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INVESTIGATING SPRINGBACK OF SEAMLESS TUBES COLD DRAWING PROCESS USING DESIGN OF EXPERIMENTS (DOE) AND MICROSTRUCTURAL INVESTIGATIONS

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Abstract

Cold drawing is widely used manufacturing process for production of seamless tubes. Spring back is one the defect occurring in cold drawing process. A cold drawn tube will try to return to its original configuration upon removal of load. The phenomenon incurs due to an elastic recovery. This work is systematic investigations of optimized parameters to minimize springback viz., reduction ratio, die semi angle, land width and drawing speed through Design of Experiments and microstructural investigations using X-Ray Diffraction, Scan Electron Microscopy and Metallurgical Microscope. The results of this study indicates that 10-15 % reduction ratio, 15 degree die semi angle,10 mm land width and 8 m/min drawing speed gives least springback for ST 52 tube material and AISI D3 die-plug material. This study has improved springback value significantly through series of experimentation and reduced the rejection by 3 % in precision tubes saving substantial amount of the cold drawing manufacturing industry.

Keywords: Cold Drawing, Springback, Reduction Ratio, Design of Experiments, ANOVA

1. Introduction

Cold drawing operation consist of pulling a tube through a tapered or curved converging die with various types of plugs. The various types of plugs include fixed, floating and movable. This process is one of the widely used metal forming process having inherent advantages like better surface finish, closer dimensional tolerances, adaptability to economical mass production and improved mechanical properties as compared to hot forming processes (Ahmed, 2011).Cold drawing process using draw bench device is also used to produce tubes of various shapes such as round, rectangular, square, hexagonal and other shapes.

Seamless tubes are manufactured with piercing and hot rolling processes, often are cold finished by drawing process. The raw material used for manufacturing seamless tubes are different types of steels i.e. carbon steels and alloy steels. Seamless tubes are used in both low and high temperature applications such as refrigeration, boilers, transporting liquids and gas automobiles and commercial vehicles, oil and petrochemical industries, refineries and fertilizer plants, heat exchangers, pressure vessels, etc. However, high pressure hydraulic and pneumatic cylinders, drilling deep bores, truck axels, bearings, steering columns, structural tubes, banjo spanner tubes, etc. are also made out of seamless tubes.

As the requirements of tubular products increased, an associated manufacturing processes also constantly improved. Apart from this, an appropriate systems for effective production control as well as quality assurance were also introduced. Though cold drawing process provides ease of manufacturing seamless tubes, but it is subjected to various defects like eccentricity, internal cracks, external cracks, ovality, scores on the tube, chattering, bending of tubes, wavy surface, tube thickness oversize, inner and outer diameter scores and the most severe defect is springback (Neves, 2005). Springback varies with many parameters, hence it becomes critical to overcome this phenomenon for seamless tubes to achieve tighter tolerances and avoid rejections.

1.1 Springback in Cold Drawing

Springback phenomenon has found during many cold working manufacturing processes including cold drawing process of the seamless tubes. While deforming a metal into the plastic region, it's total strain is composed of elastic and plastic part. After removal of deforming load, stresses will be reduced and accordingly the total strain will decreased by the elastic part which results in springback. Due to limited modulus of elasticity, as soon as the load is relieved from the material, elastic improving is followed. Due to flexibility characteristics of the material, the material on compression side tries to enlarge and the material on tensile side tries to shrink. This results in springback (Tekaslan, Seker & Ozdemir, 2006). When a load is applied, beyond the yield strength the material is over-stressed to induce a permanent deformation. When the load is removed, the stress returns to zero value along a path parallel to elastic modulus. Hence the permanent deformation value becomes lesser than the designer intended deformation. The material will not return to a zero stress state as the stresses are highest at top and bottom surfaces. This causes springback at an equilibrium point where all the internal stresses get balanced. Springback varies with composition, material properties and dimensional range of outer diameter and thickness. Springback causes deviation from designed target shape, downstream quality problems and assembly difficulties. Determination of springback by trial and error technique not only increases the cost of manufacture and repair of tool but also waste of time causing delay in the development of the product. This indicates that springback has an important role in industry and required to study how this permanent variation can be avoided.

2. Literature Review

The quality of manufactured seamless tubes depends upon many factors. A compromise solution to the problems of meeting these requirements is achieved economically by the selection of appropriate tool material, die angle, lubricants, surface treatments of undrawn tubes, heat treatment and drawing conditions such as draw speed and reduction of area. However, as there is a continuing and an increasing need to reduce cost i.e. to draw at higher speeds and at higher reductions and to eliminate or minimize cold drawing defects, different researchers have proposed different techniques in the literature. Number of studies on the analysis of cold drawing process carried out by researchers are discussed below under different criteria. This section indicates the various groups under which research studies has been categorized. Different parameters like process, metallurgical and geometric parameters along with various tools related to cold drawing process are shown in figure 1.

2.1 Process Parameters

Process parameters are the key variables influencing the production process. These attributes monitors the deviations in the standardized production procedures and quality of the formed product.

2.1.1 Defects in Cold Drawing

Appropriate standard operating procedure is much needed for any manufacturing process in order to be free from defects. Different defects incurred in the process causes deviations from targeted shape in the final product. These defects affects the performance and leads to early failure of the system.

The surface flaw defect (Yoshida, Uemori & Fujiwara, 2002) of a drawn product has a considerable impact on its quality which are similar in drawn tubes also. Mamalis and Johnson (1987) studied different defects while processing both metals and composites. The authors reported segregation and seams as a metallurgical metal working defects. Similarly defects like central bursts or chevron cracks are also occasionally en- countered in cold drawing process.

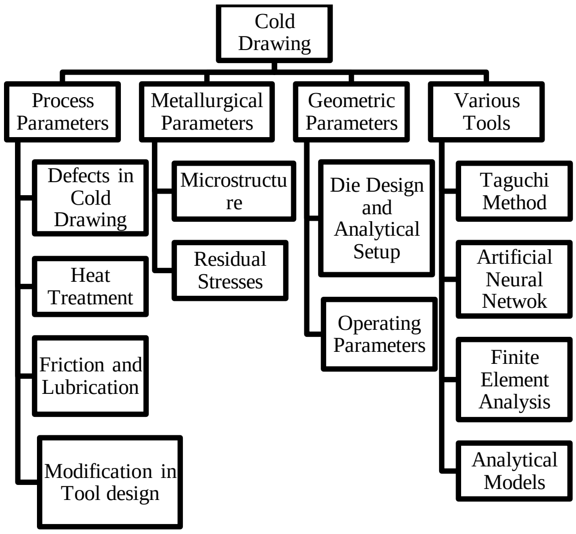

Fig.1. Approach adopted for research in cold drawing

Many researchers including Moritoki (1991), Mcallen and Phelan (2005), Ko and Kim (2000), Alberti, Barcellona, Masnata and Micari (1993), Zimerman, Darlington and Kottcamp (1971) reported qualitative methods to eliminate central bursts, prevention of this defect and supported an analytical investigation of the mechanics of central burst formation along with mathematical studies. Rajan and Narasimhan (2001) observed defects like micro cracks, fish scaling, diametral growth, premature burst, macro cracks and springback in case of high strength SAE 4130 steel tubes. Other defects like stress corrosion cracking (Toribio & Ovejero, 1997), fatigue crack propagation (Carpinteri, 2010), damage evolution (Tang, Li & Wang 2011), breakage (Li, Li , Wang & Ma, 2010) were also found in the literature. Similarly wrinkling and fracture defects are studied by Atrian and Saniee (2013). Among all these defects springback is more severe as it varies with material combinations, mechanical properties and composition of the materials, tool wear, aging process of the material, deformation rate etc. Hence it is cardinal important to reduce this severe phenomena without cracking and damaging the final product.

Similar literature review by different researchers is with the authors. Going through ample literature, it is found that most of the work is done on springback in sheet metal. Empirical research has done only in developed countries like USA, China, Germany,UK etc. Limited research has done on springback during cold drawing of seamless tubes. All the selected parameters by authors in their research articles does not mentioned interrelationship of parameters with each other. The literature review can be extended to classify as shown in figure 2 in terms of cause and effect diagram. Several techniques have been used by different researchers in their research. For experimental design of many manufacturing processes, Taguchi method and design of experiments (DOE) are found most usage. The finite element analysis (FEA) and analytical models were also applied by many researchers for the development of seamless tube drawing technology.

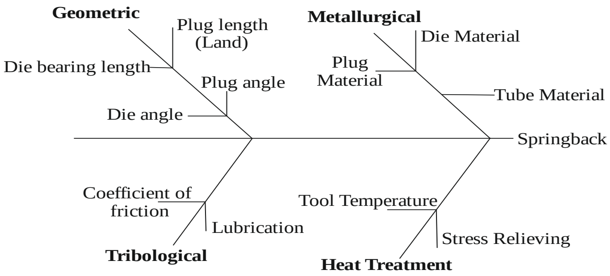

Fig.2. Fishbone diagram of cold drawing process parameters influencing springback

Process parameters like friction and lubrication, type of heat treatment, tooling are very important for the success of cold drawing process. The artificial neural network (ANN) and fuzzy logic techniques are also observed profound tools in the research. Metallurgical study including microstructure and residual stresses have high impact on the properties of formed material. Hence accuracy in this domain can affect the drawn seamless tube after cold drawing. Different manufacturing defects are altered by many researchers, but springback during seamless tube cold drawing process have not been investigated in detail so far. Hence there is a need of predictive models to be developed in order to get better understanding and relationship of the process, its parameters and its influence on springback.The utilization of DOE as a tool to predict the springback in cold drawing of seamless tubes was rare in the literature.

A research gap is identified in the areas of cold drawing of seamless tubes in investigating springback phenomenon. Under optimized process conditions, minimization of springback is the focus of this research. This research will provide a foundation for the cold drawing manufacturing industry, an optimized reduction ratio and process parameter viz. die semi angle, land width, drawing speed to minimize springback.The study will further investigate the microstructural behaviour of seamless tubes during cold drawing process affecting springback.

3. Methodology

The present study pertains to various issues related to springback and the means to control it with appropriate strategies. The approach adopted for this study is as follows:

1. Study the various process parameters affecting springback in cold drawing process of seamless tubes.

2. Classify them into different groups like process parameters, metallurgical parameters, geometric parameters etc.

3. Optimize die semi angle by different multi attribute decision making (MADM) methods.

4. Optimize reduction ratio by Taguchi's L12 Design of Experiments (DoE) technique.

5. Optimization of process parameters like die semi angle, land width and drawing speed by Full Factorial technique and Response Surface Methodology.

6. Optimization of process parameters by advanced optimization algorithms.

7. Validation by Finite element analysis.

8. Microstructural investigations to study effect of pass schedule, Young's modulus, heat treatment, microstructure on springback.

9. Numerical simulation of cold drawing process using Ls-Dyna to validate the results.

Major highlights of the above mentioned steps are given in flow chart in figure 3.

In this study die semi angle, reduction ratio and process parameters viz. land width and drawing speed are needed to optimize as they influence springback phenomenon. Prior to the design of experiments, different process parameters along with their ranges in cold drawing process should be determined depending upon the equipment conditions, expert opinion from industry personnel and literature base. Die semi angle selection is done based on multi attribute decision making (MADM) methods. Taguchi methods and full factorial experiments are conducted for optimization of reduction ratio and process parameters like die semi angle, land width and drawing speed respectively. Further advanced optimization algorithms viz. Particle swarm optimization (PSO), Simulated annealing (SA) and Genetic algorithms (GA) are used. Land widths are optimized for optimized parameters and settings for shaped seamless tubes viz. square and rectangular cross sections. Microstructural investigations carried out on universal testing machine (UTM), X-ray Diffractometer (XRD), scanning electron microscope (SEM), metallurgical microscope to find influence on springback.

3.1 Experimental Procedure

Seamless tubes are cold drawn through a die of 30.0 mm. The drawn tube outer diameter is measured using digital micrometer of 1 micron accuracy. The variation from 30.0 mm is referred to be springback. From the literature review and discussions with industry persons, process parameters and their levels considered are viz. two levels for die semi angle (10 and 15 degrees),two levels for land width (5 and 10 mm) and three levels for drawing speed (4,6 and 8 m/min).

3.2 Work Material

AISI D3 die steel is selected for die and plug materials having high wear, abrasion resistance and resistance to heavy pressure. D3 material is high carbon, high chromium cold-work tool steel. The specifications of this tool steel are according to ASTM A681 (D-3), DIN 1.2080, SAE J437, SAE J438 and UNS T30403.A typical D3 material consists of chemical composition tabulated in Table 1.

Table 1. Typical D3 Material Chemical Composition

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

Seamless tubes of ST 52 material are considered for experimentation which are cold drawn from a hollow size of 33.40 mm outer diameter and 4.00 mm wall thickness.

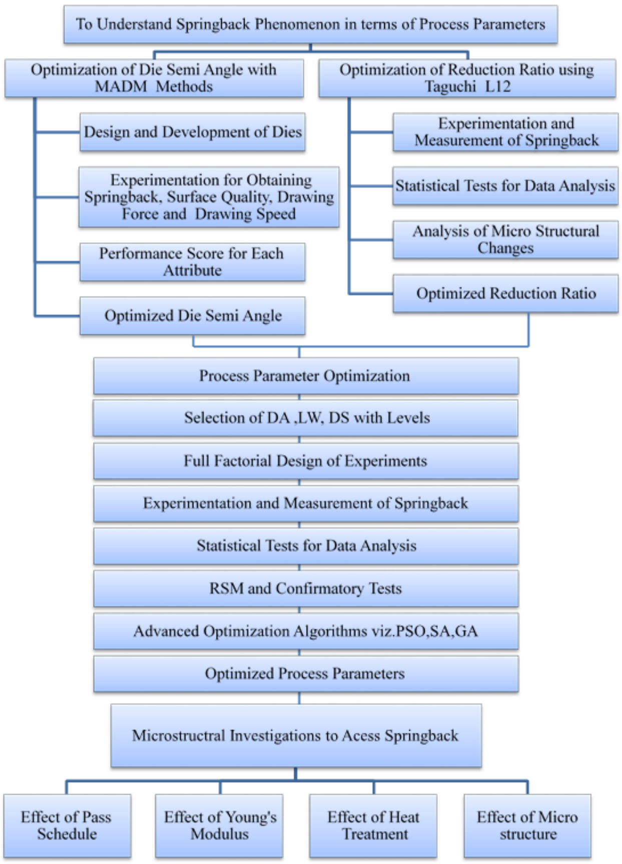

Fig.3. Experimental Design Framework

3.3 Machine Tool

The experimentation is carried out on draw bench having maximum drawing speed of 10 m/min and maximum width of drawn tube obtained is 30 mm. A draw bench for cold drawing seamless tubes consist of die and plug control devices and a draw unit. The die is held firmly in die holder and gripper provided pulls the tube through die plug assembly. Drawn tube deforms plastically in the draw bench changing its cross-sectional area, reducing its diameter and increasing its length.

4. Results and Discussions

The summary of the work done on each of the research objectives is elaborated as follows:

4.1 Screening Test

Die semi angle selection is one of the critical activities during cold drawing of seamless tube for optimized performance. The purpose of this step is to adopt structured approach to select optimized die semi angle for cold drawing of seamless tubes. The study uses Analytic Hierarchy Process (AHP) based structured approach to select optimum die semi angle by estimating the overall performance score for different values of die semi angles. Springback, Surface Quality, Drawing Force and Drawing Speed are considered for optimization of die semi angle as shown in Table 2.

Table 2. Attribute Data for Different Alternatives

Die Semi Angle (Degree)	Springback (mm)	Surface Quality	Drawing Force (KN)	Drawing Speed (m/min)
8	0.085	above average	95.5	12
10	0.065	High	91	11
12	0.072	Average	87.5	10
14	0.080	below average	85	9

Overall performance score is obtained by different multi attribute decision making methods using standard procedure and ranked as shown in Table 3.

Table 3. Ranking by Different Methods

Die Semi Angle	SAW	WPM	AHP	Revised AHP	TOPSIS	VIKOR
8^0	3	3	3	3	3	3
10^0	1	1	1	1	1	1
12^0	2	2	2	2	2	2
14^0	4	4	4	4	4	4

The same findings are reported by Sawamiphakdi (1991)in which the authors found that for 10^0 die semi angle and 0.05 coefficient of friction value, minimum drawing force is required. The outcome of this study suggests that 10^0 is better die semi angle for both ST 52 tube materiel and AISI D3 die and plug material.

4.2 Optimization of Reduction Ratio

The important parameters affecting drawing load are mechanical properties like yield stress, ultimate strength, also percentage of reduction, die semi angle, friction coefficient and peak load during start up. The springback phenomenon is also influenced by reduction ratio. The springback effect of seamless tube that has undergone cold drawing has been handled in this step for three different reduction ratios viz.10-15 %, 15-20 % and 20-25 % as shown in Table 4 with the aim of reducing it. Experiments are conducted under different reduction ratios with working conditions of Die Semi Angles of 10 and 15 degree, Land Width of 5 mm and 10 mm as well as Drawing Speed of 4, 6 and 8 m/min for ST52 tube material.

Table 4. 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

Optimum reduction ratio is finalized using Statistical Package for Social Science (SPSS) software of data analysis using statistical tests viz. Kruskal-Wallis, ANOVA, Post-hoc etc. Metallurgical and mechanical properties for different reduction ratios are also studied for validation purpose.

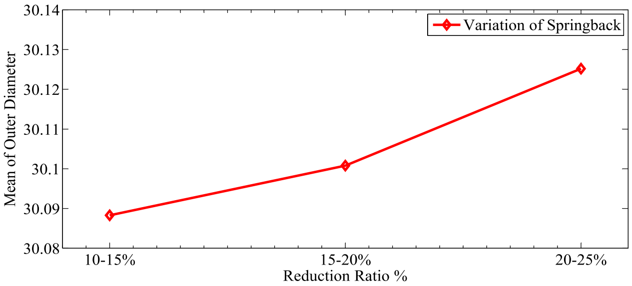

Fig.4. Optimized reduction ratio

The result of this research objective is that 10-15 % reduction ratio yields minimum springback as shown in figure 4.This can be used to help design of tools in the metal forming industry to minimize springback and improve the quality of the product.

4.3 Optimization of Process Parameters

Once the reduction ratio is finalised i.e. 10-15 % which gives least springback. Next step is to optimize process parameters. Taguchi's L36 orthogonal array is used to conduct the experiments and then optimization is done in data analysis software Minitab 17.The main effect of the factors on springback for each level is calculated and the optimum level of each parameter is identified. From the results obtained, it shows that die semi angle of 15 degree, land width of 5 mm and drawing speed of 6 m/min gives the least springback.

After identifying the optimum levels using statistical technique, the confirmation experiments was conducted and the springback obtained was compared with that one obtained from initial parameter setting as shown in Table 5.

Table 5. Confirmatory Test Results

Optimum Factors	Regression Model Springback	Experimental Value Springback	% Variation
15 degree die semi angle 5 mm land width 6 m/min drawing speed	0.021	0.0251	16.99

The results of ANOVA shows that 15 degree die semi angle,5 mm land width and 6 m/min drawing speed yields least springback. Further optimization algorithms viz. Particle Swarm Optimization (PSO), Simulated Annealing (SA) and Genetic Algorithm (GA) are applied and the results are tabulated as shown in Table 6.This table shows that die semi angle of 15 degree, land width of 10 mm and drawing speed of 8 m/min is the best parameter set in cold drawing process to minimize the springback. This set has successfully proven almost 10.5 % improvement in the springback values.

4.4 Effect of Pass Schedule, Microstructure, Property Changes and Characterization on Mechanical Properties and Springback during Cold Drawing of Seamless Tubes

An experimental study in this domain shows Young's Modulus decreases with plastic strain for ST 52 material. It is found that with increase in plastic strain, Young's Modulus reduces rapidly initially then reduces more slowly and finally settles to stable value due to increase in plastic deformation and ultimately increased residual stresses. This variation of Young's' Modulus is related to internal stresses, residual stresses, micro cracks, dislocations during plastic deformation.

Table 6. Comparison of Springback for Initial and Optimal Parameter Setting

Response Parameter	Initial Parameter Setting	Optimal Parameter Setting using PSO	Optimal Parameter Setting using SA	Optimal Parameter Setting using GA
Die Semi Angle	15 degree	15 degree	15 degree	15 degree
Land Width	5 mm	10 mm	10 mm	10 mm
Drawing Speed	6 m/min	8 m/min	8 m/min	8 m/min
Springback	0.055	0.0492	0.0491868	0.049182
Improvement		5.8E-3	5.8132E-3	5.818E-3
% improvement		10.54 %	10.57 %	10.58 %

Similarly, Scanning Electron Microscopy (SEM), Micro-hardness testing and mechanical testing using UTM reveals that 10-20% degradation occurs in Young's Modulus for 5-7% plastic strain. It is found that this springback depends upon Young's modulus of the material. It is also found that the springback and Young's modulus are inversely proportional. More the percentage of carbon, more the strength, less the value of Young's modulus and more will springback. The microstructural evaluations showed that there is grain elongations.

4.5 Numerical Simulation using Ls-Dyna

In this work, the cold drawing of tubes with fixed plug was simulated by Explicit Finite Element Analysis for validation purpose. The numerical analysis supplied results for the reactions of the die and plug and the stresses in the tube, the drawing force and the final dimensions of the product. Tube drawing process was simulated using LS-dyna Explicit Dynamic code using a 3D finite element model. This length was tested in order to obtain the steady-state condition. The geometry was analyzed for 10° and 15° die semi angle with a land width of 5 mm and 10 mm. The drawing speed considered was 4, 6, 8 m/min. Friction between die and tube and between tube and plug was estimated at and static friction 0.1 and dynamic friction 0.01. Die and plug were modeled with a rigid material (with assumed no deformation). Tube was modeled with MAT24 material card (MAT_PIECEWISE_LINEAR PLASTICITY).The results of LS dyna shows better agreement with those obtained experimentally.

5. Conclusions

In this research the spring back effect of seamless tube that has undergone cold drawing has been handled with the aim of reducing it. This study has identified optimum parameter setting which reduced 3 % rejections due to springback in case of high precision tubes. For a single tube manufacturing industry of 1000 tonnes of production per month, this optimization resulted around 2 lakh savings per month without incurring extra efforts like rework. This setting applied to other industries may save substantial amount monetary value of the industries and nation. The major findings of this research study can be summarized as follows:

i. The study carried out systematic investigations to understand the effect of optimum parameters which leads to minimization of springback by 15 % and increased dimensional accuracy, significant profit in the business and the reputation of the industries.
ii. The study optimized the Reduction Ratio from random Reduction Ratio to 10-15 % Reduction Ratio in order to minimize springback during cold drawing of seamless tubes.
iii. Among process parameters this study identified die semi angle as a major contributing factor to the springback and the study further concluded optimum die semi angle which was found to be 15º. However, 10 mm is an optimized land width of die for the least springback of seamless tubes during their cold drawing process.
iv. Springback value for optimized die semi angle was 0.065,for optimized reduction ratio it was 0.055, for optimized process parameter the obtained value was 0.042 whereas for microstructural investigations the value for springback attained was 0.0251,thus systematically improvement in the springback values as per every objective was achieved through this research.
v. This study identified that for high carbon steel tube material 4 m/min and for low carbon steel 8 m/min is the optimized Drawing Speed on draw bench in order to minimize the springback. It was also found that springback phenomenon is more severe in advanced high strength steels than plain carbon steels.
vi. Numerical simulation of cold drawing process carried validates with experimental results.

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