

## Effect of young's modulus on springback for low, medium and high carbon steels during cold drawing of seamless tubes

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**Abstract:** Cold drawing is widely used deformation process for seamless tube manufacturing. Springback is one of the major problem faced in tube drawing. Springback is due to the elastic energy stored in the tubes during forming process. It is found that this springback depends upon Young's modulus of the material. This paper reports mechanical testing of three grades of steels viz. low carbon steel, medium carbon steel and high carbon steel to measure their Young's modulus and corresponding springback. The results shows that there is 10-20 % variation in the Young's modulus and inverse proportion between the springback and Young's modulus. More the percentage of carbon, more the strength, less the value of Young's modulus and more will springback. The study further leads to identify optimum die semi angle of 15 degree, land width of 10 mm and drawing speed of 8, 6 and 4 m/min for least springback in all the three grades respectively and die semi angle as a most dominant factor causing springback.

**Keywords:** Cold drawing; Springback; Young's modulus; Low carbon steel; Medium carbon steel; High carbon steel.

### 1. Introduction

There are several ways to achieve desired geometrical and physical attributes in a product through various material processing methods. There are many conventional manufacturing processes such as casting, forming, machining, joining etc. along with non-traditional ones viz. coating, additive manufacturing and non-conventional machining processes that are used either in combination or individually to add value in a raw material. Cold drawing is one of the most widely used manufacturing processes which comes under forming processes. It is a quite popular deformation process and a cold drawn product demonstrates several advantages like very good surface finish, superior mechanical properties and greater dimensional accuracies over hot forming processes. Owing to their characteristics, cold drawn tubes are used in various engineering applications. In fact, these tubes are inseparable part of automobile manufacturing, mining industry, boiler construction, bearing manufacturing industries and others. Therefore, this process has drawn attention of several



researchers over the years [1]. Hence analysis of cold drawing process has been a topic of extensive research.

One of the most troublesome problems in cold drawing production industry is the springback in the tube making process. With the ongoing miniaturization of products, springback is a dominant effect because material behaviour greatly varies in this process. The springback is caused by the release of residual stresses in a work piece after forming process. Young's modulus is one of the most important material parameters that influence the plastic-forming quality of the components, especially springback. Young's modulus actually changes with plastic strain, and its accurate characterization is necessary to improve simulation accuracy for the cold drawing process [2].

## 2. Literature review

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 microstructure on springback have been investigated by many researchers in different manufacturing processes. The change of elastic modulus with increasing plastic strain was firstly investigated by Lems [3]. It was found that the actual springback was larger than that calculated with a constant Young's modulus value and independent of plastic deformation. However, a constant Young's modulus was often used in many commercial FEM codes because of its simplicity. A variety of theoretical and experimental investigations of phenomenon of the Young's modulus alteration depending on plastic deformation in combination with different kinds of elasto-plastic constitutive models have been investigated. Vin *et al.* [4] used a simple analytical model to describe the relationship between Young's modulus and plastic deformation based on experimental results. Great efforts have been made to study Young's modulus and its effect on spring-back in recent years. Eggertsen and Mathieson [5] concluded that the correct choice of the yield criterion and consideration of the change in Young's modulus are essential for improving the prediction accuracy of spring-back in the numerical simulation. Yoshida *et al.* [6] reported that Young's modulus decreased with the increase of plastic strain during cyclic tension–compression deformation and proposed an empirical expression to describe the variation of Young's modulus with respect to plastic strain.

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  $\Delta\alpha$  have to be determined, the springback angle is easily determined to be:  $\Delta\alpha = \phi_1 - \phi_2 = \left\{ \frac{1}{K} - 1 \right\}$  where  $s$  is the thickness of the bending material. Gusel [7] carried out the experimentation for validation of springback predictability with experimental measurements and die compensation for automotive panels. Authors confirmed the influence of the effective strain to springback ratio and springback angle. However using regression analysis, the influence of parameters on springback ratio and springback angle represented in the form of equations. With higher effective strain springback angle also increases while springback ratio decreases. Springback ratio depends also on thickness of the sheet to be bent and on proportion  $r/s$ . The results indicated higher springback ratio and lower springback angle for thicker material. Z. Noriega *et al.* [8] developed new equation to predict the springback in the bending and rolling processes of metallic sheet. The Kalpakjian equation [9] was deduced by analyzing the bending process as a pure flexion problem, assuming that for  $Ri > 2T$  the neutral axis is located at the center of the sheet thickness and that the applied bending moments generate a plane deformation [6]. In literature springback prediction approach using the modified Ludwik stress-strain relation was studied. The

assumption of narrow beam of a wide sheet can significantly alter the magnitude of the predicted results in sheet metal bending because this ignorance of the transverse stresses are present during forming.

In spite of ample of research on springback dependence on Young's modulus in different manufacturing processes like sheet metal bending, rolling, forming, drawing etc., still there is scope for the mathematical modelling of springback in cold drawing and its dependence on Young's modulus.

In this research firstly low carbon, medium carbon and high carbon steel grades are cold drawn with draw bench machine and the drawn tube samples are tested using standard tensile test on Universal testing machine (UTM) to measure Young's modulus as well as corresponding dimensional variation from targeted size i.e. springback is measured to model the relationship between springback and Young's modulus. Secondly the springback in drawn tubes of all three grades is considered to identify optimum level of the process parameters using MINITAB 18 statistical software. The results are validated by confirmatory tests.

### 3. Materials and methods

Draw bench is a device with die and plug in which the pulling force is supplied by chain drive. The machine draws tubes and reduces the cross section of the tubes as per pass schedule. The machine considered here for experimentation has strength of 50 tonnes and drawn tubes can have a size of 3-30 mm thick. The machine has drawing speed of 1-10 m/min and return speed of 10-48 m/min.

#### 3.1 Seamless tube materials

Seamless tubes of three different grades viz. low carbon steel (IS 2062 E250 Gr A), medium carbon steel (IS 2078:1998 Gr C45) and high carbon steels (DIN 17350 Gr C85W) are cold drawn from size of 33.40 mm outer diameter and 4.00 mm wall thickness to one and the same reduction ratio of 14.39% with die 30 mm and plug 22.30 mm to achieve thickness of 3.85 mm.

The chemical composition for each tube materials under study are measured using optical emission spectrometer (Spectromaxx make) as given in table 1.

Table 1. Chemical composition of tube material.

Low Carbon Steel IS 2062 E250 Gr A					
Element	C	Mn	Si	S	P
Weight %	0.198	0.876	0.145	0.023	0.021
Medium Carbon Steel IS 2078: 1998 Gr C45					
Element	C	Mn	Si	S	P
Weight %	0.465	0.745	0.216	0.022	0.014
High Carbon Steel DIN 17350 Gr C85W					
Element	C	Mn	Si	S	P
Weight %	0.856	0.621	0.278	0.014	0.016

The mechanical properties for tube materials under consideration are as tabulated in table 2.

Table 2. Mechanical properties.

	Low carbon steel IS 2062 E250 Gr A	Medium carbon steel IS 2078:1998 Gr C45	High carbon steel DIN 17350 Gr C85W
Yield stress	377.22 N/mm <sup>2</sup>	391.08 N/mm <sup>2</sup>	416.67 N/mm <sup>2</sup>
Ultimate strength	508.81 N/mm <sup>2</sup>	725.23 N/mm <sup>2</sup>	661.69 N/mm <sup>2</sup>
Hardness	197 HBW	223 HBW	222 HBW
% Elongation	23.60 %	24.10 %	27.10 %

### 3.2 Tooling materials

The die and plug are made up of AISI D3 air hardened, high-carbon, high-chromium tool steel. It displays excellent abrasion/wear resistance and has good dimensional stability and high compressive strength. The chemical composition of AISI D3 steel measured on spectrometer shows 2.10 % Carbon, 0.30 % Silicon, 11.50 % Chromium, 0.40 % Manganese, 0.31 % Nickel.

## 4. Experimentation

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 width and 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 3. Levels of experiments.

Sr.no.	Process parameter	Unit	Factor level		
			Level 1	Level 2	Level 3
1	Die semi angle	Degree	10		15
2	Land width	Millimeter	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 strain curve obtained for all three grades are as shown in figures 1, 2 and 3.

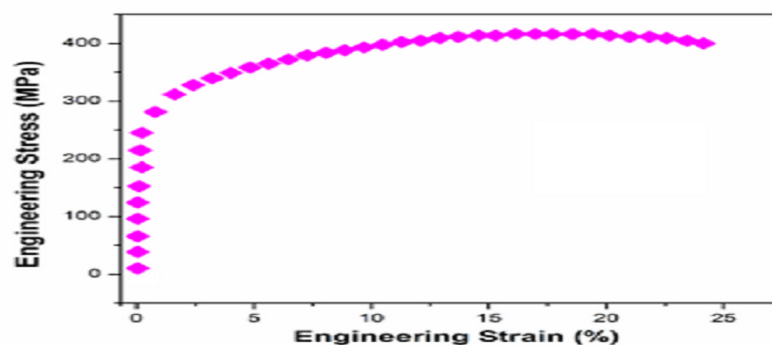


Figure 1. Stress-strain curve for low carbon steel.

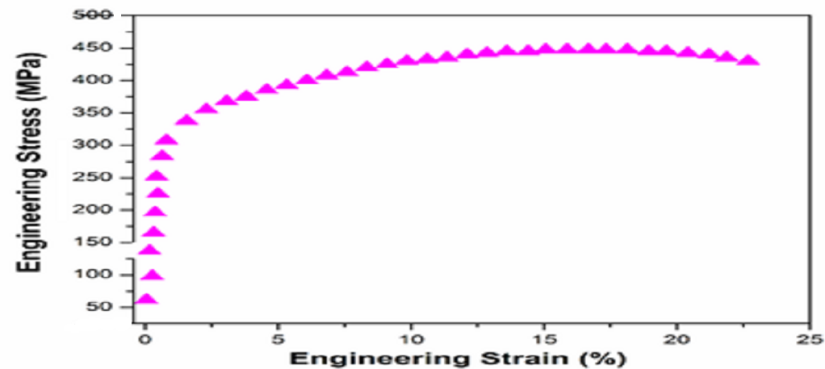


Figure 2. Stress-strain curve for medium carbon steel.

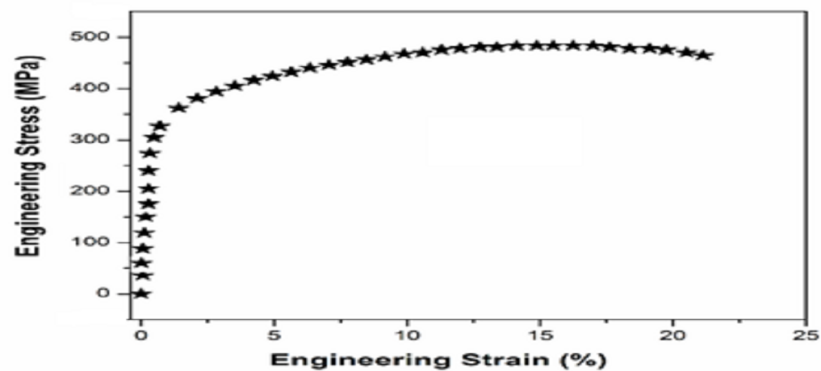


Figure 3. Stress-strain curve for high carbon steel.

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 denoted as a springback which is measured with digital micrometer of 1 micron accuracy after cold drawing process and 15 minutes time lag for dimensional settlement.

## 5. 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.

### 5.1 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 relationship between Springback and Young's modulus. Let  $H_0$ : There is correlation between Springback and Young's modulus and  $H_1$ : There is no correlation between Springback and Young's modulus. For level of significance,  $\alpha : 0.05$  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  $\text{N/mm}^2$ .

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  $\rho$  (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.

### 5.2 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 the relationship 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 level of 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 level 95 %, p value must have value less than or equal to 0.05 to indicate that the factors are statistically significant.

Table 4. Analysis of Variance (ANOVA).

	Sum of squares	Degree of freedom	Mean Square	F	Sig.
Regression	431387998.948	1	431387998.948	12.043	0.004
Residual	501492824.490	14	35820916.035		
Total	932880823.438	15			

	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	beta		
(Constant)	212941.131	3474.306		61.290	0.000
Springback	-58522.051	16863.738	-0.680	-3.470	0.004

Table 4 shows that ANOVA test is significant where  $f(1, 14) = 12.043$  and  $p = 0.004$ . This indicates that the model is significant. From the coefficients  $a = 212941.131$  and  $b = -58522.051$  it is clear that Young's modulus has negative impact on springback. The regression model can be presented by equation (1).

$$\text{Springback} = 212941.131 - 58522.051 \times \text{Young's modulus} \quad (1)$$

## 6. Results and discussions

Springback, a phenomenon that is related to the elastic strain recovery after removal of forming loads, is physically governed by the stress state achieved at the end of forming

process. Young's modulus influences the amount of springback is seen in this work. A material with a higher yield strength will have a greater ratio of elastic to plastic strain, and will exhibit more springback than a material with a lower yield strength. On the other hand, a material with a higher elastic modulus will show less springback than a material with a lower elastic modulus. The scatter plots as shown in figures 4 ,5 and 6 for low carbon steel, medium carbon steel and high carbon steel indicates negative correlation between springback and Young's modulus. Further the regression model is developed for all the three grade steels as given by equations (2), (3) and (4).

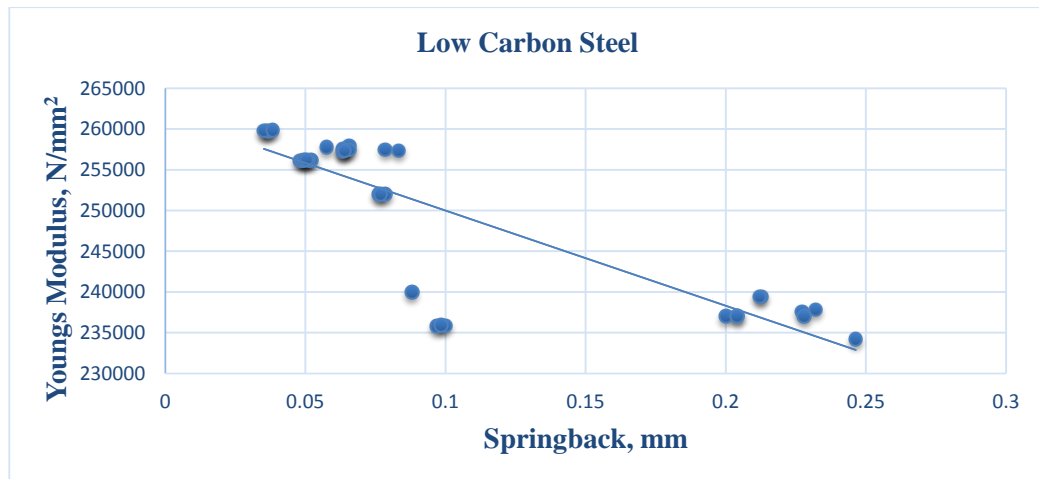


Figure 4. Scatter plot for low carbon steels.

For low carbon steels the regression model is given by

$$\text{Young's modulus} = -116845 \times \text{springback} + 261696 \quad (2)$$

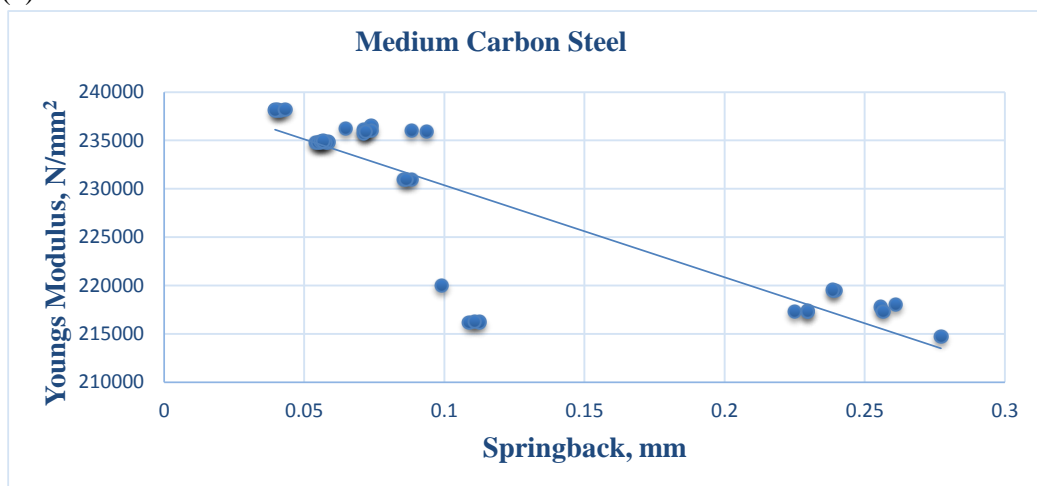


Figure 5. Scatter plot for medium carbon steels.

For medium carbon steels the regression model is given by

$$\text{Young's modulus} = -95205 \times \text{springback} + 239888 \quad (3)$$

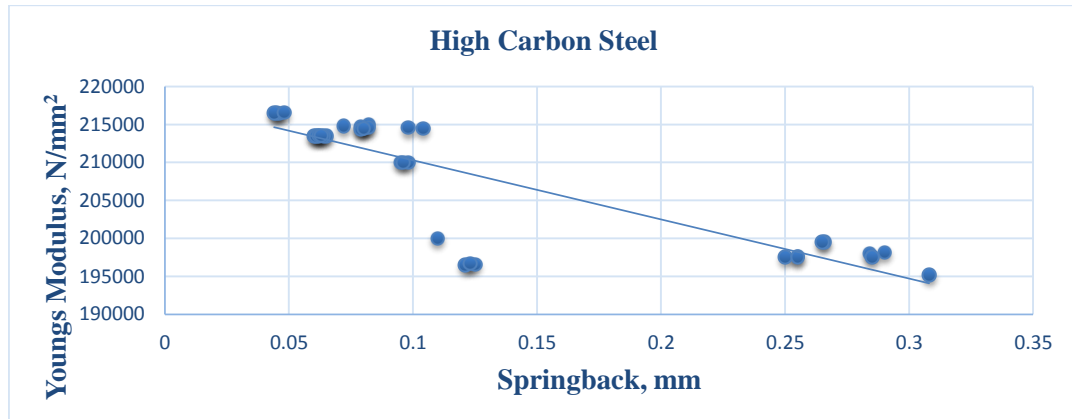


Figure 6. Scatter plot for high carbon steels.

For high carbon steels the regression model is given by

$$\text{Young's modulus} = -77895 \times \text{springback} + 218080 \quad (4)$$

Young's modulus is the second derivative of the interatomic potential, hence, any alloy change would also alter the modulus. Hence higher carbon content leads to slightly higher stiffness. This change in Young's modulus is due to micro-plastic strain, which did not overcome the barriers set up during forward flow nor created storage of a new dislocation network.

Keeping minimization of springback as an objective, smaller is better option, the main effective plots for S/N ratios are obtained using MINITAB 18 as shown in figures 7, 8 and 9. For low carbon steels, it is found that 15 degree die semi angle gives less springback as compared to 10 degree die semi angle. The reason is diametrical force is more in 15 degree die which causes less springback as compared to 10 degree die.

For the same grade steel it is found that 10 mm land width is better than 5 mm land width to minimize springback. This is because more contact length settles the residual stresses set up during cold drawing which causes springback. However drawing speed of 8 m/min is better as for low carbon steels the alloying elements are lesser requires lesser load and hence can be drawn with greater speed.

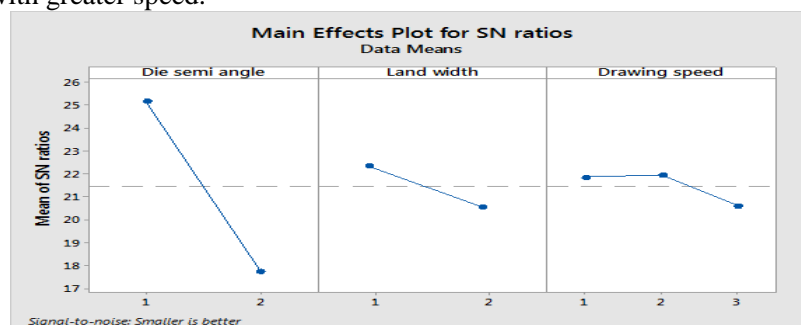


Figure 7. Main effect plot for SN ratios for low carbon steel



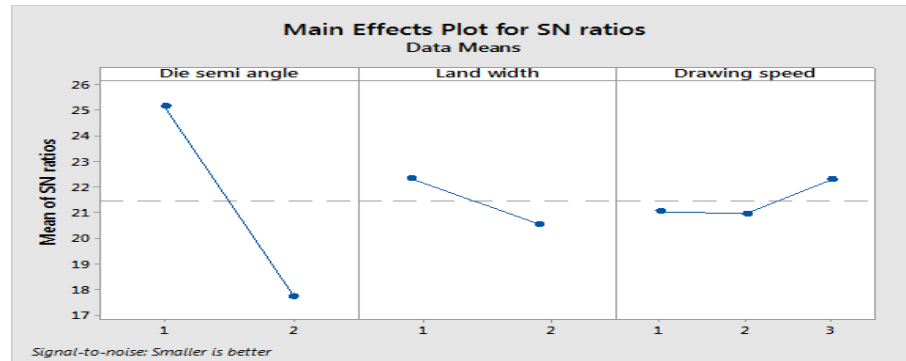


Figure 8. Main effect plot for SN ratios for medium carbon steel

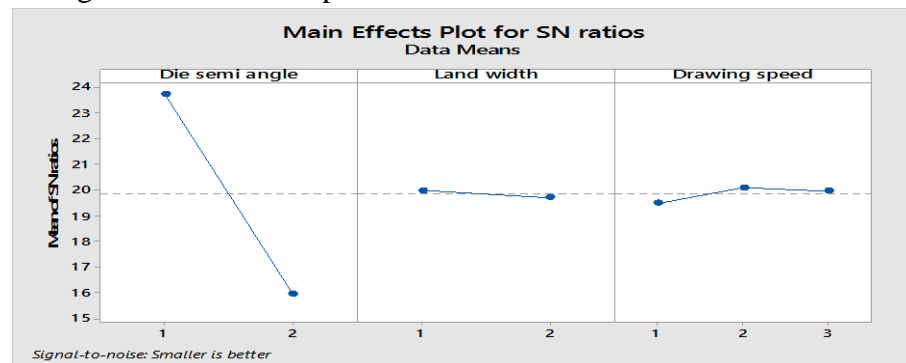


Figure 9. Main effect plot for SN ratios for high carbon steel.

Similarly for medium carbon steels, it is evident that 15 degree die semi angle, 10 mm land width and 6 m/min drawing speed gives least springback. For high carbon steels 15 degree die semi angle, 10 mm land width and 4 m/min drawing speed is the optimized condition. For high carbon steels as the alloying elements are more, it needs to draw at lesser speed.

The response tables are obtained to identify most dominant factor among die semi angle, land width and drawing speed as shown in table 5.

Table 5. Response table for signal to Noise ratios.

Level	Die semi angle	Land width	Drawing speed
1	23.21	18.61	19.12
2	15.79	20.40	19.03
3			20.36
Delta	7.42	1.79	1.33
Rank	1	2	3

Table 5 shows die semi angle with rank 1 is most dominant factor causing springback followed by land width and then drawing speed. Further investigation concludes that the percentage contribution for springback of die semi angle is 70.40, land width is 16.98 and drawing speed is 12.62 as shown in figure 10.

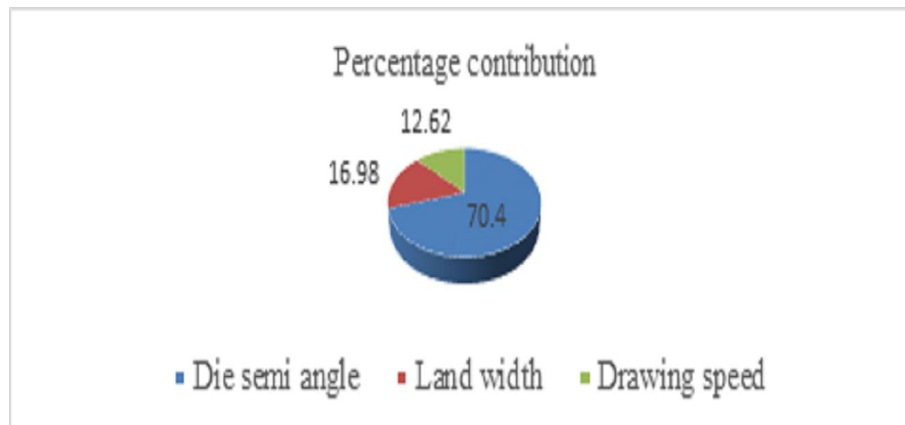


Figure 10. Percentage contribution of each process parameter in springback.

Confirmatory tests are conducted with the optimized parameter setting gives similar results which were obtained initially.

## 7. Conclusions

This research work focused the springback study for low carbon, medium carbon and high carbon steels and corresponding Young's modulus is measured. The results shows that there is 10-20 % variation in Young's modulus in which 10-14 % variation is found in low carbon steels and 16-20 % variation in the Young's modulus of high carbon steels. It is also found that the springback and Young's modulus are inversely proportional. This research concludes that more the percentage of carbon in steel, more the strength, less the value of Young's modulus and more will be springback. Similarly less the percentage of carbon, less the strength, more the value of Young's modulus and less will be the springback. Further it is found that die semi angle of 15 degrees and land width of 10 mm gives least springback in low carbon, medium carbon and high carbon steels. The optimum drawing speed is 8 m/min in low carbon steels, 6 m/min in medium carbon steels and 4 m/min in high carbon steels indicating low carbon steels can be drawn at higher speed than medium and high carbon steels. It is also found that die semi angle is most dominant factor than land width and drawing speed causing springback.

## 8. Limitations and future scope

This work is completely based on the experimental results. The results are validated using confirmatory tests. It could be interesting to do mathematical modelling of the cold drawing process. Finite Element Analysis (FEA) using ABAQUS or LS-Dyna could also be very effective tool for the same.

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