Experiment investigation and optimization of some parameters on strain for Stainless steel-202 using Deep Drawing

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Abstract: Deep drawing process is widely used in industries. Quality of product is highly depending upon the accuracy of finished product. Which can be achieved through controlling the thickness variation of the finished product. The parameters considered for the thickness variation are Punch nose radius which is required to minimize the defect in drawing product, Die shoulder radius and Blank holding force. This is greatly affected on the design of machine tool for the deep drawing process. Experimental approach is used with taguchi design to simulate the model. ANNOVA is used to identify the effect of each parameter and results can be seen through interaction plots. General linear model is developed to simulate the results. Genetic Algorithm is implemented to identify the optimum parameters for the minimum thickness variation. MATLAB software used for the optimization. Optimization tool box are used to import the conditions and evaluate the results.

***Index Terms* – Deep drawing, DOE, Taguchi, ANOVA, Optimization, MATLAB, etc…**

1. INTRODUCTION

Cup drawing or deep drawing is one of the widely used sheet metal forming operations. Cup shaped objects, utensils, pressure vessels, gas cylinders, cans, shells; kitchen sinks etc are some of the products of deep drawing. In this process, a sheet metal called blank is placed on a die cavity, held in position using a holding plate or holding ring and pressed against the die cavity using a solid punch. The sheet metal attains the shape of the die cavity with flat bottom. Both die and punch should be provided with corner radius in order to avoid shearing of the sheet. During drawing of sheet into the die, there is thickening of the sheet up to 12%. Therefore, clearance is provided between the punch and die. The radial clearance therefore is equal to the sheet thickness plus the thickening of sheet. Punch pushes the bottom of the sheet into the die cavity. The flat portion of the sheet under the holding plate moves towards the die axis, then bends over the die profile. After bending over the die profile, the sheet unbends to flow downward along the side wall.Figure 1 show the equipment setup in deep drawing process [9].

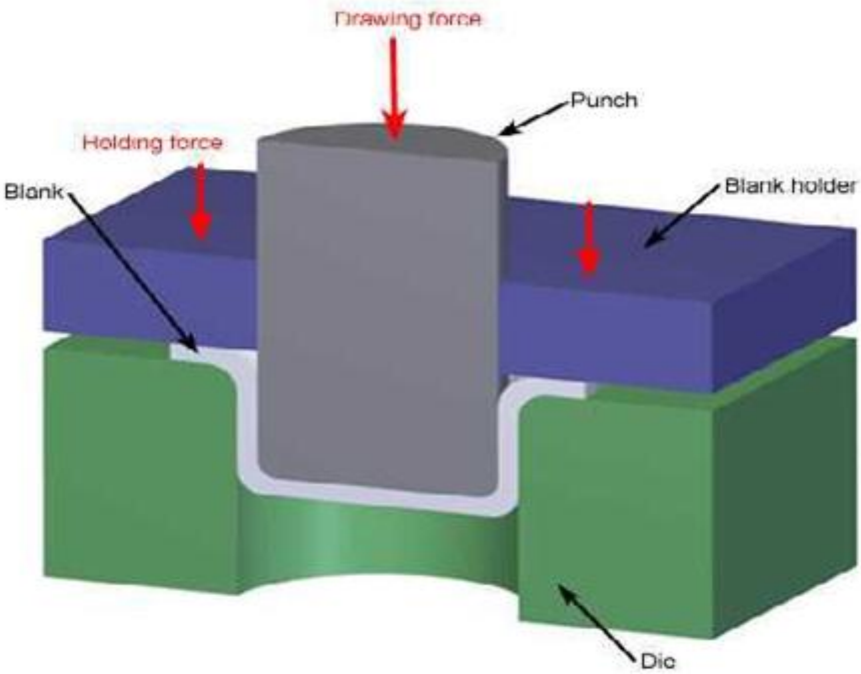

Fig.1: Equipment setup [9]

The vertical portion of the sheet then slips past the die surface. More metal is drawn towards the centre of the die in order to replace the metal that has already flown into the die wall. Friction between holding plate and blank and that between die and blank has to be overcome by the blank during its horizontal flow. [9]

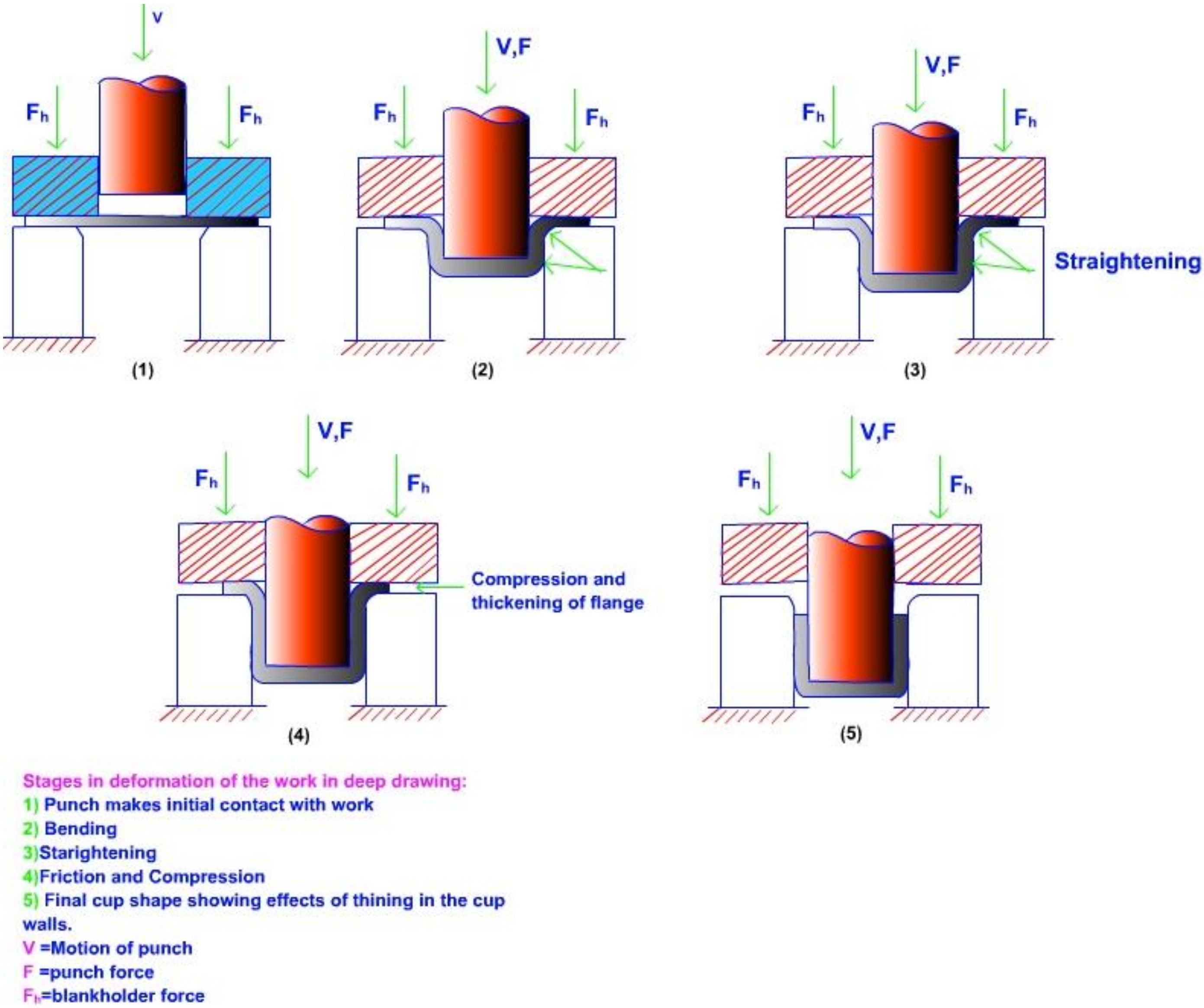

Fig.1: Cup drawing process – sequence of operation. [9]

1.1 Analysis of Cup Drawing:

Figure 3 show the stress generated in draw product. According to below figure it can be conclude that at the flange thickness of sheet is increased due to high amount of compressive stress compared to tensile stress which is called as thickening of sheet, while at the cup wall thickness of sheet is reduced due to high amount of tensile stress compared to compressive stress which is call as thinning of sheet. At the joining point of punch and die thickness of sheet is nearly equal to the thickness of blank because of same amount of tensile and compressive stress.

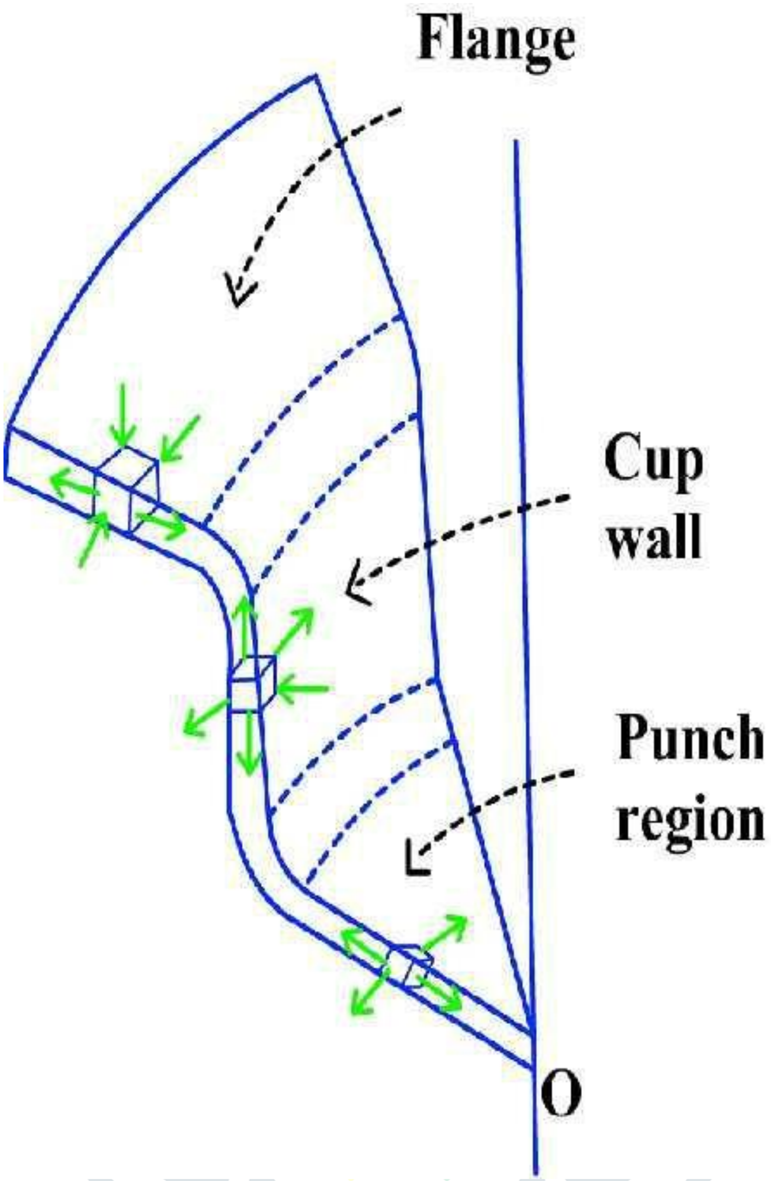

Fig.3: Stresses in deep drawing process [9]

1.2 Defects in deep drawing process

1 Wrinkling in the flange of the drawn product,
2 Wrinkling in the wall of the drawn product,
3 Tearing in the drawn product,
4 Earing in the drawn product,
5 Surface scratches in drawn product. [1]

(1) Wrinkling in the flange:

Wrinkling in a drawn part consists of a series of ridges that form radically in the undrawn flange of the work-piece due to compressive buckling. This is also occur due to small amount of blank holding force.

(2) Wrinkling in the wall:

If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall due to small amount of punch force

(3) Tearing:

Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(4) Earing:

This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal.

(5) Surface Scratches

Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

1.3 Advantages of deep drawing process:

Deep drawn stamping is advantageous for use in production or projects like complicated axi-symmetric geometries, as well as minimal labor. Waste material created during the deep drawn stamping method may be recycled for later use in other applications.

1.4 Disadvantages of deep drawing process:

In general, the deep drawing method is highly valuable for large quantity or long run production.

1.5 Application of deep drawing process:

Deep Drawing process are widely use in the manufacturing for part of aircraft, automobile Engineering. In recent years composite material is widely used in aerospace, auto motive.

2. Problem identification

- ✓ Aim of the study is to improve the quality of deep drawing process by minimizing the thickness variation of sheet metal of stainless steel.

2.2 Objectives:

- ✓ To study the process parameters of deep drawing process
- ✓ To control the thickness variation
- ✓ To simulate the process to identify the effect of process parameters
- ✓ To optimize the parameters for minimum thickness variation

The quality of finished product obtained from deep drawing process is highly depends upon the extent to which a thickness variation is achieved. The Thickness variation can be controlled using various parameters like punch nose radius, die shoulder radius, blank holding force and friction coefficient.

Material Property of sheet metal are producing various defects such as wrinkling, tearing, fracture defects in D.D. Higher amount of strain is producing fracture near to the punch corner. From the study of literature, it is also said that the optimum amount of blank shape is reduce the forming load while increase forming limit, reducing the possibility of effect of wrinkling and tearing on the drawn product. In this dissertation work we will do parametric study of effect of various process parameters on Deep-Drawing. Which are as follow,

- Punch nose radius
- Die shoulder radius
- Blank holding force

2.1 Process parameters in deep drawing

(1) Blank holder force

A blank holder force plays a major role in this process. Due to loos BHF wrinkling effect is produced. As well as higher BHF is producing fracture in drawing product. [2]

(2) Effect of Blank Shape

Optimum amount of blank shape is reducing the forming load, increase forming limits, and reduce possibility of wrinkling and tearing effect on drawn product. [3]

(3) Effect of Die Radius

To minimize the drawing load, it is required to optimized the die radius, while optimal die radii can be found only for very low co-efficient. [4]

(4) Effect of punch to die clearance

Radial clearance is difference between die radius and punch radius. Sheet metal thickness increase when radial clearance decreases. When radial clearance is less than blank thickness, the cup fails due to increase in thinning. When the radial clearance is greater than blank thickness thinning is stable. [4]

(5) Effect of the Press Speed

Due excessive press speed has result in cracking and wall thinning in drawing product. [4]

(6) Effect of Punch nose Radius

The effects of punch nose radius in deep drawing process are play an important role in thickness distribution and thinning of sheet metal. It is also play major role in metal thickness distribution. [5]

(7) Effect of Blank Thickness

This play a major role in thickness distribution and thinning of sheet metal. As well as the percentage of thinning increases with increase of blank thickness. [5]

(8) Effect of Cracking Load

According to this paper the definition of cracking load is given as follow. The largest allowable drawing load is limited by the load that can be transmitted by the sheet in the region of the punch radius or at the transition from cup wall to bottom radius, which is known as cracking load. [5]

(9) Effect of punch force

The standard deviation decreases with the increase in punch force. As well as the higher punch force is required to produce optimum results during drawing. [6]

3. Experimental Setup

Stainless Steel 202 is a Cr-Ni-Mn type stainless steel. The toughness of grade 202 at low temperatures is excellent. It is one of the most widely used hardening grades material, and possesses good corrosion resistance, toughness, high hardness, and strength. Below table show the Chemical composition on ss-202,

Table 1: Chemical composition of stainless steel-202

Element	Content (%)
Iron, Fe	68
Chromium, Cr	17-19
Manganese, Mn	7.50-10
Nickel, Ni	4-6
Silicon, Si	≤ 1
Nitrogen, N	≤ 0.25
Carbon, C	≤ 0.15
Phosphorous, P	≤ 0.060

Sulphur, S	≤ 0.030

Table 2: Mechanical property of stainless steel-202

Properties	Metric	Imperial
Tensile strength	515	74694psi
Yield strength	275	39900psi
Elastic modulus	207	30000ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Elongation at break	40%	40%

Figure 4 represents the different die sets which are considered for the experiments. There are three die variations of 3mm, 5mm and 8mm shoulder radius were considered for the experiments.

Fig.4: Photographs of Die prepared for the experiments

3.1 Experimental Machine's detail

Machine name - Mechanical Deep Drawing power press - 5
Technical data of Mechanical Deep Drawing power press – 5 are as follow

Table 3: Mechanical Deep Drawing power press – 5

Type in No	5
Deepest Draw	203 mm/ 8 inch
Diameter of Crankshaft	165 mm/ 6 inch
Width Between Sides of Frame	710 mm/ 28 inch
Bed Front to Back	787 mm/ 31 inch
Hole thought Bed	305 mm/ 12 inch
Motor H. P	20 H. P
Stroke Per minute	8

Figure 5 represents the photograph of press tool machine in which the experiments were conducted. The deep drawing was performed using a deep drawing hydraulic press with a maximum load capacity of 70 tonnes. Soap water was used as lubrication. The experiment al setup is shown in below fig. The blanks of 254mm in diameter were cut from the sheet and cups were drawn giving to the experimental design.

Fig.5: Photograph of experimental setup

4. Methodology

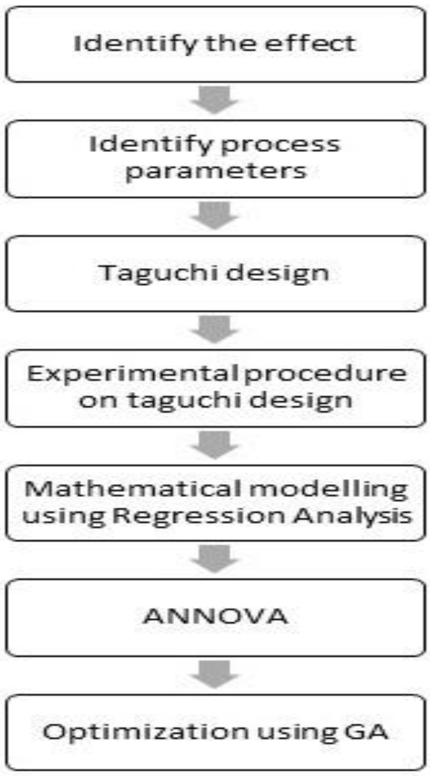

Fig.6: Flow Chart

Above figure 6 represents the flow chart of methodology of process of this dissertation work. The main aim behind this study is to optimize the process parameters of the deep drawing process. Criteria chosen to improve the accuracy of deep drawing is thickness variations along the components or sheet. To simplify the procedure, some parameters have been identified to analyze the effect of thickness various.

4.1 Input Parameters

There are various parameters can be studied to control the process as discussed in literature survey section but some major parameters have been identified are listed below:

1 Punch nose radius (rp), mm
2 Die shoulder radius (rd), mm
3 Blank holder force (BHN), KN

These three parameters are selected because of it greatly effect on the design of machine tool for deep drawing process. Process parameter limits are selected based on research paper study and industrial expert guidance. This is shown in table.

Table 4: Process parameters levels

Levels	**Punch Nose Radius (mm)**	**Die Shoulder Radius (mm)**	**Blank Holder Force (N)**
1	3	3	800
2	5	5	900
3	8	8	1000

4.2 Output Parameter

(1) Thickness variation

Thickness variation is most important criteria to evaluate the performance of the deep drawing process. Quality of sheet metal product produced from deep drawing process is depend on the extent to which the thickness variation is achieved.

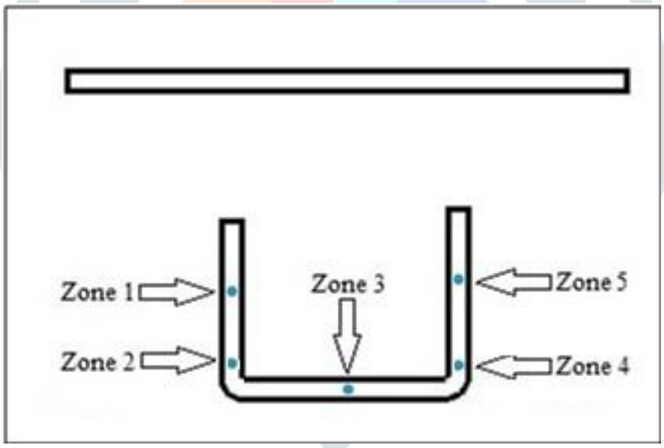

Fig.7: Different zone of thickness variation

The distribution of sheet thickness is uneven in drawn part. Thickness variation is compared with reference to the initial blank thickness before process. Minimum thickness occurs in the zone of connection between the part wall and bottom and in vertical walls while flange zone can be identified as a zone of maximum thickness variation.

5. Design of experiments

What is Taguchi Method?

- Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.

- The goal of the Taguchi method is to produce high quality product at low cost to the manufacturer and to society from variability in manufacturing processes.

- The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies.

- Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations.

- Optimize product and process designs, study the effects of multiple factors (i.e.- variables, parameters, ingredients, etc.) on the performance, and solve production problems by objectively laying out the investigative experiments.

- Study Influence of individual factors on the performance and determine which factor has more influence, which ones have less. From this method it can also find out which factor should have tighter tolerance and which tolerance should be relaxed.[8]

5.1 Application of Taguchi Method

- To generate experimental design.
- Development testing.
- Process development.
- Manufacturing.
- Successfully used in airlines, insurance, hotels and restaurants.
- To improve the quality of manufactured products.
- The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations.
- It can determine which factor is causing most variations in the result.
- It can also determine which factors have more influence on the mean performance.[8]

5.2 Advantage of Taguchi Method

- DOE using Taguchi approach attempts to improve quality which is defined as the consistency of performance. Consistency is achieved when variation is reduced.

5.3 Minimum number of experiments to be conducted

The design of experiments using the orthogonal array is, in most cases, efficient when compared to many other statistical designs. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach.

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV} (L_i - 1)$$

For example, in case of 3 independent variables study having 1 dependent variable with 3 levels and remaining 2 independent variables with 3 levels (L27 orthogonal array), the minimum number of experiments required based on the above equation is 27. Because of the balancing property of the orthogonal arrays, the total number of experiments shall be multiple of 3 and 3. Hence the number of experiments for the above case is 27. Higher the value of sum of square of an independent variable, the more it has influence on the performance parameter. [7]

Table 4 represents results obtained from taguchi experimental design. L27 approach was selected for the appropriate prediction using Minitab software.

Table 5: Taguchi design results L27

Experiment No.	Punch Nose Radius (mm)	Die Shoulder Radius (mm)	Blank Holder Force (N)
1	3	3	800
2	3	3	900
3	3	3	1000
4	3	5	800
5	3	5	900
6	3	5	1000
7	3	8	800
8	3	8	900
9	3	8	1000

10	5	3	800
11	5	3	900
12	5	3	1000
13	5	5	800
14	5	5	900
15	5	5	1000
16	5	8	800
17	5	8	900
18	5	8	1000
19	8	3	800
20	8	3	900
21	8	3	1000
22	8	5	800
23	8	5	900
24	8	5	1000
25	8	8	800
26	8	8	900
27	8	8	1000

6. Measurements of experiments

Experimental setup is prepared to measure the thickness variation of final product using standard measuring instruments and gauges. Initial thickness is compared with the final product thickness at major area of variation (Table 6) to evaluate the thickness change. Highlighted reading represents the zone at which the maximum thickness change observed in the measurements.

Table 6: Experimental observation

Experiment No.	Observation at different zone (mm)					variation
	1	2	3	4	5	
1	0.56	0.53	0.62	0.54	0.56	0.18
2	0.57	0.55	0.63	0.55	0.57	0.15
3	0.55	0.52	0.63	0.51	0.54	0.20
4	0.56	0.54	0.63	0.54	0.57	0.17
5	0.58	0.56	0.64	0.56	0.58	0.13
6	0.55	0.51	0.63	0.53	0.54	0.20
7	0.57	0.55	0.63	0.56	0.57	0.14
8	0.58	0.56	0.63	0.57	0.58	0.12
9	0.55	0.53	0.62	0.52	0.55	0.19
10	0.57	0.54	0.63	0.54	0.57	0.17
11	0.58	0.55	0.63	0.55	0.57	0.15
12	0.55	0.55	0.63	0.52	0.55	0.20
13	0.57	0.54	0.63	0.52	0.57	0.16
14	0.57	0.55	0.63	0.56	0.57	0.15
15	0.55	0.51	0.63	0.52	0.54	0.21
16	0.58	0.55	0.64	0.56	0.57	0.14
17	0.58	0.57	0.63	0.57	0.58	0.12
18	0.56	0.52	0.61	0.52	0.56	0.19
19	0.56	0.52	0.63	0.52	0.55	0.19
20	0.55	0.53	0.61	0.53	0.56	0.18
21	0.53	0.49	0.62	0.50	0.54	0.23
22	0.55	0.52	0.62	0.52	0.56	0.19
23	0.56	0.53	0.63	0.53	0.55	0.18
24	0.53	0.51	0.62	0.50	0.54	0.22
25	0.56	0.52	0.63	0.53	0.55	0.19
26	0.56	0.54	0.64	0.54	0.56	0.17
27	0.54	0.51	0.62	0.52	0.54	0.21

7. ANOVA

ANOVA is a statistical technique used to describe relationships among variables. The simplest case to examine is one in which a variable Y, referred to as the dependent or target variable, may be related to one variable X, called an independent or explanatory variable. For the more complex behaviour of data, sometimes non-linear model (i.e.) are used to accurately fit the data in analytical equation. The accuracy of curve fitting is depending upon the R^2 value. According through experimental result thickness variation equation is generated using general linear model of ANOVA.

By the use of General linear model of ANOVA equation of thickness variation is generated which are as follow,

Thickness variation = 0.17524 - 0.01168 Punch Nose Radius_3 - 0.01363 Punch Nose Radius_5
+ 0.02530 Punch Nose Radius_8 + 0.00857 Die Shoulder Radius_3
+ 0.00111 Die Shoulder Radius_5 - 0.00968 Die Shoulder Radius_8
- 0.00675 Blank Holder Force_800 - 0.02572 Blank Holder Force_900
+ 0.03247 Blank Holder Force_1000

According to above equation of thickness variation, Chart 1 represents the effect of input parameters on thickness variation. These relationships can be plotted using ANNOVA methods. The effect of input parameters is studied between the bounded ranges. It can be identified from the ANNOVA that all three factors are significantly affected on the thickness variation while BHF has slightly major effect on thickness variation. Minimum punch nose radius is desirable to reduce the thickness variation but the behavior is nonlinear, and thickness variation is slightly increased at beginning and then change is drastic with increase in Punch nose radius. Thickness variation is reduced with increase in Die shoulder radius; therefore higher value of die shoulder radius is required for minimum thickness variation. While in case of Blank holder force, thickness variation is reduced at begin but drastically increases after certain change. So, the minimum thickness is lied between upper and lower value.

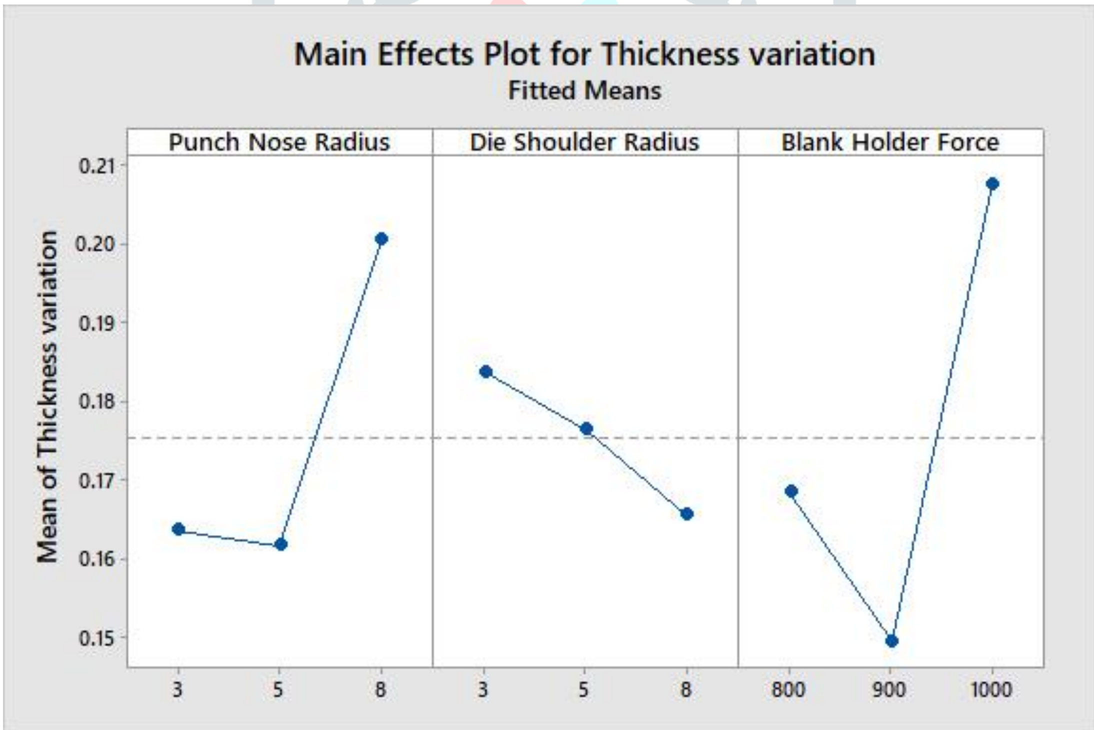

Chart 1: Main effects plot for Thickness variation

Chart 2 represents interaction effect of input parameters on thickness variation. These graphs show the combined effect of punch nose radius and die shoulder radius for different value of blank holding force. It can be observed that the interaction effect of punch nose radius and die shoulder radius provide minimum thickness variation at beginning when BHF is minimum and this behavior is reverse when BHN is at higher value. The combine effect of rp*rd it gives two different behavior for lower and higher value of BHF. As lower BHF value requires minimum value of rp*rd while higher value of BHF requires maximum value of rp*rd to obtain desired value of thickness variation.

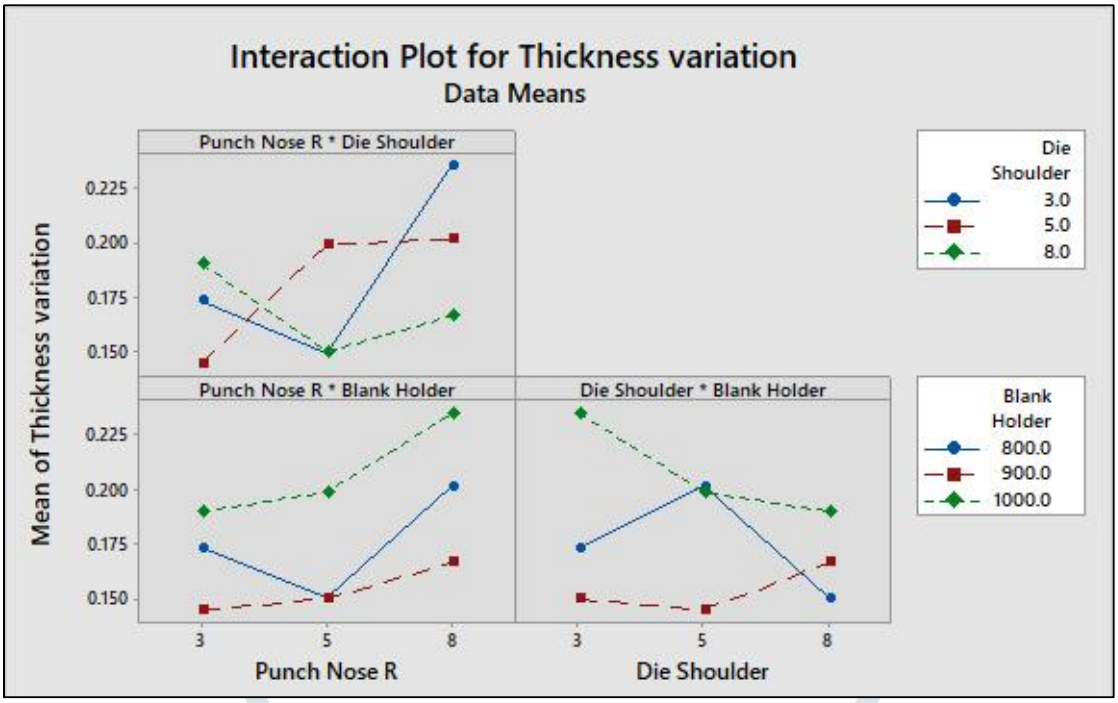

Chart 2: Interaction effects plot for Thickness variation

7. Optimization

To identify the optimum values of input parameters for minimum thickness variation, genetic algorithm is used. MATLAB software is used to simulate the mathematical modeling. Tool box is used to implement Genetic Algorithm for the optimum thickness variation.

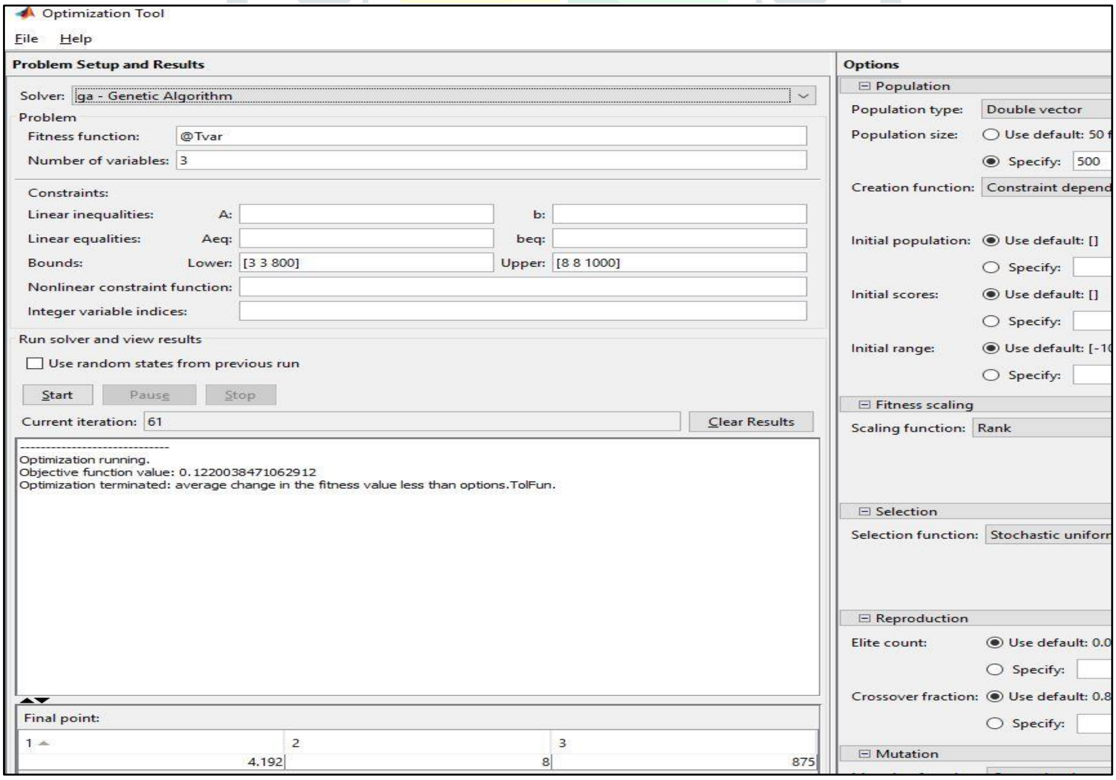

Chart 3: Setup for Genetic Algorithm

Chart 3 represents the setup required to run the optimization with desired limits. Fitness function with boundary limits is imported in tool box to get the desired results. Population size was selected 500 for the given problem and default settings were used.

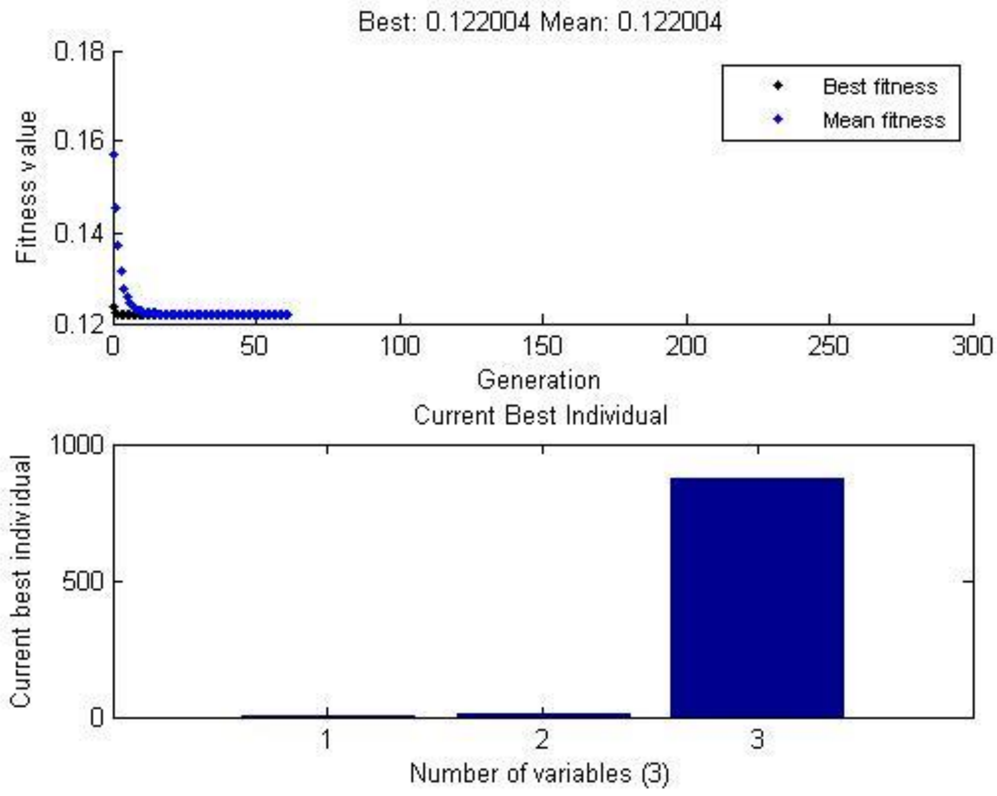

Chart 4: Fitness function vs. generation

Chart 4 represents the change in fitness value with progression of genetic algorithm. It shows that 61 generations ware required to get the optimum results. The best value for fitness function is 0. 1222. The results obtained by tool box are as described below. Table 7 represents the optimum parameters obtained using Genetic Algorithm.

Table 7: Optimum parameters

Input Parameters	**Punch nose radius rp**	**Die shoulder radius rd**	**Black holding force BHF**	**Thickness variation**
Optimized value	4.192	8	875	0.1222

8. Conclusion

Process parameters effect has been studied in this work. The thickness variation criteria have been chosen for the improvement of deep drawing process as the defect and stress can be minimized. Three parameters have been identified for the control of thickness variation. Which are as punch nose radius, Die shoulder radius, and Blank holder force. From the table no 5 it can be conclude that, lower amount of punch nose radius, higher amount of die shoulder radius & near to the maximum value of blank holder force gives the minimum thickness variation. However the lower amount of die shoulder radius and higher amount of punch nose radius & blank holder force are result in large amount of thickness variation.
ANNOVA described the effect of all three factors on thickness variation. It has been observed that higher value of Die shoulder radius is required for reducing the thickness variation. While in case of Punch nose radius and Black holding force, minimum thickness variation can be achieved between near the lowest point or mid value. Interaction plots (Chart 2) have been developed to identify the combine effect of the parameters.
Optimization has been implemented through genetic algorithm, using Optimization tool box in MATLAB software and minimum thickness variation was identified as 0.1222 around 61 generation. The optimum process parameters are identified as punch nose radius = 4.192 mm, Die shoulder radius = 8mm and Blank holding force = 875N.

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