The effect of heating temperature and methods towards the formability of deep drawn square metal cup

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Abstract. Deep drawing operation is one of the most crucial sheet metal forming processes in industrial applications, but it usually requires expensive multi-step production processes, which is necessary in order to produce complex parts. On top of that, room temperature may cause poor formability or failure due to mechanical properties of the material. The objective of this study is to investigate the effects of heating temperature and the most efficient heating position to perform warm square deep drawing operation without failure. Besides that, this study also aims to compare the thickness distribution of drawn cup’s profile obtained from experiment and finite element analysis. A warm formability study of aluminium, mild steel and stainless steel sheet metals are tested by deep drawing experimental methods. The Taguchi approach, which applies L9 orthogonal array, is used to conduct experiments. Different sizes of square blanks are deep drawn at room temperature, 100°C, 150°C and 200°C using three heating techniques, which are heating die only, heating punch only and heating both the die and punch. The results show that warm deep drawing process has more uniform thickness distribution within the square cup profile compared to room temperature condition. Furthermore, maximum thinning condition at the punch corner is noticeably reduced. Lower and upper limit of heating temperature exists, as there is a low and high-temperature failure. Combination of stainless steel with 45 mm blank size, heating temperature of 150°C and die heating technique is optimal in order to obtain uniform thickness distribution in square cup deep drawing process.

1. Introduction
Deep drawing is a forming process where a sheet metal is pushed by a punch into a die cavity and formed into a desired shape such as cup or box like structures. In this operation, a metal blank is placed over a die cavity and held by a blank holder which shown in figure 1. A mechanical action of a punch forces the blank into the forming die involving tensile and compressive forces. It is widely used in numerous industrial fields as it can achieve high production rate. Typical examples of deep drawn components are beverage cans, kitchenware, electrical appliance bodies, aircraft panels and automobile bodies.
However, parts with complex geometries can only be achieved by costly multi-step deep drawing process. One of the methods to solve this problem is to conduct deep drawing process at elevated temperature due to its significant effects on formability of a sheet metal.

Formability of a material can be described by limiting drawing ratio (LDR), which is ratio of the maximum diameter of the workpiece that is drawn without tearing and the diameter of the punch [1]. Many factors that can influence the formability of a material such as characteristics of sheet metal die and punch corner radii, blank holder force, thickness of blank, forming temperature and heating technique. According to Reddy, R. et al. [2], the increment of the wrinkle height can be observed when the small die radius was implemented, whilst for the shorter drawn cup, the wrinkles have a greater amplitude as the die radius increased. Based on curiosity, a further investigation on the formability of deep drawn cup from deep drawing process with a proper design of experiment is needed.

Taguchi approach is one of the designs of experiment methods, which is frequently utilized to determine the effect of parameters on performances in a deep drawing process. Taguchi approach is an effective and standardized method to achieve experimental cost and time savings by omitting some of the possible combinations of parameters in a full factorial design of experiment. Quality of a process can be improved and optimized by determining the best combination of the variables. For example, Colgan & Monaghan [3] aims to determine the vital factors that influence deep drawing process through experimental and finite element analysis (FEA) approach. Therefore, Taguchi method is used in order to specify the runs of the experiment conduct.

Besides that, previous scholars found that the formability of the material expanded by deforming it at higher temperatures [4] [5]. According to Zhang et al. [6], the limiting drawing ratio (LDR) increased significantly when conduct in warm condition compare to room temperature condition. Effects of forming temperature and heating technique in deep drawing process are the parameters, which will be further investigated in this study.

2. Methodology

2.1 Designation of Experiment

The set up for the experimental procedures for warm deep drawing has been shown in figure 2. A single acting hydraulic cylinder is attached to a die set and it is controlled by hydraulic pump as shown in figure 3. On top of that, a temperature controller which shown in figure 4, is used to control the die set temperature while the die set is heated up by heater. A set of type K thermocouple is used to sense temperature and the reading is shown on the controller. The punching force generated from single acting hydraulic cylinder and being control by hydraulic pump. It has 101 kN capacity of force with 105 mm stroke which will press sheet metal downward into die cavity when the process takes place. The material, blank size (mm), temperature (°C), and heating technique has been chosen as experimental parameters in order to analyze the formability of the deep drawn cup which can be refer to table 1. In this study, the Taguchi method has been decided as design of experiment method and implementing L9 orthogonal array which shown in table 2. The experimental works will conducted at room temperature first, and then proceed with warm temperatures (100°C, 150°C, and 200°C).
Table 1. Selected factors and levels for square deep drawing

| Factors             | Level 1 | Level 2 | Level 3 |
|---------------------|---------|---------|---------|
| Material            | Aluminium | Mild steel | Stainless steel |
| Blank size (mm)     | 45      | 50      | 55      |
| Temperature (°C)    | 100     | 150     | 200     |
| Heating techniques  | Die     | Punch   | Die and punch |

Figure 2. Experimental setup

Figure 3. Hydraulic pump

Figure 4. Temperature controller, heater and type K thermocouple


Table 2. L9 Orthogonal array for square deep drawing

| Experiment No. | Material       | Blank size (mm) | Temperature (°C) | Heating Technique |
|----------------|----------------|-----------------|-----------------|------------------|
| 1              | Aluminium      | 45              | 100             | Die              |
| 2              | Aluminium      | 50              | 150             | Punch            |
| 3              | Aluminium      | 55              | 200             | Die and punch    |
| 4              | Mild steel     | 45              | 150             | Die and punch    |
| 5              | Mild steel     | 50              | 200             | Die              |
| 6              | Mild steel     | 55              | 100             | Punch            |
| 7              | Stainless steel| 45              | 200             | Punch            |
| 8              | Stainless steel| 50              | 100             | Die and punch    |
| 9              | Stainless steel| 55              | 150             | Die              |

2.2 Die set and square blanks
Next, the square die set consists of square die and punch as its components. For this particular experiment, the square die has fix height of 35 mm, fix external width and length of 90 mm and 2 mm die corner radius. On the other hand, the square punch has the dimension of 32.5 mm for width and length. Meanwhile, it also has height of 20 mm along with 2 mm punch corner radius. It also equipped with full type blank holder that has thickness of 5 mm along with internal width and length of 34.5 mm. The material used in this research involving aluminium 1050, mild steel and stainless steel 304. Based this material, the square blank is prepared as appeared in figure 5. It has been prepared into three different sizes, which is 45 mm, 50 mm, and 55 mm with 5 mm of blank corner radii.

![Figure 5. Samples of squares blank with different sizes](image)

The formability of the drawn cup will be measured in term of thickness distribution and the most influential parameters will be researched by using ANOVA method. For this purpose, the deep drawn square cup will be dissected into half and the thickness of 24 point along the dissected cup profile will be measured by using Dino-Lite Pro Digital Microscope.

3. Results and Discussion

3.1 Condition of deep drawn square cup
The outcomes of proper drawn cup formation for each experiment are recorded in table 3 for room temperature condition while warm temperature condition being recorded at table 4. Based on observation, most of the drawn cups manage to be drawn successfully without defect. Failed outcomes from room temperature condition happened on second and third experiment as the drawn cup suffers tearing condition. On the other hand, for the experiment that conducted in warm temperature conditions, it shows three failures of deep drawn square cup through the outcome of experiment number 2, 3 and 6.
Table 3. Drawability condition for Aluminium, Mild Steel and Stainless Steel in Deep Drawing at Room Temperature

| Experiment No. | Material       | Blank size (mm) | Temperature (°C) | Heating Technique | Results  |
|----------------|----------------|-----------------|-----------------|------------------|---------|
| 1              | Aluminium      | 45              | Room Temperature| Successful       |         |
| 2              | Aluminium      | 50              | Room Temperature| Failed           |         |
| 3              | Aluminium      | 55              | Room Temperature| Failed           |         |
| 4              | Mild Steel     | 45              | Room Temperature| Successful       |         |
| 5              | Mild Steel     | 50              | Room Temperature| Successful       |         |
| 6              | Mild Steel     | 55              | Room Temperature| Successful       |         |
| 7              | Stainless Steel| 45              | Room Temperature| Successful       |         |
| 8              | Stainless Steel| 50              | Room Temperature| Successful       |         |
| 9              | Stainless Steel| 55              | Room Temperature| Successful       |         |

Table 4. Drawability condition Aluminium, Mild Steel and Stainless Steel in Warm Deep Drawing

| Experiment No. | Material       | Blank size (mm) | Temperature (°C) | Heating Technique | Results  |
|----------------|----------------|-----------------|-----------------|------------------|---------|
| 1              | Aluminium      | 45              | 100             | Die              | Successful |
| 2              | Aluminium      | 50              | 150             | Punch            | Failed    |
| 3              | Aluminium      | 55              | 200             | Die & Punch      | Failed    |
| 4              | Mild Steel     | 45              | 150             | Die & Punch      | Successful |
| 5              | Mild Steel     | 50              | 200             | Die              | Successful |
| 6              | Mild Steel     | 55              | 100             | Punch            | Failed    |
| 7              | Stainless Steel| 45              | 200             | Punch            | Successful |
| 8              | Stainless Steel| 50              | 100             | Die & Punch      | Successful |
| 9              | Stainless Steel| 55              | 150             | Die              | Successful |

3.2 Thickness distribution of deep drawn square cup

Figure 6 illustrates the comparison of thickness measured from cup wall to bottom centre of square aluminium cup with 45 mm blank size in warm deep drawing and deep drawing at room temperature. From the graph, maximum thinning at the punch corner is lower in warm temperature condition compared to deep drawing at room temperature. The numerical descriptive measures are shown in table 5. The results show that the standard deviation of thickness distribution in warm deep drawing is 31.87% lower than deep drawing at room temperature. Maximum thinning is 17.45% less than initial thickness in warm deep drawing and 24.98% less than initial thickness in deep drawing at room temperature.
Table 5. Numerical Descriptive Measures for deep drawn aluminium square cup with 45 mm blank size

| Numerical Descriptive Measures | Aluminium with 45 mm Blank Size |
|-------------------------------|--------------------------------|
|                               | Warm Deep Drawing (100°C; Die) | Deep Drawing at Room Temperature |
| Initial Thickness              | 0.980                          | 1.041                          |
| Mean                           | 0.947                          | 0.972                          |
| Standard Deviation             | 0.062                          | 0.091                          |
| Maximum                        | 1.011                          | 1.041                          |
| Minimum                        | 0.809                          | 0.781                          |
| Range                          | 0.202                          | 0.260                          |

Figure 7 illustrates the comparison of thickness measured from cup wall to bottom centre of square mild steel cup with 45 mm blank size in warm deep drawing and deep drawing at room temperature. The graph shows that maximum thinning at the punch corner in warm deep drawing is about the same as deep drawing at room temperature. However, it can be seen that thickness is more evenly distributed in deep drawing at room temperature. The numerical descriptive measure is shown in table 6. The results show that the standard deviation of thickness distribution in warm deep drawing is 12.99% lower than deep drawing at room temperature. Maximum thinning is 19.31% less than initial thickness in warm deep drawing and 21.32% less than initial thickness in deep drawing at room temperature.
Table 6. Numerical Descriptive Measures for deep drawn square mild steel cup with 45 mm blank size

| Numerical Descriptive Measures | Mild Steel with 45 mm Blank Size |
|-------------------------------|----------------------------------|
|                               | Warm Deep Drawing (150°C; Die & Punch) | Deep Drawing at Room Temperature |
| Initial Thickness             | 0.979                              | 0.999                              |
| Mean                          | 0.921                              | 0.987                              |
| Standard Deviation            | 0.067                              | 0.077                              |
| Maximum                       | 0.980                              | 1.208                              |
| Minimum                       | 0.790                              | 0.786                              |
| Range                         | 0.190                              | 0.422                              |

Figure 8 illustrates the comparison of thickness measured from cup wall to bottom centre of square mild steel with 50 mm blank size in warm deep drawing and deep drawing at room temperature. Both graphs exhibit identical trend of data. The numerical descriptive measure is shown in table 7. The results show that the standard deviation of thickness distribution in warm deep drawing is 8.00% lower than deep drawing at room temperature. Maximum thinning is 28.79% less than initial thickness in warm deep drawing and 28.40% less than initial thickness in deep drawing at room temperature.
Figure 9 illustrates the comparison of thickness measured from cup wall to bottom centre of square stainless steel with 45 mm blank size in warm deep drawing and deep drawing at room temperature. From the graph, it can be seen that maximum thinning at the punch corner is lower in warm deep drawing as compared to deep drawing at room temperature. The numerical descriptive measure is shown in table 8. The results show that the standard deviation of thickness distribution in warm deep drawing is 16.05% lower than deep drawing at room temperature. Maximum thinning is 18.28% less than initial thickness in warm deep drawing and 25.08% less than initial thickness in deep drawing at room temperature.
Table 8. Numerical Descriptive Measures for deep drawn square stainless steel cup with 45 mm blank size

| Numerical Descriptive Measures | Stainless Steel with 45mm Blank Size |
|--------------------------------|-------------------------------------|
|                                | Warm Deep Drawing (200°C; Punch)    | Deep Drawing at Room Temperature |
| Initial Thickness              | 0.952                               | 0.997                             |
| Mean                           | 0.935                               | 0.954                             |
| Standard Deviation             | 0.068                               | 0.081                             |
| Maximum                        | 1.042                               | 1.065                             |
| Minimum                        | 0.778                               | 0.747                             |
| Range                          | 0.264                               | 0.318                             |

Figure 10 illustrates the comparison of thickness measured from cup wall to bottom centre of square stainless steel with 50 mm blank size in warm deep drawing and deep drawing at room temperature. From the graph, maximum thinning at punch corner is higher in warm deep drawing as compared to deep drawing at room temperature. The numerical descriptive measures are shown in table 9. The results show that the standard deviation of thickness distribution in warm deep drawing is 30.99% higher deep drawing at room temperature. Maximum thinning is 28.86% less than initial thickness in warm deep drawing and 21.84% less than initial thickness in deep drawing at room temperature.
Table 9. Numerical Descriptive Measures for deep drawn square stainless steel cup with 50 mm blank size

| Numerical Descriptive Measures | Stainless Steel with 50mm Blank Size |
|-------------------------------|-------------------------------------|
|                              | Warm Deep Drawing (100°C; Die & Punch) | Deep Drawing at Room Temperature |
| Initial Thickness             | 0.998                               | 0.998                              |
| Mean                          | 0.901                               | 0.953                              |
| Standard Deviation            | 0.093                               | 0.071                              |
| Maximum                       | 1.011                               | 1.039                              |
| Minimum                       | 0.710                               | 0.780                              |
| Range                         | 0.301                               | 0.259                              |

Figure 11 illustrates the comparison of thickness measured from cup wall to bottom centre of square stainless steel with 55mm blank size in warm deep drawing and deep drawing at room temperature. The graph shows that maximum thinning at punch corner is lower in warm deep drawing as compared to deep drawing at room temperature. The numerical descriptive measures are shown in table 10. The results show that the standard deviation of thickness distribution in warm deep drawing is 6.76% lower than deep drawing at room temperature. Maximum thinning is 21.32% less than initial thickness in warm deep drawing and 24.23% less than initial thickness in deep drawing at room temperature.
Maximum thinning occurs at the punch corner because of high stress concentration in this region. The material at this region will first undergo bending around the die radius, then unbending when it is being drawn against the wall of the die under tensile stress and finally bending around the punch corner in the opposite direction. Therefore, the punch corner is the most critical region as severe thinning can lead to fracture of the cup [7].

Thinning occurs at the centre of the cup wall in the deep drawing of square cup in both warm deep drawing and deep drawing at room temperature. Thinning at this region occurs due to the small die radius. Material is not easily to flow over a small die radius and it is highly stressed. As the die radius goes smaller, the greater the force on the blank, which leads to a thinner wall thickness [8].

On the other hand, the square cups are not fully deformed due to restriction in the height of the punch based on observation. The material cannot be fully drawn into the die cavity which causes incomplete flow of the material. Thereby, thickness is not well distributed in the cup.

Table 10. Numerical Descriptive Measures for deep drawn square stainless steel cup with 55 mm blank size

| Numerical Descriptive Measures | Stainless Steel with 55mm Blank Size |
|-------------------------------|-------------------------------------|
|                               | Warm Deep Drawing (150°C; Die)      | Deep Drawing at Room Temperature |
| Initial Thickness              | 1.013                               | 0.978                              |
| Mean                           | 0.960                               | 0.906                              |
| Standard Deviation             | 0.069                               | 0.074                              |
| Maximum                        | 1.021                               | 0.990                              |
| Minimum                        | 0.797                               | 0.741                              |
| Range                          | 0.224                               | 0.249                              |
Table 11 shows the analysis on thickness distribution in square deep drawing. It shows that, during the warm deep drawing of aluminium with 45 mm blank size, mild steel with 45 mm and 50 mm blank size as well as stainless steel with 45 mm and 55 mm blank size, there is an improvement in the standard deviation when compared to deep drawn cup at room temperature. Thickness is more uniformly distributed in these experiments and the percentage of maximum thinning also reduced compared to deep drawn cup at room temperature. These results prove that thickness distribution and thinning condition at the punch corner can be improved by warm deep drawing under certain heating condition [9].

However, in the warm deep drawing of stainless steel with 50 mm blank size, the value of standard deviation is higher than deep drawing at room temperature. Moreover, the value of percentage of maximum thinning at warm temperature condition is higher compared to room temperature condition. This indicates that thickness is unevenly distributed and the maximum thinning condition at the punch corner is not improved by warm deep drawing. The low heating temperature (100°C) is insufficient to impart uniform temperature distribution within the stainless steel blank which has a low thermal conductivity. On top of that, the both die and punch heating technique also influences this outcome. Based on previous works, it been proven that partial heating in the holder or matrices area was much better when compared with the homogeneously heated tools [10].

| Material     | Size (mm) | Temperature and Heating Technique | Improvement in Standard Deviation (%) | Maximum thinning in warm deep drawing (%) | Maximum thinning in deep drawing at room temperature (%) |
|--------------|-----------|-----------------------------------|---------------------------------------|------------------------------------------|--------------------------------------------------------|
| Aluminium    | 45        | 100°C; Die                        | 31.87                                 | 17.45                                   | 24.98                                                  |
|              | 50        | 150°C; Punch                      | N/A                                   | N/A                                     | N/A                                                    |
|              | 55        | 200°C; Die & Punch                | N/A                                   | N/A                                     | N/A                                                    |
| Mild Steel   | 45        | 150°C; Die & Punch                | 12.99                                 | 19.31                                   | 21.32                                                  |
|              | 50        | 200°C; Die                        | 8.00                                  | 28.79                                   | 28.40                                                  |
|              | 55        | 100°C; Punch                      | N/A                                   | N/A                                     | N/A                                                    |
| Stainless Steel | 45   | 200°C; Punch                      | 16.05                                 | 18.28                                   | 25.08                                                  |
|              | 50        | 100°C; Die & Punch                | -30.99                                | 28.86                                   | 21.84                                                  |
|              | 55        | 150°C; Die                        | 6.76                                  | 21.32                                   | 24.23                                                  |

3.3 Analysis of Variance (ANOVA) and Analysis of Means (ANOM) for deep drawn square cup

The quality characteristic in this experimental study using Taguchi approach is thickness distribution. As the results are desired to be a uniform thickness distribution, quality characteristic is of the nominal-the-best type. The nominal-the-best S/N ratios on thickness distribution are calculated based on equation (1). Table 12 shows the results of ANOVA for square cup. The level mean S/N ratio is the average S/N ratio at each level of the process parameters.

\[
\frac{S}{N} = 10 \log_{10} \left( \frac{\bar{Y}}{\sigma^2} \right)
\]
### Table 12. ANOVA results for four parameters tested at three levels

| Parameter          | Level | Experiment No. | S/N | Level Mean S/N |
|--------------------|-------|----------------|-----|---------------|
| Material           | 1     | 1              | 23.698 | 5.892       |
|                    |       | 2              | -3.010 |             |
|                    |       | 3              | -3.010 |             |
|                    | 2     | 4              | 22.772 |             |
|                    |       | 5              | 19.739 | 13.167      |
|                    |       | 6              | -3.010 |             |
|                    | 3     | 7              | 22.823 |             |
|                    |       | 8              | 19.713 | 21.802      |
|                    |       | 9              | 22.872 |             |
| Blank Size         | 1     | 1              | 23.698 |             |
|                    |       | 4              | 22.772 | 23.097      |
|                    |       | 7              | 22.823 |             |
|                    | 2     | 2              | -3.010 |             |
|                    |       | 5              | 19.739 | 12.147      |
|                    |       | 8              | 19.713 |             |
|                    | 3     | 3              | -3.010 |             |
|                    |       | 6              | -3.010 | 5.617       |
|                    |       | 9              | 22.872 |             |
| Heating Temperature| 1     | 1              | 23.698 |             |
|                    |       | 6              | -3.010 | 13.467      |
|                    |       | 8              | 19.713 |             |
|                    | 2     | 2              | -3.010 |             |
|                    |       | 4              | 22.772 | 14.211      |
|                    |       | 9              | 22.872 |             |
|                    | 3     | 3              | -3.010 |             |
|                    |       | 5              | 19.739 | 13.184      |
|                    |       | 7              | 22.823 |             |
| Heating Technique  | 1     | 1              | 23.698 |             |
|                    |       | 5              | 19.739 | 22.103      |
|                    |       | 9              | 22.872 |             |
|                    | 2     | 2              | -3.010 |             |
|                    |       | 6              | -3.010 | 5.617       |
|                    |       | 7              | 22.823 |             |
|                    | 3     | 3              | -3.010 |             |
|                    |       | 4              | 22.772 | 13.158      |
|                    |       | 8              | 19.713 |             |

Applying equation (2), the sum of squares due to the variation from the average S/N ratio for the $y^{th}$ factor, $SSy$ can be calculated. Applying equation (3) and equation (4), the percentage of contribution of $y^{th}$ factor can be obtained. The contribution of process parameters on warm deep drawing process are shown in table 13.
\[ SS_y = \sum_{i=1}^{n} \left[ \left( \frac{S}{N} \right)_{yz} - \left( \frac{S}{N} \right) \right] \]  \hspace{1cm} (2)

\[ SS_T = \sum_{i=1}^{n} \left[ \left( \frac{S}{N} \right)_{yi} - \left( \frac{S}{N} \right) \right]^2 \]  \hspace{1cm} (3)

Percentage of contribution of \( y \) parameter \[ \frac{SS_y}{SS_T} \times 100\% \]  \hspace{1cm} (4)

Table 13. Contribution of Process Parameters on Warm Deep Drawing Process

| Process Parameter    | Sum of Square, \( SS_y \) | % of Contribution |
|----------------------|-----------------------------|-------------------|
| Material             | 126.874                     | 30.2%             |
| Blank Size (mm)      | 156.038                     | 37.2%             |
| Heating Temperature (°C) | 0.564                     | 0.1%              |
| Heating Technique    | 136.480                     | 32.5%             |

Figure 12 illustrates the plots of level average values of material, blank size, heating temperature and heating technique. The optimum levels of the three process parameters are analysed through ANOM and presented in Table 14.

Table 14. Optimal Condition for Warm Deep Drawing

| Factor                | Level Description | Level |
|-----------------------|-------------------|-------|
| Material              | Stainless Steel   | 3     |
| Blank Size (mm)       | 45                | 1     |
| Heating Temperature (°C) | 150               | 2     |
| Heating Technique     | Die               | 1     |
The ANOVA results shown in table 13 indicates the degrees of importance of each process parameter considered, namely, material, blank size, heating temperature and heating technique. It shows how the process parameters affect the thickness of the square cup in warm deep drawing. Blank size has the greatest influence (37.2%) on the thickness of the square cup, followed by heating technique (32.5%), material (30.2%) and heating temperature (0.1%).

Optimum condition for a uniform thickness distribution of square cup can be obtained through ANOM. The level which provides the greatest S/N ratio in process parameters is known as optimal level for that factor. Combination of stainless steel with blank size 45 mm, heating temperature of 150°C and die heating technique is optimal in order to obtain uniform thickness distribution of square cup.

4. Conclusion
In order to investigate the warm formability of aluminium, mild steel and stainless steel sheet metals were going through deep drawing experimental methods. The outcomes of the experiments such as, the relationship between thickness distribution of cup’s wall and heating temperature and method were discussed. Therefore, the important conclusions that can be highlighted from the study were as follows:

1. In square deep drawing process, the results of thickness distribution show that in certain heating condition, thickness is more uniformly distributed within the round and square cup and the maximum thinning at the punch corner is reduced when compared to deep drawing at room temperature.
2. For square deep drawn cup, there was no improvement in thickness distribution and thinning condition when low heating temperature is applied shows that lower limit of heating temperature exists. At low heating temperature, uneven distribution of temperature within the blank occurs due to short heating duration and low thermal conductivity of the material such as stainless steel and mild steel, which lead to uneven deformation of the blank.
3. The ANOVA results show that blank size has the greatest influence (37.2%) on the thickness of the square cup, followed by heating technique (32.5%), material (30.2%) and heating temperature (0.1%). Meanwhile, ANOM results show that combination of stainless steel with blank size 45mm, heating temperature of 150°C and die heating technique is optimal in order to obtain uniform thickness distribution of square cup.

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References
[1] D Banabic 2010 Sheet Metal Forming Processes: Constitutive Modelling and Numerical Simulation.
[2] D G C M R Reddy, R Venkat, Dr T A Janardhan Reddy 2012 Int. J. Eng. Trends Technol. 3 53–58
[3] M Colgan and J Monaghan 2003 J. Mater. Process. Technol. 132 35–41
[4] R K Desu, S K Singh, and A K Gupta 2015 Int. J. Adv. Manuf. Technol. 11
[5] Y W Lean and M Azuddin 2016 IOP Conf. Ser. Mater. Sci. Eng. 114 12009
[6] K F Zhang, D L Yin, and D Z Wu 2006 Int. J. Mach. Tools Manuf. 46 1276–1280
[7] Z C Zhang, Y C Xu, and S J Yuan 2016 Trans. Nonferrous Met. Soc. China (English Ed.) 26 1538–1545
[8] F K Chen, T B Huang, and C K Chang 2003 Int. J. Mach. Tools Manuf. 43 1553–1559
[9] Y Moon, Y Kang, J Park, and S Gong 2001 Int. J. Mach. Tools Manuf. 41 1283–1294
[10] J Winklhofer, G Trattnig, C Lind, C Sommitsch, and H Feuerhuber 2010 AIP Conf. Proc. 1252 927–934