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# DIE PARAMETER ANALYSIS USING TAGUCHI METHOD

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**ABSTRACT:** Sheet metal forming is used to produce various products from mild steel, stainless steel, copper, aluminium, gold, platinum, tin, nickel, brass and titanium. To reduce costs and increase the performance of manufactured products, more and more lightweight and high strength materials have been used as a substitute to the conventional steel. In sheet metal forming, a piece of material is plastically deformed between tools to obtain the desired product. Sheet metal forming is characterised by the conditions in which the stress component normal to the plane of the sheet is generally much smaller than the stresses in the plane of the sheet. The common defects that occur in sheet metal forming are wrinkling, necking, scratching, cracks, stretcher strains and orange peeling.

**KERWORDS:** deep drawing, defect, material properties, sheet metal, process parameter.

## INTRODUCTION

Sheet metal forming is used to produce various products from mild steel, stainless steel, copper, aluminium, gold, platinum, tin, nickel, brass and titanium. To reduce costs and increase the performance of manufactured products, more and more lightweight and high strength materials have been used as a substitute to the conventional steel. These materials usually have limited formability, thus, a thorough understanding of deformation processes and the factors limiting the forming of sound parts is important, from both engineering and economic viewpoint. The common defects that occur in sheet metal forming are wrinkling, necking, scratching, cracks, stretcher strains and orange peeling. Wrinkling occurs in areas of high compressive strains and necking in areas with high tensile strains. Scratching is caused by defects on the tool surface and orange peel may occur after excessive deformation depending on the grain size of the material . In sheet metal forming operations, the amount of useful deformation is limited by the occurrence of unstable deformation which mainly takes the form of localized necking or wrinkling. Failure by wrinkling occurs when the dominant stresses are compressive, tending to cause thickening of the material.. The commonest sheet metal forming process is deep drawing and is frequently used in the automotive, packaging and home appliances/kitchen utensil producing industries. The objective of sheet metal forming processes is primarily to produce a desired shape by plastic deformation. The final product quality is dependent on both the sheet material characteristics and process variables such as strain, strain rate and temperature. These variables are influenced by the tool and die design, blank geometry, properties of the lubricant used (such as coefficient of friction and heat capacity) and drawing speed. A deviating product shape can result if incorrect combinations of these process parameters are used. A deviating shape is usually caused by elastic spring back of the job after forming and retracting the tool. During forming, the forces and the properties of the work piece material are of concern to the design engineer. The material properties of the sheet being formed change and affect the process parameters during processing. For example, a full deep drawing process which comprises blanking, deep drawing, trimming, hemming and flanging would have the blank material properties altered during and at the end of each of these forming processes. It is precisely because of this that the design of a full deep drawing process still depends on the knowledge and experience of the tool design engineer, wherein the selection of values for the various process parameters is based on trial and error methods.

Iseki and Murota investigated the blank shape design for deep drawing of non axisymmetric cups using finite element simulations with an objective of eliminating the earing effect. They optimized the blank shape for square cup and partially drawn cylindrical cup with a square flange. They developed an inverse finite-element technique to calculate the optimum blank shapes. Moshksar and Zamanian conducted a series of cup-drawing tests on commercial aluminium blanks by recording the critical die and punch shoulder radii, the limiting blank diameters and the limiting drawing ratios. They concluded that the process is highly sensitive to the die and punch-nose radii. Eriksen studied the relationship between die edge geometry and maximum wear and wear distribution over the die edge. He developed a numerical model and validated it against experimental results. Using this model he examined different die edge geometries, including a standard circular edge, an elliptical edge, a tractrix edge and an edge designed for making wear distribution mode uniform. They concluded that the drawing process is strongly influenced by die and punch nose radius.

The material used in the present work was the commercially available AA 6061 aluminum alloy sheet shown in Figure 1.1. The thickness of the sheet was 3mm. The mechanical properties and the composition (wt %) of the AA 6061 are given in Table 1.1 and Table 1.2

**Figure 1.1 AA 6061 aluminium alloy sheet.**

**Table 1.1:** Mechanical properties of AA 6061

| | |
|---|---|
| Ultimate Tensile Strength (MPa) | 125 |
| Tensile Yield Strength (MPa) | 57 |
| Elongation (%) | 15-20 |

**Table 1.2:** The composition (wt. %) of AA 6061.

| Mg | Si | Mn | Zn | Cr | Mo | Ti | Cu | Fe | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.80-1.20 | 0.40-0.80 | 0.15 | 0.25 | 0.04-0.35 | 0.012 | 0.15 | 0.15-0.40 | 0.7 | Balance |

**Experiment:-**The deep drawing was conducted using a double action hydraulic press with a maximum load capacity of 60 ton. The experimental setup is shown in Fig. 1.2.

**Fig. 1.2 Experimental setup.**

**Table 1.3:** Levels for various control factors for drawn parts parameter (height and thickness) analysis.

| Control factor | Level | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | Units |
| C: Punch Load | 75 | 150 | 225 | 300 | kN |
| D: Punch Velocity | 1 | 2 | 3 | 4 | mm/s |

Two parameters, punch load and punch velocity, each are considered, at four levels in this study. In Table 1.4, each row gives a test condition and column represents a test parameter which is simple combination of parameter levels. Five parameters each at three levels would require $3^4$ = 81 runs in a full factorial experiment whereas Taguchi's factorial experiment approach reduces it to 16 runs only offering a great advantage. The deep drawing tests for AA 6061 are conducted as per experimental design given in Table 1.4.

This method achieves the integration of design of experiments (DOE) with the parametric optimization of the process yielding the desired results. Taguchi's method uses a statistical measure of performance called signal-to-noise ratio (S/N), which is logarithmic function of desired output to serve as objective functions for optimization.

**Table 1.4:** Experimental design ($L_{16}$ orthogonal array).

| S. No. | Punch Load (C) (kN | Punch Velocity (D) (mm/s) |
|---|---|---|
| 1. | 75 | 1 |
| 2. | 150 | 2 |
| 3. | 225 | 3 |
| 4. | 300 | 4 |
| 5. | 150 | 3 |
| 6. | 75 | 4 |
| 7. | 300 | 1 |
| 8. | 225 | 2 |
| 9. | 225 | 4 |
| 10. | 300 | 3 |
| 11. | 75 | 2 |
| 12. | 150 | 1 |
| 13. | 300 | 2 |
| 14. | 225 | 1 |
| 15. | 150 | 4 |
| 16. | 75 | 3 |

The S/N ratio considers both the mean and the variability into account. It is defined as the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product/process to be optimized. The S/N ratio can be calculated as logarithmic transformation of the loss function as shown in Eq. (1.1). Smaller is the better characteristic:

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y^2\right) \tag{1.1}$$

Where; n the number of experiments and y the observed data (drawn part height or thickness)

The overall mean ($\overline{\frac{S}{N}}$) ratio is expressed as:

$$\overline{\frac{S}{N}} = \frac{1}{16}\sum_{i=1}^{16}\left(\frac{S}{N}\right)_i \tag{1.2}$$

The sum of squares (SS) due to variation about the overall mean is

$$SS = \sum_{i=1}^{16}\left(\left(\frac{S}{N}\right)_i - \overline{\frac{S}{N}}\right)^2 \tag{1.3}$$

For the i$^{th}$ process parameter, the sum of squares due to variation about the mean ( $SS_i$ ) is

$$SS_i = \sum_{j=1}^{4}\left(\left(\frac{S}{N}\right)_{ij} - \overline{\frac{S}{N}}\right)^2 \tag{1.4}$$

The percentage contribution of individual process parameter on the deep-drawing process can be calculated by

$$(contribution, \%)_i = \frac{SS_i}{SS}\times 100$$

## RESULT AND DISCUSSION

The experiment of AA 6061 was conducted using a double action hydraulic press with a maximum load capacity of 60 ton. Drawn part were sectioned at the middle and measured for height and thickness. The thickness of the drawn part was measured at five points.

## INFLUENCE OF PROCESS PARAMETERS DRAWN PART HEIGHT

The drawn parts were sectioned at the middle and the height was measured from bottom to top of the cup, as shown in Fig. 1b. The measured values for height against four experiments for each level are shown in Table 1.5 respectively. The S*/N is* used to measure the deviation in drawn part height and calculated by using Eq. 1.1. The overall mean S/N is calculated as per Eq. 1.2 and shown in Table 1.5

**Table 1.5:** ANOVA data table for drawn part height.

| Parameter | Level | Experiment No. | Height | $\frac{S}{N}$ | $\frac{S}{N_{ij}}$ |
|---|---|---|---|---|---|
| **Punch Load** | 75 kN | 1 | 7.66 | 17.685 | 21.028 |
| Level 1 | | 6 | 10.35 | 20.299 | |
| | | 11 | 12.67 | 22.056 | |
| | | 16 | 15.98 | 24.072 | |
| Level 2 | 150 kN | 2 | 9.86 | 19.878 | 21.947 |
| | | 5 | 12.78 | 22.131 | |
| | | 12 | 13.34 | 22.503 | |
| | | 15 | 14.58 | 23.275 | |
| Level 3 | 225 kN | 3 | 11.54 | 21.244 | 20.786 |
| | | 8 | 13.32 | 22.490 | |
| | | 9 | 10.50 | 20.424 | |
| | | 14 | 8.90 | 18.988 | |
| Level 4 | 300 kN | 4 | 16.23 | 24.206 | 20.665 |
| | | 7 | 7.55 | 17.559 | |
| | | 10 | 11.45 | 21.176 | |
| | | 13 | 9.68 | 19.718 | |
| **Punch Velocity** | 1 mm/s | 1 | 7.66 | 17.685 | 19.184 |
| Level 1 | | 7 | 7.55 | 17.559 | |
| | | 12 | 13.34 | 22.503 | |
| | | 14 | 14.58 | 18.988 | |
| Level 2 | 2 mm/s | 2 | 9.86 | 19.878 | 21.035 |
| | | 8 | 13.32 | 22.490 | |
| | | 11 | 12.67 | 22.056 | |
| | | 13 | 9.68 | 19.718 | |
| Level 3 | 3 mm/s | 3 | 11.54 | 21.244 | 22.156 |
| | | 5 | 12.78 | 22.131 | |
| | | 10 | 11.45 | 21.176 | |
| | | 16 | 15.98 | 24.072 | |
| Level 4 | 4 mm/s | 4 | 16.23 | 24.206 | 22.051 |
| | | 6 | 10.35 | 20.299 | |
| | | 9 | 10.50 | 20.424 | |
| | | 15 | 14.58 | 23.275 | |

The level average response analysis by $\frac{S}{N_{ij}}$ ratio is shown in Table 1.5 and Fig.1.3 although the physical meaning of $\frac{S}{N_{ij}}$ ratio is not as straight forward as simple level average response analysis by values; it is more objective towards the target because the $\frac{S}{N_{ij}}$ ratio reflects both the average (mean) and the scatter (variance). For optimum values of the selected parameters, the level that gives the highest S/N ratio was chosen.

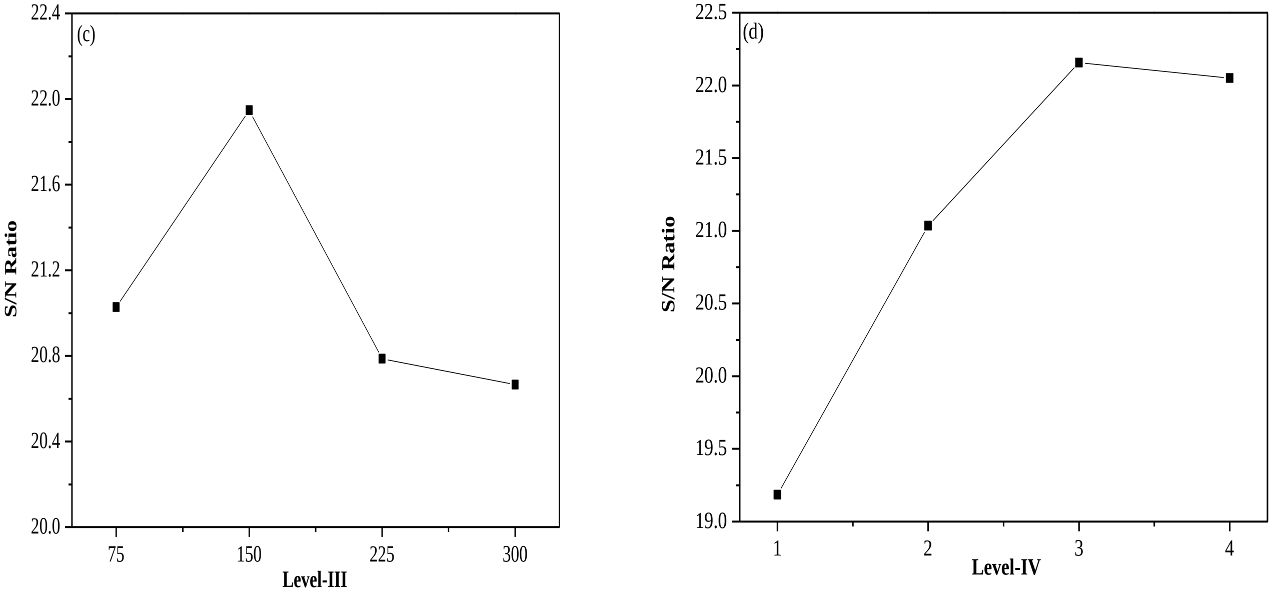

**Fig. 1.3.**Plots of overall mean (S/N*ij)* of four parameters: (c) Punch Load; (d) Punch Velocity.

## CONCLUSION

1. For thickness distribution the parameter settings are die radius of 8mm, blank temperature of 450$^o$C, and punch load of 225kN and punch velocity of 4mm/s.
2. Die radius has greatest influence on the drawn part thickness with 51.73% influence followed by the punch velocity with 23.41%, punch load with 14.98% and the blank temperature with 9.88%.

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