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# An experimental study on effect of process parameters in deep drawing using Taguchi technique

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**Abstract**

The effects of various deep drawing process parameters were determined by experimental study with the use of Taguchi fractional factorial design and analysis of variance for AA6111 Aluminum alloy. The optimum process parameters were determined based on their influence on the thickness variation at different regions of the blank material. Three important process parameters i.e., punch nose radius, die shoulder radius and blankholder force were investigated in this study. Plan of experiments based on Taguchi's technique were used for acquiring the data. An orthogonal array, the signal to noise ratio and the analysis of variance were employed to investigate the deep drawability characteristics. Influence on thickness due to variation of these parameters was individually evaluated in terms of percentage. The results showed that the blankholder force (56.98%) was the most significant parameter followed by punch nose radius (30.12%) and the least influence (12.90%) was with die profile radius.

*Keywords:* Axisymmetric deep drawing, Taguchi method, orthogonal array, S/N ratio, anova

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## 1. Introduction

Quality is of vital importance in today's manufacturing world due to complex working environment and conditions associated in the use of the sheet metal components (Jeswiet *et al.,* 2008). Indeed, the quality of a product can be defined as the degree of customer satisfaction during the service life of the product (Jahanshahi *et al.,* 2011). It is evident that, proper selection of parameters influencing the quality needs to be well defined. Prevention of defects under controlled quality measurements eventually ends up with reduced trial and error, tryout methods. As the complexity of the part formed is continuously increasing in the present era with the requirement of high quality and the use of advanced optimization methods demands for in depth research in sheet metal forming.

Indeed, deep drawing is one of the widely used sheet metal forming process used in industries for cup shaped components produced at very high rate (Jeswiet *et al.,* 2008; Reddy *et al*., 2014). The components produced through this process are being widely used in aerospace, automobile, marine, beverage and other applications (Roll, 2008; Sutherland *et al.,* 2004).The deep drawing process consists of five associated activities. i.e., 1) pure radial drawing between the die and blankholder, 2) bending and sliding over the die profile, 3) stretching between the die and the punch, 4) bending and sliding over the punch profile radius, and 5) stretching and sliding over the punch face (Raju *et al.,* 2009). It is essential to find out an optimal process parameter levels capable of producing required product quality. Appropriate level selection of process parameters leads to defect free products.

Literature review reveals that the research on various aspects of modeling, simulation and process optimization of deep drawing consistently progressed during the past few decades (Volk *et al.,* 2011). Numerical simulation methods with optimization techniques for improving design, quality and short cycle times have been used extensively (Menezesa *et al*., 2000). The philosophies of six sigma and computer simulation were combined to perform robust design (Li *et al.* 2005). A lean six-sigma approach for touch panel quality improvement was made by employing a well-structured continuous improvement methodology by effectively reducing the process variability and quality of business process by the use of statistical tools (Chen and Lyu, 2009). Deep drawing experiments on axi-symmetric cup production were carried out according to central composite design. The optimum parameter settings for most even wall thickness were found out using Taguchi's signal to noise ratio (Raju *et al.* 2009). The use of finite elements (FE) simulations with Taguchi design of experiments (DOE) technique for determination of the contribution of the important process parameters in the deep deformation response of drawing process namely blank temperature, die radius and punch velocity were studied. The Pareto anova was carried out for obtaining the influence of process parameters for the deformation of the drawing cup and their percentage contribution (Venkateswarlu *et al.,* 2010*)*. Research made on application of Taguchi method to determine the optimal process parameters for cylindrical grinding process with the concept of analysis of variance (anova) to determine the effect and influence of process parameters namely work speed, feed rate and depth of cut on output responses and it was found that the developed model was very significant (Janardhan and Krishna, 2011*)*.

An optimization procedure based on LMecA method coupled with the finite element method was presented by Axinte for evaluation of optimization of springback in deep drawing (Axinte *et al.,* 2006*)*. A finite element method (FEM) based Taguchi method was used to determine the effect of forming parameters such as fluid pressure, friction coefficient, die entrance radius and gap between die rim block and punch holder on the part formability in the process of hydrodynamic deep drawing assisted by radial pressure. Anova was also used to quantify the influence of the forming parameters on the quality characteristics of hydrodynamic deep drawing (Zareh *et al.,* 2013). The use of FEM with Taguchi technique for the used in determination of the contribution of three important process parameters in the deep-drawing process namely die radius, blankholder force and friction coefficient had been illustrated by Padmanabhan and it is evident that die radius has the highest influence on the deep drawing of stainless steel blank followed by the blankholder force and the friction coefficient (Padmanabhan *et al.,* 2007). Yang *et al*. (1998) have used Taguchi method to optimize the turning operation of S45C steel bars using tungsten carbide cutting tools and reported that cutting speed, feed rate, and depth of cut are the significant parameters affecting the surface roughness of the part. Venugopal *et al.* (2012) used Taguchi method for obtaining the optimum parameters for maximum expansion of tube ends. The various process parameters namely punch/die cone angle, the expansion ratio and the friction conditions are taken as input process conditions. The hydro-mechanical deep drawing process parameters were studied by using DOE method with Taguchi's robust parameter design and anova method (Halkacı *et al.,* 2012).

In the present study, Taguchi method of experimental design was applied to establish relationships between punch nose radius, die profile radius and blankholder force in influencing sheet thickness of drawn cup. In this proposed method, statistical approach based on Taguchi and anova techniques had been adopted for obtaining the influence of each parameter such as punch nose radius, die shoulder radius and blankholder force on drawing of axi-symmetrical cup.

## 2. Taguchi Technique

When it is impossible to construct a mathematical model to express the relationship between various design or process parameters for optimization of the process can be solved by experimental design and optimization techniques. The method used to define and evaluate every possible condition in a test with multiple factors is called design of experiment (Jha, 2014; Wu *et al*., 2014). In a full factorial design method, the possible number of experiments can be calculated as

$$N = L^m \tag{1}$$

where $L$ is the number of levels chosen for each factor and m is the number of evaluating factors (Arezodar and Eghbali, 2012).

Taguchi's parameter design method is a powerful tool for optimization of the performance characteristic of a process. The aim of a parameter design experiment is to identify and design the settings of the process parameters that optimize the chosen quality characteristic and are least sensitive to noise factors. Selection of control factors and their levels are made on the basis of some preliminary trial experiments conducted in the laboratory and also from literature review on the subject. The experiments were designed based on the orthogonal array technique. An orthogonal array is a fractional factorial design with pair wise balancing property. Using orthogonal array design the effects of multiple process variables on the performance characteristic can be estimated simultaneously while minimizing the number of test runs. Indeed, Taguchi technique is one of such experimental design optimization techniques, which uses standard orthogonal array for forming a matrix of experiments in such a way that required information can be obtained with minimum number of experimental runs. Taguchi's approach has been built on traditional concept of DOE, such as full factorial, fractional design and orthogonal arrays based on signal to noise ratio, robust design and parameter and tolerance design (Reddy *et al.,* 2012). Taguchi had envisaged for a method of conducting the DOE which is based on well-defined guidelines known as Taguchi method and it has been successfully applied in several industrial organizations in order to change their outlooks towards quality assessment and for improvement (Rajesham et al., 1989). This method uses a special set of arrays called orthogonal arrays that stipulates the way of conducting the minimal number of experiments which could give the full information of all the influencing factors that affects the parameters. It is a powerful tool for designing high quality systems and provides a simple, efficient and systematic approach for optimizing the designs for performance, quality and cost. This methodology is valuable only when the design parameters are qualitative and discrete.

Taguchi parameter design and optimization of performance characteristics through settings of design parameters are tested for reducing the sensitivity of the system performance for the sources of variation. In recent years, the rapid growth of interest in the Taguchi method has shown the way for numerous applications of this method in all industries throughout the world (Yang *et al.,* 1998). Taguchi philosophy is to design quality into the product rather than to inspect it after it is produced. It is a multi-stage evaluation process consisting of system design, parameter design and tolerance design. System design is to determine suitable working levels necessitates in design stage including materials selection and parts. Parameter design is concerned with evaluation of factor levels for producing the best performance of the product or process under study. In parameter design two types of factors i.e., control factors and noise factors that affect the product's functional characteristics are considered. Tolerance design is a way to fine-tune the results of the parameter design by tightening the tolerance which significantly influences on the product quality. The step by step procedure involved in Taguchi methodology is: 1) Identification of the main function, side effects and its failure modes, 2) Identification of noise factors, testing conditions and quality characteristics, 3) Identification of the objective function that needs be optimized, 4) Identification of the control factors and their levels, 5) Selection of orthogonal array matrix for experimental design, 6) Conducting of matrix experiment, 7) Analyzing the data, prediction of optimum levels and performance, 8) Performing of experiment verification and planning for future action. The sequence of steps to be followed in Taguchi's approach to parameter design suitable for deep drawing is described in the Figure 1.

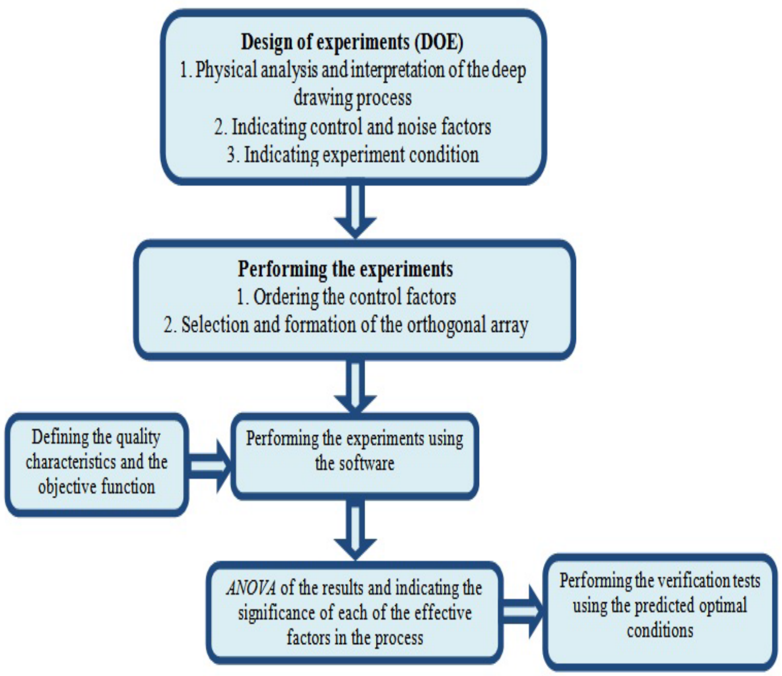


**Figure 1**: Flowchart showing Taguchi method of robust design (Mohammadi and Mohammadi, 2011)

Taguchi method provides a systematic and efficient approach for conducting experiments in determination of optimum parameter settings for better performance and cost reduction. This method can reduce research and development costs by simultaneously studying a large number of parameters. In order to analyze the results, the Taguchi method uses a statistical measure of performance called signal to noise ratio (S/N). The S/N ratio takes the mean and the variability into account. The S/N equation depends on the criteria for the quality characteristic to be optimized. After performing the statistical analysis of S/N ratio, anova can be employed in estimation of error variance and to judge the relative importance of the control factors.

*2.1 Properties of an orthogonal array:* The orthogonal array used in Taguchi method has special properties that reduce the number of experiments to be conducted. The special properties of Taguchi method are: 1) The vertical column under each independent variables of the orthogonal array table has a special combination of level settings. All the level settings can appear in equal number of times called balancing property of orthogonal arrays, 2) All level values of independent variables are used for conducting the experiments, 3) The sequence of level values for conducting the experiments shall not be changed, 4) The array of each factor columns are mutually orthogonal to any other column of level values and the inner product of weighing factors should be equal to zero, 5) The minimum number of experiments that are required to be conducted in Taguchi method can be expressed as given in Equation 2.

$$N_e = 1 + \sum_{i=1}^{n} (L_i - 1) \tag{2}$$

where $N_e$ = number of experiments
$L_i$= number of levels of parameter i
$n$ = number of parameters considered in the experiment

The design of experiment in Taguchi method consists of selection of independent variables, selection of number of level settings for each independent variable, selection of orthogonal array, assigning the independent variables to each column, conducting the experiments, analyzing the data and inference. This method involves reducing the variation in a process through robust DOE. The overall objective of the method is to produce high quality product at low cost. The experimental design proposed by Taguchi involves orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. In contrast to testing all possible combinations as in full factorial design, the Taguchi method tests only for pairs of combinations. This allows collection of necessary data for determining factors that are mostly affecting the product quality with a minimum amount of experimentation and thus saving time and resources (Vijay, 2014). Taguchi method is a powerful DOE tool for optimization of engineering processes in which the concept of S/N ratio is used for the improvement of quality through variability reduction and improvement of measurement. The transformation of the repetition data to another value which is a measure of the variation requires at least two data points for determination of S/N ratio (Çiçek *et al.,* 2013).

*2.2 Selection of Orthogonal Array:* Techniques of laying out experiments under multiple factors had been known for long time and are known as the Factorial DOE. This method helps the researchers in determination of the possible combinations of factors and the identification of the best combination. However in industrial settings it is extremely costly process to run large number of experiments in testing all combinations. The Taguchi approach delineate the rules in carrying out experiments and are further simplified and also standardized the design of the experiment along with minimum number of factor combinations that would be required for testing the influence of diverse factors (Bendell *et al.,* 1989; Eşme, 2009).

## 3. Experimental study on Deep Drawing

In this study, an experimental method is proposed to fully understand effects of various parameters on thickness variation of cup formed by deep drawing process. The deep drawing process had prominently acquired its popularity due to rapid press cycle times, less skilled labor requirement and simplicity of this process. The desired shape of the component can be stored in punch and die shapes and can be imparted to the blank when it passes through the clearance between the punch and die. Indeed, a blankholder with suitable force or pressure can postpone the initiation for wrinkles or tearing failure by suppressing these failures (Reddy, *et al.* 2013). In essence, punch forces the blank through the clearance between punch and die under the blankholder pressure. The deep drawing tests were conducted on 200T double acting mechanical press with the tool setup as shown in Figure 2 and the corresponding tool specifications for blank, punch, die, blankholder force and friction coefficient used in deep drawing process are as shown in Table 1. The oil lubricated 90 µm thick Teflon layers were introduced between punch, blank and die interface.

**Table 1**: Parameters used in deep drawing process

| Parameter | Quantity |
|---|---|
| Blank Diameter, mm | 350 |
| Blank thickness, mm | 0.9 |
| Punch Diameter, mm | 80 |
| Punch nose radius, mm | 3 – 8 |
| Die inner Diameter, mm | 83 |
| Die shoulder radius, mm | 3- 8 |
| Lubrication | Teflon Film |
| Friction Coefficient between punch and blank | 0.24 |
| Friction Coefficient between die and blank | 0.12 |
| Blankholder force, kN | 4 – 10 |

The material selected for investigation is an aluminum alloy AA6111 with mechanical properties as shown in Table 2 and Chemical composition was 97.8% Al, 1.0% Mg, 0.6 Si and 0.6% Cu. The blanks were prepared form a commercially available rolled sheets exhibiting isotropic nature of forming properties by laser cutting. The Nd:YAG laser with oxygen cutting gas were used at cutting speed of 30 mm/sec and with this method of cutting the heat affected zone is very less and doesn't have any adverse effect on forming properties of the aluminum blank .

**Table 2:** Mechanical properties of the material used in test material

| Property | Unit | Quantity |
|---|---|---|
| Ultimate tensile strength | (MPa) | 115 |
| Yield strength | (MPa) | 48 |
| Work hardening exponent | ---- | 0.27 |
| Strain ratio in rolling direction ($R_0$) | ----- | 0.935 |
| Strain ratio at $45^0$ to rolling direction ($R_{45}$) | ----- | 0.388 |
| Strain ratio at $90^0$ to rolling direction ($R_{90}$) | --- | 0.640 |

Amongst the various factors influencing the deep drawing process, blankholder force, die shoulder radius and punch nose radius play an important role in quality of the formed part and hence, blankholder force, die shoulder radius and punch nose radius are considered in the optimization of deep drawing process. Three levels i.e., level 1, level2 and level 3 were considered for each parameter in order to capture the non-linear effects. It is assumed that higher order interactions among these three factors are assumed negligible and the information on the main effects can be obtained by running $3^3 = 27$ experiments. The use of orthogonal arrays can avoid costly a costly full factorial experiment in which all combinations of all factors at different levels are studied. In fractional factorial designs, the number of columns in the design matrix is less than the number necessary to represent every factor and all interactions of those factors. L9 orthogonal array had used to investigate the effect of punch nose radius, die shoulder radius and blankholder force on thickness variation by conducting only nine experiments under three levels of each parameter as shown in Table 3.

**Table 3:** Orthogonal array (L9) of Taguchi method

| Experiment no. | Parameters | | |
|---|---|---|---|
| | Punch nose radius ($R_p$) | Die shoulder radius ($R_d$) | Blankholder force ($F_h$) |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

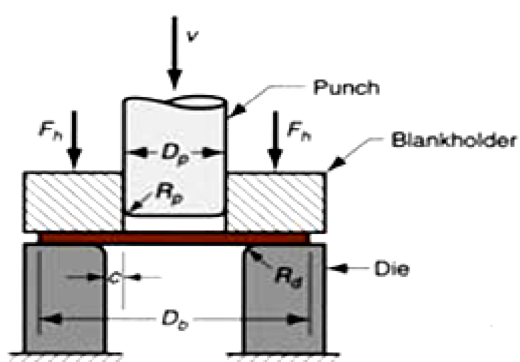


**Figure 2**: Scheme of deep drawing process (Patil and Bajaj, 2013)

There are several types of S/N ratios available for characteristic study namely lower is the better (LB), nominal is the better (NB), higher is the better (HB) and mathematical equations for S/N ratios can be expressed as depicted in equations (3), (4) and

(5). Lower is the better S/N can be defined as the negative of ten times the log of the mean of sum of the squares of measured data and it can be mathematically expressed as

$$\text{LB state of S/N} = -10log[1/n(\sum y_i^{\,2})] \tag{3}$$

HB state of S/N can be defined as the negative of 10 times the log of the mean of sum of the squares of reciprocal of measured data and it can be expressed as

$$\text{HB state of S/N} = -10log[1/n(\sum \frac{1}{y_i^{\,2}})] \tag{4}$$

And NB state of S/N can be defined as ten times the log of the ratio of square of the mean and variance and it can be expressed as

$$\text{NB state of S/N} = 10log(\frac{\bar{y}^2}{S_y^2}) \tag{5}$$

Where $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$, $S_y^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y}^2)}{n-1}$ and y is measured value of thickness.

*3.1 Experimental Details:* A set of experiments were conducted out on deep drawing machine with aluminum blank to determine effect of punch nose radius, die shoulder radius and blankholder force. The experiments were performed so as to investigate the thickness variation on deep drawn cup. Three level and three factors L9 Orthogonal array is used to design the orthogonal array by using DOE and relevant ranges of parameters. Total nine experiments were conducted and nine thickness measurements were made on each drawn cup at different locations i.e., point 1 at 15 mm from the flange and then maintaining 20 mm distance between adjacent points, as shown in Figure 3. The drawn cup were cut into two halves as shown in Figure 4 and the thicknesses measurements were made with dial thickness gauge having least count of 0.002 mm and the recorded thickness measurements were also represented graphically in Figure 5.

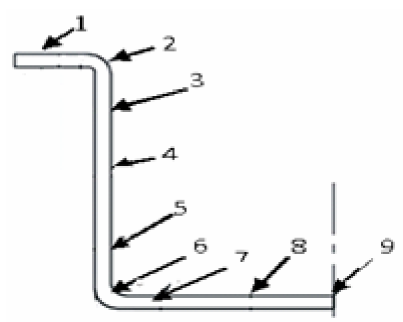


**Figure** 3: Measuring positions after cutting the drawing cups

**Figure** 4: The split cup

While evaluating the thickness, at each location three measurements were made and average values were computed. Such average values at nine locations of the cup were recorded for determination of mean thickness of the cup. Then the variance and S/N ratio were computed. Three levels and three factors L9 orthogonal array was used to design the orthogonal array by using DOE and relevant ranges of parameters and the measured thickness readings under different experiments were recorded as shown in Table 4. It had been observed from Figure 5 that in the first run at measuring point 9, the measured thickness value is following different trend. This different trend may be due to unrevealed localized microstructure changes and its influence on overall thickness may be very less and hence its effect had been ignored.

*3.2 Methodology and Choice of Process Parameters:* The formability of the blank sheet depends on the process parameters such as punch radius ($R_p$), clearance between punch and die (C), die shoulder radius ($R_d$), punch velocity (v), mechanical properties, sheet thickness and part geometry. The quality of the formed part depends on the degree of the influence of these parameters during deep drawing process. There are various defects like wrinkles, fracture, and thickness variation in deep drawing process. The thickness variation was the parameter to study in improving formability of the cup drawn in deep drawing process. Among all the process parameters; rather, die arc radius, punch nose radius and bank holder force were mainly influences on thickness and hence in the present investigation being made an attempt to study the effect of punch nose radius, die shoulder radius and blankholder force. In essence the thickness of the deep drawn cup section should be as uniform as possible, i.e., the nominal values are preferred throughout the section of the cup. If the nominal value for a characteristic is the best, then the design should be to maximize the S/N ratio and accordingly the S/N ratio chosen was as shown in equation 5. The appropriate Taguchi orthogonal array for the above parameters with three levels is $L_9$ which requires only nine experiments. The thickness measurements and S/N ratios calculated were as shown in Table 5.

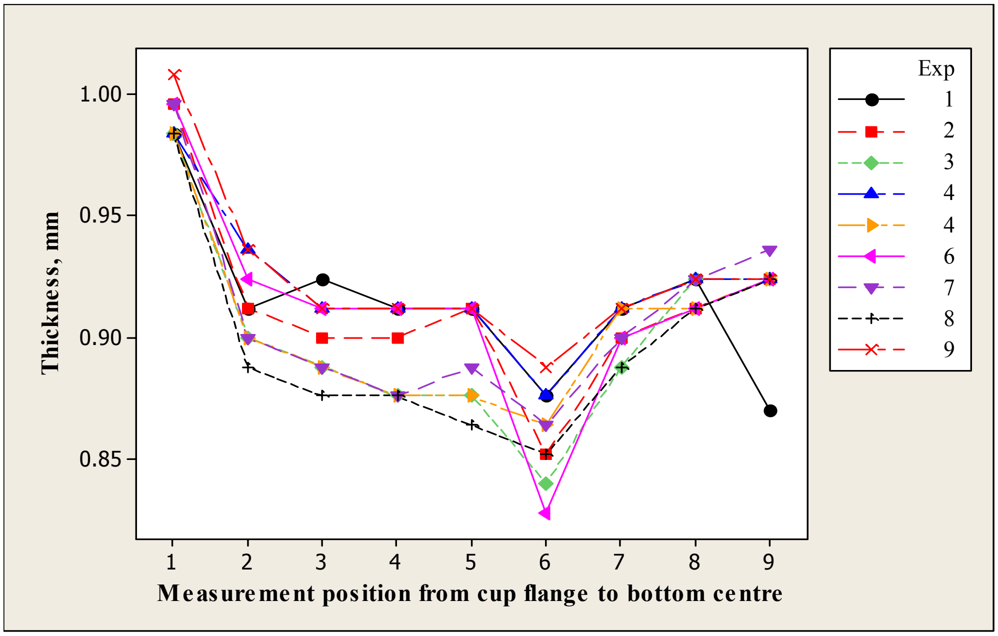


**Figure 5:** Thickness measurements

**Table 4:** Process parameters and their levels

| Process Parameter | Level | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| Punch nose radius ($R_p$), mm | 3 | 5.5 | 8 |
| Die shoulder radius ($R_d$), mm | 3 | 5.5 | 8 |
| Blankholder force ($F_h$), kN | 4 | 7 | 10 |

## 4. ANOVA

The purpose of the anova is to investigate which process parameters significantly affect the quality characteristic. It is a statistical technique evaluated for percentage of contributions for variance by each input factor. Anova is a collection of statistical models and associated procedures used to determine the contributions of each parameter on the output characteristic. In this study Anova is used to explicate the input parameters, i.e. $R_{p,}$ $R_d$ and $F_h$ that markedly influence the thickness variation. This furnishes the information on weightage of each parameter on thickness distribution. Taguchi recommended a logarithmic transformation of mean square deviation (S/N ratio) for the analysis of results. Anova separates the overall variation from the average S/N ratio into contribution by each of the parameters and the errors.

First, the total sum of the squared deviations $SS_T$ from the total mean S/N ratio (Zarch *et al*., 2013) can be calculated as

$$SS_T = \sum_{i=1}^{m} (\frac{S}{N})_i^2 - [\sum_{i=1}^{m} (\frac{S}{N})_i ]^2 \tag{6}$$

where m is the number of experiments in the orthogonal array and $(S/N)_i$ is the S/N ratio of the $i^{th}$ experiment. The sum of the squares due to the variation from the total mean S/N ratio for the $P^{th}$ parameter is expresses as

$$SS_P = \sum_{j=1}^{l} \frac{(\frac{S}{N})_j^2}{t} - \frac{1}{m}[\sum_{i=1}^{m}(\frac{S}{N})_i]^2 \tag{7}$$

where i is the number of parameter levels (i = 3 in this study), j is the level number of this specific parameter p, $(S/N)_j$ is the sum of the S/N Ratio involving this parameter and level j and t is the repetition of each level of parameter p. The percentage contribution of the $P^{th}$ parameter can be calculated as

$$P_c(\%) = \frac{SS_p}{SS_T} x100 \tag{8}$$

**Table 5:** Experimental observations and S/N ratio

| Experimental run no. | Parameter Level | | | Thickness values measured at different positions , mm | | | | | | | | | S/N Ratio | Overall Mean S/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $R_p$ , mm | $R_d$ , mm | $F_h$, kN | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | |
| 1 | 3 | 3 | 4 | 0.984 | 0.912 | 0.924 | 0.912 | 0.912 | 0.876 | 0.912 | 0.924 | 0.870 | 24.4222 | 26.9447 |
| 2 | 3 | 5.5 | 7 | 0.996 | 0.912 | 0.900 | 0.900 | 0.912 | 0.852 | 0.900 | 0.912 | 0.924 | 27.4325 | |
| 3 | 3 | 8 | 10 | 0.984 | 0.900 | 0.888 | 0.876 | 0.876 | 0.840 | 0.888 | 0.924 | 0.924 | 26.8858 | |
| 4 | 5.5 | 3 | 7 | 0.984 | 0.936 | 0.912 | 0.912 | 0.912 | 0.876 | 0.912 | 0.924 | 0.924 | 28.4863 | |
| 5 | 5.5 | 5.5 | 10 | 0.984 | 0.900 | 0.888 | 0.876 | 0.876 | 0.864 | 0.912 | 0.912 | 0.924 | 27.9973 | |
| 6 | 5.5 | 8 | 4 | 0.996 | 0.924 | 0.912 | 0.912 | 0.912 | 0.828 | 0.900 | 0.912 | 0.924 | 26.3039 | |
| 7 | 8 | 3 | 10 | 0.996 | 0.900 | 0.888 | 0.876 | 0.888 | 0.864 | 0.900 | 0.924 | 0.936 | 27.0767 | |
| 8 | 8 | 5.5 | 4 | 0.984 | 0.888 | 0.876 | 0.876 | 0.864 | 0.852 | 0.888 | 0.912 | 0.924 | 26.9328 | |
| 9 | 8 | 8 | 7 | 1.008 | 0.936 | 0.912 | 0.912 | 0.912 | 0.888 | 0.912 | 0.924 | 0.924 | 26.9644 | |

The results of anova for cylindrical cup are shown in Table 6. The blankholder force (56.98%) is the most significant parameter followed by punch nose radius (30.12%). Die profile radius has the least significant parameter (12.90%) influencing the thickness ratio.

## 5. Results and Discussion

This paper illustrates experimental study using Taguchi technique for forming quality characteristic i.e., thickness distribution. The Figure 6 shows how S/N ratio varies at different levels for each parameter such as punch nose radius, die shoulder radius and blank holder force. Regardless of the category of the performance characteristics, higher S/N value corresponds to a better performance. Therefore, the optimal level of the forming parameters is the level with the higher value as shown in Table 7. The optimum levels of the three factors presented above, in order to obtain an equal distribution of the thickness of the cup is as shown in Figure 7 as punch nose radius of 5.5 mm, die shoulder radius of 5.5 mm and the blank holding force of 7 kN. Taguchi's method was used in order to be able to identify the relative influence of each parameter of the process taken into consideration in this study. The quality of the drawing depends on the deforming conditions and on the optimum values of the three parameters taken into consideration within the analyzed process, and their combination is important for the deep drawing process. The anova was used to quantify the influence of the forming parameters on the quality characteristic.

The proportion of contribution of the process parameters considered namely punch nose radius, die shoulder radius and blankholder force. The Taguchi orthogonal array, the S/N ratio and the anova were used for optimization of punch nose radius, die shoulder radius and blankholder force. The anova results shown in Table 8 shows how the punch nose radius, die shoulder radius and blankholder force affects the thickness of the formed cup. One can notice that the strongest influence (56.98%) belongs to blank holder force, followed by that of punch nose radius (30.12%), the influence of die shoulder radius (12.90%) is the minimum.

**Table 6:** Anova results for three parameters tested at three levels

| Parameter | Level | Exp. Number | S/N | Level Mean S/N |
|---|---|---|---|---|
| Punch nose Radius (mm) | 1 | 1 | 24.4222 | 26.2468 |
| | | 2 | 27.4325 | |
| | | 3 | 26.8858 | |
| | 2 | 4 | 28.4863 | 27.5958 |
| | | 5 | 27.9973 | |
| | | 6 | 26.3039 | |
| | 3 | 7 | 27.0767 | 26.9913 |
| | | 8 | 26.9328 | |
| | | 9 | 26.9644 | |
| Die shoulder Radius (mm) | 1 | 1 | 24.4222 | 26.6617 |
| | | 4 | 28.4863 | |
| | | 7 | 27.0767 | |
| | 2 | 2 | 27.4325 | 27.4542 |
| | | 5 | 27.9973 | |
| | | 8 | 26.9328 | |
| | 3 | 3 | 26.8858 | 26.7180 |
| | | 6 | 26.3039 | |
| | | 9 | 26.9644 | |
| Blankholder Force (kN) | 1 | 1 | 24.4222 | 25.8863 |
| | | 6 | 26.3039 | |
| | | 8 | 26.9328 | |
| | 2 | 2 | 27.4325 | 27.6277 |
| | | 4 | 28.4863 | |
| | | 9 | 26.9644 | |
| | 3 | 3 | 26.8858 | 27.3199 |
| | | 5 | 27.9973 | |
| | | 7 | 27.0767 | |

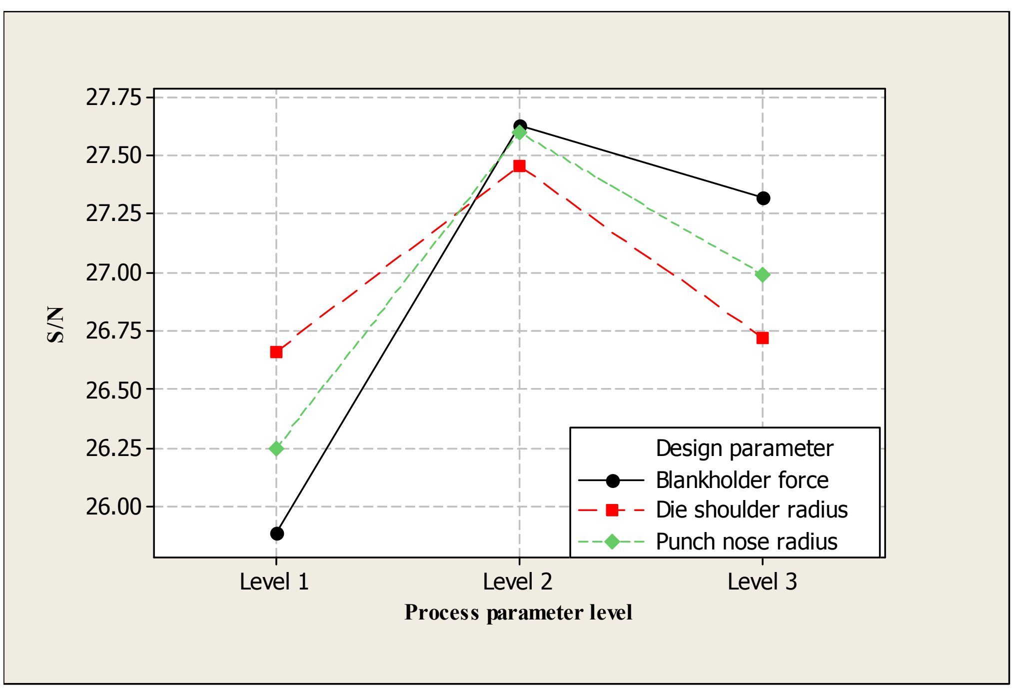


**Figure 6:** Plots of level average values of Punch nose radius die shoulder radius and blankholder force

**Table 7:** Optimal Condition

| Factor | Level Description | Level |
|---|---|---|
| Punch nose radius, mm | 5.5 | 2 |
| Die shoulder radius, mm | 5.5 | 2 |
| Blank holder force, kN | 7 | 2 |

**Table 8:** Contribution of process parameters on deep drawing process

| Process Parameter | Sum of Squares S S | % of Contribution |
|---|---|---|
| Punch Radius ($R_P$) | 0.913167 | 30.12049 |
| Die Radius ($R_d$) | 0.391072 | 12.89937 |
| Blankholder Force ($F_h$) | 1.727475 | 56.98013 |

**Confirmation Test**

A confirmation experiment is needed to determine the optimum conditions and to compare the results with the expected conditions. Table 6 gives the optimum conditions for attaining uniform thickness. It reveals that for optimum thickness, the punch nose radius should be at level 2 (5.5 mm), the $R_d$ should be at level 2 (5.5 mm), the $F_b$ should be at level 2 (7.5 kN). Since the optimum combination is not one of the experimental runs (according to Table 3) an extra confirmation run is required.

## 6. Conclusions

The deep drawing experimental tests were conducted on $L_9$ orthogonal array considering 3 process parameters such as punch nose radius, die shoulder radius and blankholder force. The readings of thickness obtained were transformed into signal to noise ratio. The significance of the design factors were estimated by the anova statistical method.

The main conclusions obtained through this research are summarized as follows

- Experiments designed based on the orthogonal array of the Taguchi method can be used to identify the most significant forming parameter affecting deep drawing.
- The greatest effect on thinning ratio in deep drawing is contributed from blank holder force. The second greatest effect is from punch nose radius.
- Anova results reveal that blankholder force has most significant parameter 56.98%, followed by punch nose radius 30.12%. the die shoulder radius has lower effect on maximum thickness variation
- The results from this work open the avenue of determination of optimal blank holder force for better quality products.
- Based on the results from anova analysis, further confirmation tests needs to be conducted.
- The results obtained from this study can be used for a wide range of industrial products for improving of formability by selection of appropriate level combinations of different parameters.

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