise extensometer. Seven samples taken under study are one sample of hollow tube, one each sample before and after heat treatment of first pass, one each sample before and after heat treatment of second pass and one each sample before and after heat treatment of final pass.

Mechanical properties of these seven samples were determined using standard methods. For hardness testing, oxide layers formed during heat treatment were removed by stage-grinding and then polished. Average Brinell Hardness Number (BHN) readings were determined by taking two hardness readings at different positions on the samples, using a Brinell hardness tester. The standard grain size scale is mounted on the optical microscope was used to measure the average grains. Individual grains were measured and the results of the measurements of all the seven samples are noted as given in Table 6. The average grain size of the hollow and first pass samples were 9 and final, whereas for second and final passit was 10. The increase in the grain sizes of the formed samples compared to the parent material shows that the materialwas plastically deformed due to the drawing operation. The microhardness of samples were given in Table 7.

Table 5. Summary of microstructure of all seven samples.

Sample description	Microstructure developed
Hollow tube	Ferrite
First pass before heat treatment	Ferrite
First pass after heat treatment	Ferrite + Pearlite
Second pass before heat treatment	Ferrite + Pearlite
Second pass after heat treatment	Pearlite
Final pass before heat treatment	Pearlite + Cementite
Final pass after heat treatment	Pearlite + Cementite

Table 6. Microhardness and grain results

Sample No.	Sample condition	Hardness (HV 0.20)	Average hardness	Grain size number
1	Hollow tube	128,124,127	122.26	9 and final
2	First pass before heat treatment	269,271,172	170.00	9 and final
3	First pass after heat treatment	207,208,109	100.00	9 and final
4	Second pass before heat treatment	149,151,143	141.00	10 and final
5	Second pass after heat treatment	99,100,101	99.00	10 and final
6	Final pass before heat treatment	152,152,153	133.00	10 and final
7	Final pass after heat treatment	105,105,114	109.00	10 and final

5. ANOVA TEST TO COMPARE THE EXISTENCE OF SIGNIFICANT DIFFERENCES.

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. The aim of the test is to study if there is a significant difference in springback values of 7 combinations of reduction ratio 15-20% for level of significance $\alpha = 0.041$. The independent variables considered are die semi angle, land width, drawing speed combinations, and dependent variable is springback values of 15-20% reduction ratio measured in mm.

Table 7. ANOVA for all 3 reduction ratio

Reduction ratio		Sum of Squares	Dof	Mean Square	F	Result
10-15 %	Between Groups	1.212	11	0.110	26.774	0.039
	Within Groups	4.395	1068	0.004		
	Total	5.607	1079			
15-20 %	Between Groups	1.724	11	0.157	5.947	0.041
	Within Groups	28.145	1068	0.026		
	Total	29.869	1079			
20-25 %	Between Groups	8.662	11	0.787	13.943	0.045
	Within Groups	60.316	1068	0.056		
	Total	68.978	1079			

From the results of investigation on the effect of pass schedule on mechanical properties and microstructure of ST 35 steel, the following conclusions can be made:

Tensile strength, yield strength and hardness of ST 35 steel increased with plastic deformation. Maximum hardness is found 86-87 HRB in first pass .Maximum UTS is found in the same sample. Microstructure reveals ferrite + pearlite in all phases. Elongated grains observed with the increase in number of passes. SEM photographs also validated these observations with grain size evaluations. Microhardness value is found maximum in final pass with value 159-165 and the grains are found highly stressed.

Variation in mechanical properties (UTS, hardness) depends on % reduction in cold drawing. Also the heat treatment temperature and soaking time of stress relieving plays a vital role in determining the properties. Vickers hardness test may vary from surface to core. Increase in reduction sample will have high micro hardness on the surface as compared to the core. The micro hardness evaluation is phase specific. Ferrite will reveal lower hardness as compared to pearlite. Finally we can choose the processing path with varying % reduction and stress relieving temperature and soaking time to obtain the required mechanical properties as per specifications.

Effect of pass schedule on mechanical properties.

The effect of the pass schedule on the mechanical properties (ultimate tensile strength, hardness, toughness, percentage elongation, and percentage reduction) of the seven samples, treated and untreated is tabulated (Table 5). The ultimate tensile strength of the hollow tube specimen was 300.226 N/mm^2, yield strength198.N/mm^2, elongation 19.80%.

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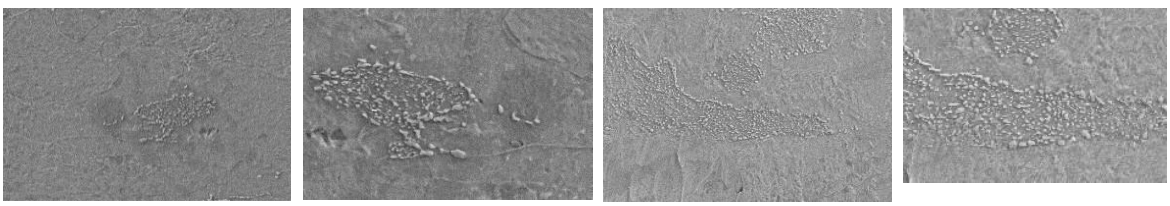
Table 8. Mechanical properties of all three samples.

***Effect of Pass Schedule with* Particle swarm optimization (PSO)**

The PSO scans a high-energy electron beam across the surface of a specimen and measures one of a number of signals resulting from the interaction between the beam and specimen. The PSO images of samples at different conditions were provided in Fig. 8 by using scan electron microscopy (SEM).

Sample condition: Hollow tube Sample condition: First pass before heat treatment



SEM at 5000 X SEM at 10000 X SEM at 5000 X SEM at 10000 X

Sample condition: First pass after heat treatment Sample condition: Second pass before heat treatment SEM at 5000 X SEM at 10000 X SEM at 5000 X SEM at 10000 X

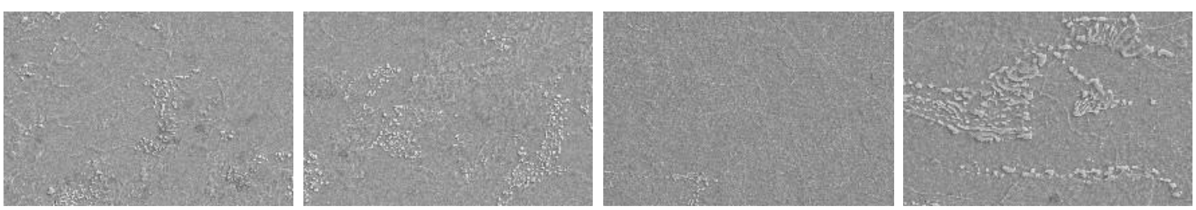


Fig.1 Scanning conditions.

6. Experimentation on stresses and strain during testing.

Cold drawing of seamless tubes on draw bench is carried out to check the minimum variation in the drawn tube. Less the variation from targeted value, less is the springback. Sets of experiments for each material are conducted for various die semi angle, land widthand drawing speed combinations. Two levels of die semi angle and land width whereas three levels of drawing speed are considered as shown in table 3.

Table 9. Levels of experiments.

Sr.no.	Process parameter	Unit	Factor level		
			Level 1	Level 2	Level 3

1	Die semi angle	Degree	10	5.5	15
2	Land width	Millimeter	5	5	10
3	Drawing speed	Meter/min	4	6	8

The drawn tube samples for tensile test are prepared as per ASTM E370 and resulting Young's modulus is measured using TUE-600 Universal Testing Machine with precise extensometer. Sample stress stain curve obtained for all three grades are as shown in figures 1, 2 and 3.

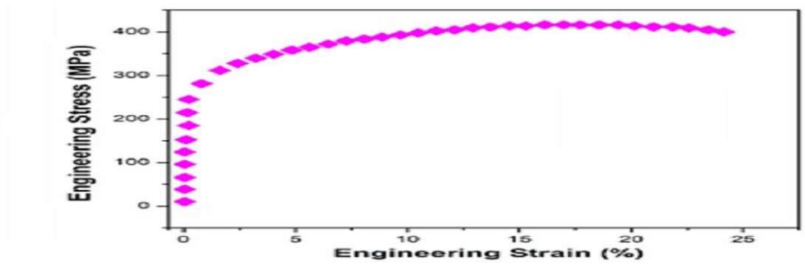


Figure 2. Stress-strain curve for low carbon steel.

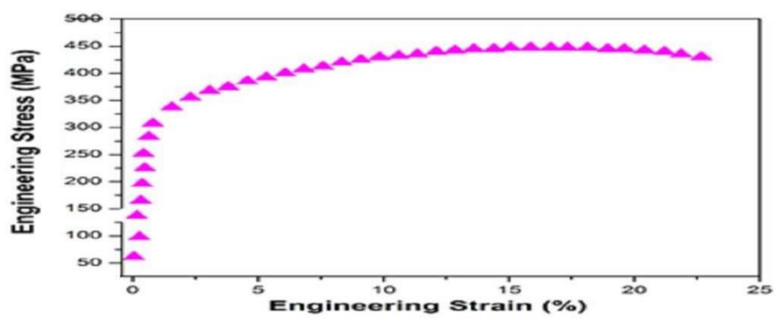


Figure 3. Stress-strain curve for medium carbon steel.

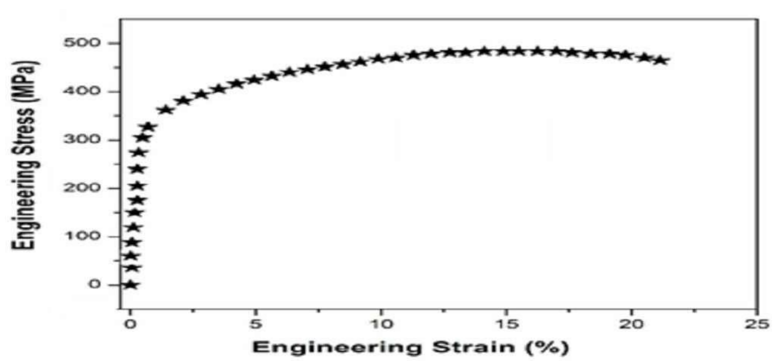


Figure 4. Stress-strain curve for ST35 material.

The experiments are conducted using Taguchi's L36 orthogonal array. The resultant springback is measured. As 30 mm is targeted value, a deviation from this value is denotedas a springback which is measured with digital micrometer of 1 micron accuracy after colddrawing process and 15 minutes time lag for dimensional settlement.

7. Data analysis:

Data analysis is done using SPSS software of statistical analysis. SPSS Statistics is a software package used for logical batched and non-batched statistical analysis. Long produced by SPSS Inc., it was acquired by IBM in 2009. The current versions (2015) are officially named IBM SPSS Statistics.

Spearman's Correlation Test

Spearman's correlation coefficient is a statistical measure of the strength of a monotonic relationship between paired data. This test is used to study whether there is any relationshipbetween Springback and Young's modulus. Let H_0: There is correlation between Springbackand Young's modulus and H_1: There is no correlation between Springback and Young's modulus. For level of significance, α : 0.05 the correlations are found where springback was
measured as a dimensional variation from targeted value in mm and Young's modulus was measured from the tensile test of the sample prepared of drawn tubes in N/mm^2.
P value observed in this test (0.024) is less than level of significance (LOS: 0.05) the null hypothesis is rejected. Hence it is concluded that there is significant relationship between Springback and Young's modulus. However ρ (rho) i.e. Spearman's coefficient of correlation = -
0.559 indicates that there is moderate relationship between Springback and Young's modulus and it is negative.

Simple Regression Test

Regression analysis is used when two or more variables are thought to be systematically connected by a linear relationship. In simple regression, we have only two variables say x and y and they are related by an expression of the form $y = \beta_0+\beta_1 x +\varepsilon$. It is used to study therelationship between springback and Young's modulus. Let H_0: Young's modulus doesn't influences springback and H_1: Young's modulus affects significantly springback. For levelof significance, $\alpha = 0.05$ the model values are found significant.
For better fitment between the experimental data and experimental model the R squared value must be close to unity. The results of study shows this value as 0.962.The fitness is also revealed by the good agreement of adjusted R squared value (0.924).
The ANOVA test is performed for checking the developed model adequacy. Table 4 indicates the significance of various factors affecting the springback. With confidence level95 %, p value must have value less than or equal to 0.05 to indicate that the factors are statistically significant.

8. 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 makewith 1micron accuracy).

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.

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.

9. 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 isrelated to springback.

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. Thegrain 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.

10. Results and Discussions

Effect of pass schedule on mechanical properties

The effect of the pass schedule on the mechanical properties (ultimate tensile strength, hardness, toughness, percentage elongation, and percentage reduction) of the seven samples, treated and untreated is tabulated (Table 5). The ultimate tensile strength of the hollow tube specimen was 415.226 N/mm^2, hardness value of 70-72HRB, yield strength 208.775 N/mm^2, elongation 22.80%.

Table 5.Mechanical properties of all seven samples

Sample no.	Sample condition	Tensile strength (N/mm^2)	Hardness (BHN)	% elongatin	% reductin	Yield strengh (N/mm^2)
1	Hollow tube	415.26	70-72	22.80	59.23	208.74
2	First pass before heat treatment	660.53	86-87	8.53	32.89	444.66
3	First pass after heat treatment	376.46	60-61	42.93	59.13	300.46
4	Second pass before heat treatment	555.66	83-84	10.94	39.78	547.20
5	Second pass after heat treatment	353	58-59	45.94	59.62	200
6	Final pass before heat treatment	378.21	84-85	37.55	59.53	203.035
7	Final pass after heat treatment	514.63	60-62	13.02	50.32	504.86

From the results of investigation on the effect of pass schedule on mechanical properties and microstructureof ST 35 steel, the following conclusions can be made:

Tensile strength, yield strength and hardness of ST 35 steel increased with plastic deformation. Maximum hardness is found 86-87 HRB in first pass .Maximum UTS is found in the same sample. Microstructure reveals ferrite + pearlite in all phases. Elongated grains observed with the increase in number of passes. SEM photographs also validated these observations with grain size evaluations. Microhardness value is found maximum in final pass with value 162-165 and the grains are found highly stressed.

Variation in mechanical properties (UTS, hardness) depends on % reduction in cold drawing. Also the heat treatment temperature and soaking time of stress relieving plays a vital role in determining the properties. Vickers hardness test may vary from surface to core. Increase in reduction sample will have high micro hardness on the surface as compared to the core. The micro hardness evaluation is phase specific. Ferrite will reveal lower hardness as compared to pearlite. Finally we can choose the processing path with varying % reduction and stress relieving temperature and soaking time to obtain the required mechanical properties as per specifications.

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.

Acknowledgment

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Nomenclature

BHN : Brinell Hardness Number

OD: Outer diameter

ID: Inner diameter

TH: PSO: SEM Wall thickness

Particle swarm optimization Scan Electron Microscopy.

References:

[1] John, V.B., 1980, Introduction to Engineering Materials, 2nd Edition. Macmillan Publishing Company Ltd., pp 321-324.

[2] Alawode, A.J., 2002, M. Eng Thesis, Mechanical Engineering Department, University of Ilorin, Nigeria.

[3] T. G. Fadara and O. Y. Akanbi D. A. Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.3, pp.299-308, 2011

[4] Dell, K.A., 1989, American Technical Society,Chicago, pp. 351-353.

[5] Ashish Bhateja, Aditya Varma, Ashish Kashyap and Bhupinder Singh, The International Journal of Engineering And Science (IJES) Volume 1, Issue 2, Pages 253-259 2012

[6] Kempester M.H.A., 1984, Materials for Engineers, 3rd Edition.

[7] Raymond A., Higgins B., 1985, Properties of Engineering Materials.

[8] Dieter Fahr, Metallurgical Transactions July 1971, Volume 2, Issue 7, pp 1883–1892.

[9] R.L. Klueh, , A.T. Nelson, Journal of Nuclear Materials , Volume 371, Issues 1–3, 15 September 2007, Pages 37–52

[10] ASTM E23. 2008, American Society of Testing and Materials.

[11] Liu,C.,Zhao, Z.,Liu, Y.,Journal of Materials Science (2001) 36: 5045.

[12] Lee, Y. B., Shin, D. H., Park, K. T., & Nam, W. J. (2004). Scripta materialia, 51(4), 355-359.