# EFFECT OF DRAW BEAD GEOMETRY AND APPLIED FORCE TO DRAWING OF ALUMINIUM AA6061

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## List of Abbreviations

| Abbreviations | Descriptions |
|---|---|
| UTM | Universal Testing Machine |
| FEM | Finite Element Method |
| DBRF | Draw Bead Restraining Force |
| CAD | Computer Aided Design |

## Abstrak

Dalam tesis ini, kesan radius drawbead dan kuasa beban drawbead telah disiasatkan. Kesan telah dikaji dengan membandingkan dengan mengukur kuasa penahan yang dijanakan oleh drawbead dalam keadaan radius drawbead and kuasa beban drawbead yang tidak sama. Bahan yang dipilih sebagai specimen adalah aluminium AA6061. Drawbead unik membolehkan tukaran radius dan jig ujian dengan mekanisme yang menghasilkan beban telah direkabentuk dan dihasilkan. Jig dan drawbead akan dipasang pada Universal Testing Machine (UTM) untuk menjalankan eksperimen. Fungsi UTM adalah untuk menarik spesimen melalui drawbead dan mengukur daya penahan yang dihasilkan oleh drawbead semasa operasi menarik. Tiga jenis radius drawbead (5mm, 6mm dan 7mm) dan tiga beban drawbead yang berbeza digunakan untuk kajian. Keputusan telah menunjukkan bahawa lebih tinggi beban drawbead yang digunakan untuk menarik manik, lebih tinggi daya penahan yang akan dihasilkan. Manakala radius drawbead 6mm akan menjana kuasa penahan tertinggi dan sebarang kenaikan atau penurunan radius akan mengurangkan daya penahan yang dijanakan. Kemungkinan yang tinggi bahawa 5mm 4.5Nm dan 6mm 4.5Nm akan memutuskan specimen.

## Abstract

In this thesis, the effect of draw bead radius and draw bead apply force are being investigated. The effect are being study and compare by measuring the restraining force generated by draw bead under different setting of draw bead radius and apply force. The material selected as specimen are aluminium AA6061. A specific draw bead with exchangeable male draw bead and a test jig with force apply mechanism are being design and fabricated. The test jig and draw bead are then being install on Universal Testing Machine (UTM) to perform the experiment. The UTM function to perform pulling of specimen through draw bead and measure the restraining force generated by draw bead during the pulling operation. Three different draw bead radius (5mm, 6mm and 7mm) and three different torque are being apply to force apply mechanism to produce three different force for testing. The results shows that as higher force being apply to draw bead, higher restraining force will be generated. While 6mm draw bead radius will generate highest restraining force and any further increase or decrease in radius will decrease restraining force generated. Results also shows that high possibility of specimen fracture at setting of 5mm radius 4.5Nm torque and 6mm radius 4.5Nm torque.

# Chapter 1 Introduction

## 1.1 Introduction draw bead and deep drawing

Sheet metal forming processes are important manufacturing process for current modern world industrial manufacturing sector. It is predict that there will a 7% growth in sheet metal industry employment from year 2014 to year 2024. This is equivalent to 9400 job opening in a decade.[1] Sheet metal forming allows the production of intricate sheet metal part at a relatively low manufacturing cost. It is capable of manufacturing product form small sizes product such as metal fancy good over car body elements to big structural element of air crafts.[2] Sheet metal forming is manufacturing process where the sheet metal is being exerted with huge force and experience large plastic deformation transforming it into product of desired shape and geometry.[3]

One of the common sheet metal forming process would be deep drawing. Deep Drawing is the process where sheet metal is being produce into hollow container usually from round shape sheet metal. The process involve using a punch to exert pressure on the center of a circular metal sheet and compress into a die opening of required shape. In a more formal word, deep drawing can be define as by combining both tensile and compression deformation on sheet metal to form a hollow body.[3]

Among the most popular product manufacture by deep drawing process would be aluminium can. Each year, over 200 billion of aluminium can have been manufactured and consumed worldwide. The huge demand of sheet metal product from deep drawing process cause a necessity to fully gain complete control on this metal forming process. First of all, there are three major defect which might occur during deep drawing process fracture, wrinkling and earing. Fracture usually occurs around punch corner where maximum forming load and stress line concentrate in this region causing the strain in this region to exceed the safe strain limit of the material. Wrinkling occurs on the flange of the product when the circumferential compression force becomes unstable or insufficient blanking force. Lastly, earing caused by planar anisotropy of the blank material and results in uneven top edge.[3]

There numerous factor affecting the quality of product form by deep drawing process. One of the factor could be access and easily control would be draw bead. Draw bead are used to control the flow of metal flow into the die cavity and punch of a draw die. It is a small rib like tools which usually install on blank holder. It force the metal sheet to get bend and unbend before entering the die cavity. It generate a restriction that will cause the metal to flow into the die cavity at a slower rate and less volume.[4] Besides, defect such as wrinkles could also be avoided by using draw bead. The bend and unbend motion caused by draw bead would increase the radial tensile stress acting on the metal sheet which is flowing into the die cavity and thus reducing the possibility of wrinkles.[3]

Optimum utilization of draw bead could help to obtain the most desirable outcome of product. However, it is difficult to controlling effect of draw bead without full understand of draw bead. Experiment will be carried out on different geometry of draw bead such as height of draw bead and corner radius of draw bead to study the effect of this geometry on the needed force to be applied on the sheet metal and the occurrence of defect. By changing on the geometry of the draw bead, the friction acting on the sheet metal will also change accordingly. Altering the friction acting the sheet metal will generate different restriction force which in turn causing different material flow rate. Therefore, by understand the effect of different geometry of draw bead, we could control the restriction force, the speed of metal flowing into die cavity, volume of material flow and others factor. Thus, combining the most suitable geometry to obtain a desirable outcome.

## 1.2 Research background

In this era of globalization, productivity on doubt is one of the main concern in manufacturing industry. High productivity of a factory will contribute to higher competitiveness and lead to higher profit margin for the company. However, producing defects product will definitely bring down the productivity of a factory. But in order to reduce the defect rate and producing desire product, the manufacturing process had to be studies and understand thoroughly. Therefore, it is important to investigate the factor affecting manufacturing process and ways to control these factors.

Among all metalworking process, deep drawing process serve an important role in mass production of hollow box like container at low cost. Deep drawing is a secondary forming process where the output product is produced from a thin disc of sheet metal by subjecting it to a compressive force through a circular punch.[5] Based on Aleksandrovic et al. in [6,7], there are two factors which could be controlled in deep drawing process would be contact pressure on the flange and draw bead height. Therefore, draw bead clearly plays an important role in controlling the quality of product formed.

During deep drawing process, draw bead forces the sheet metal to bend and unbend before entering the die cavity, thus creating restriction force to lower the flow of material. The geometry of draw bead directly affecting the restriction force created which in turn affect the load needed to be applied on the metal blank. Therefore, the effect of different draw bead geometry would be another factor needed to be investigated.

In short, draw bead is effective tools in controlling deep drawing process. It help prevent common defect from occurring and help to produce desired output product of deep drawing process. But in order to use this powerful tools, experiment had to be done to master the effect of the draw bead geometry and draw bead height.

## 1.3 Problem Statement

Deep drawing is an important metal sheet manufacturing process which primarily used industrially to produce cup shape or box shaped product. One of the main factor affecting the quality of product produce from deep drawing process would be the use of draw bead. By optimizing the use of draw bead, flow of material during deep drawing process can be controlled and defect such as crack and wrinkles can be avoided. But without proper understanding on factor affecting the function of draw bead and how these factor affect the draw bead functionality, optimizing the use of draw bead in deep drawing process would be a problem

## 1.4 Objective

- To study the effect of draw bead part geometry to restraining force acting on blank.

- To study the effect of normal forces applied to draw bead to restraining force acting on blank.

## 1.5 Scope of research

A draw bead test rig with exchangeable part geometry will be design and fabricated. The draw bead will used to study the effect of different part geometry to load and occurrence of defect. The experiment will be conducted by using an aluminium strip insert between the draw bead and clamp to a universal testing machine. The universal testing machine be used to obtain data of load applied to aluminium strip under two condition different draw bead geometry and different load applied to the draw bead. The result will be analyze.

# Chapter 2 Literature Review

## 2.1 Draw bead profile

Draw beads are generally shape as rib like projection with a half round head and will usually be located on the binder surface or the die surface and mounted on it.[8]

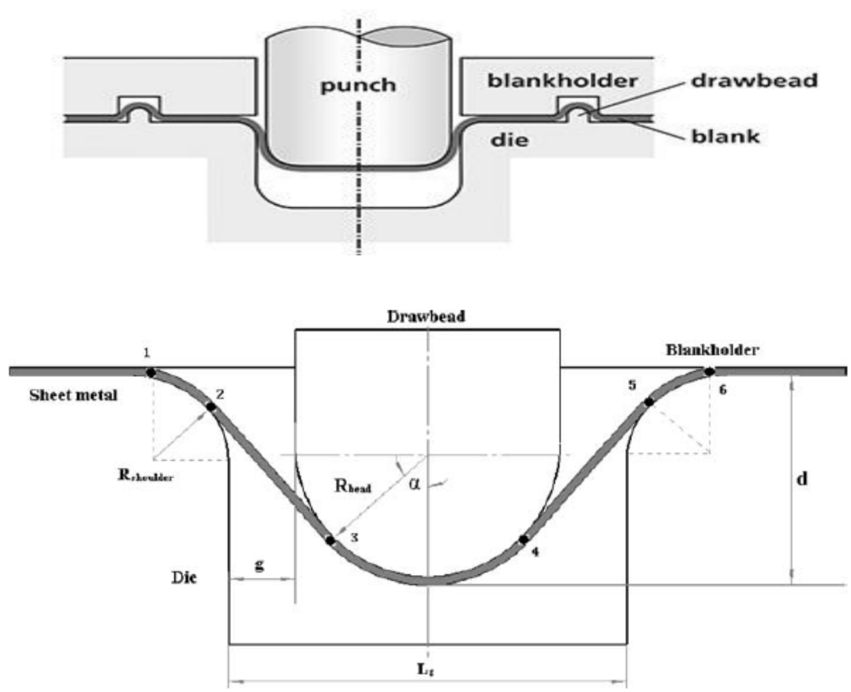


Figure 2-1: (A) draw bead location [8] (b) draw bead shape profile [9]

Figure 2.1(a) shows the general location of a draw bead during deep drawing process. From the figure, it can be clearly see that the draw bead is location on the die surface with curtain distance from the punch.

Figure 1(b) shows the general profile of a draw bead. *d* is penetration of the draw bead to the blank, $R_{shoulder}$ is radius of the groove, *t* thickness of blank, $R_{bead}$ is radius of the drawbead, and *g* gap between drawbead and groove. These are common parameters to be consider when designing a draw bead. [9]

## 2.2 Effect of draw bead height

Height of the draw bead is a critical factor of draw bead. The height of draw bead will affect the friction generated between draw bead and the blank. Which then affect the restraining force produce and affecting the material flow rate. Defect such as earing occurs due to some part of the sheet metal blank flow unevenly in from different direction into the die cavity.[10] Sufficient restraining force produce by draw bead could effectively reduce the defect.[11] Therefore, effect of draw bead height is being tested by experimental method.

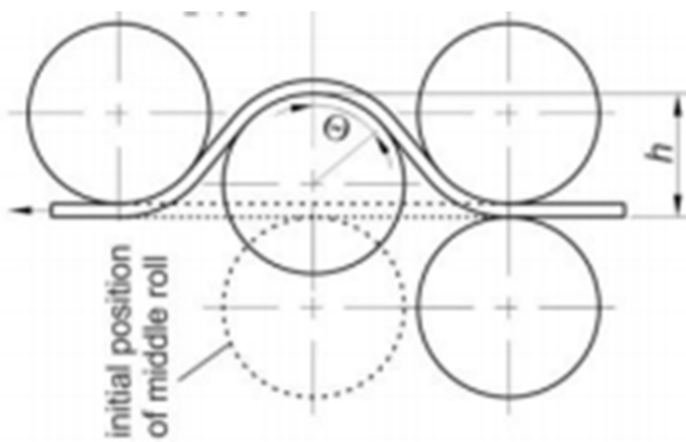


Figure 2-2 : set up of draw bead for testing

The model for performing experiment is as shown in figure 2.2. The *h* in the figure represent the height of the draw bead and the middle roller resemble the draw bead. During the test, *h* is being carried out in many different value.

The test was carried out with middle roll displacement, *h* of 6mm, 12mm, and 18mm respectively. While for each displacement *h*, three different width of metal strip, 7mm, 14mm, and 20mm are being used for testing for pull force required which then used to calculate friction coefficient for each different condition. Friction force created by draw bead is proportion to normal force of the draw bead on the blank. The coefficient of proportionality between friction force and normal force would be coefficient of friction.[12]

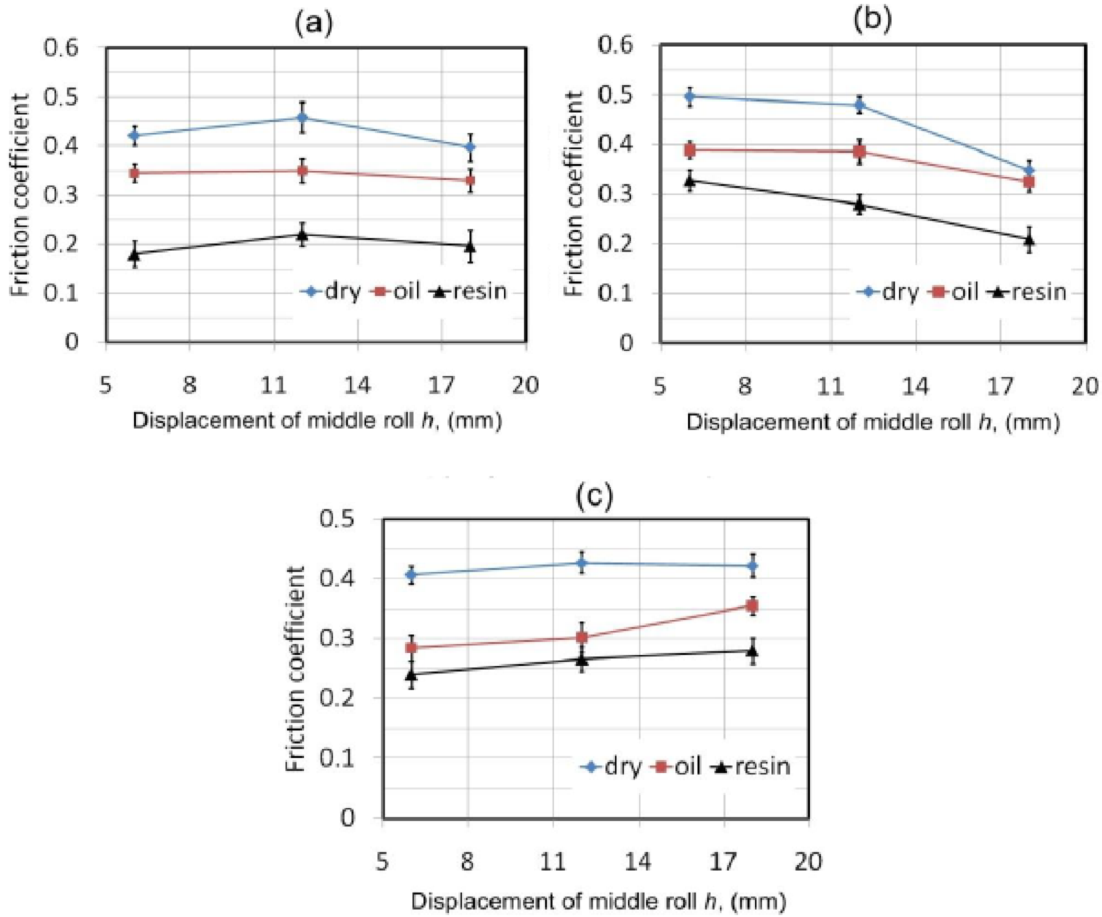


Figure 2-3: Effect of displacement of the middle roll on the value of the friction coefficient determined for sample widths: (a) 7, (b) 14, and (c) 20 mm

In figure 2.3 show the results of friction coefficient of draw bead against height of draw bead in graph method. The result for 7mm width of strip shows that 12mm displacement *h*, cause highest friction coefficient. While test for 14mm strip shows that increase in displacement causes decrease in friction coefficient. Lastly 20mm strip result shows that displacement *h* causes less effect on friction coefficient. [13]

Besides the study above, there is another study by Thipprakmas on effects of part geometry on wall features in rectangular deep drawing processes using FEM [7]. In this study the effect of draw bead height on the concave/convex wall features was being investigated through FEM method. The results of the study shows that as the height of draw bead increases, it will decrease in concave wall feature. This is due to the increase in difficulties for material flow as height of draw bead increase causing decreasing in tensile stress in direction of punch movement and increase in tensile stress distribution to corner zone. This type of stress distribution will results in decrease in concave wall feature.[7]

## 2.3 Effect of location of draw bead

Location of draw bead means the distance of draw bead from the center of die cavity. This distance will affect the outcome of the process. A study by Murali et al had been made on the Influence of Draw Bead Location and Profile in Hemispherical Cup Forming [14] through FEM simulation. In the simulation, the location of draw bead is being set at different distance from the center of the die cavity and the two draw bead rectangular and circular shape are being tested.

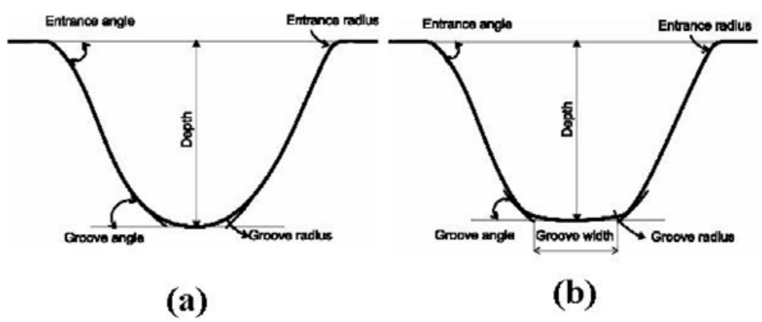


Figure 2-4: Profiles of Circular (a) and Rectangular (b) draw beads

Figure above shows the profile of circular draw bead and rectangular draw bead that are going to under goes simulation test. The effect of location of draw bead on effective strain, Von-misses stress and thickness of product are being investigated. Von-misses stress is used to determine whether a material will continue to yield or fracture. If Von-misses stress of a material under load is equal or greater than yield limit of that material under tension, then the material will yield. [15]

The simulation had been repeated by locating the draw bead at distance 62mm to 67mm from the center of the die cavity.

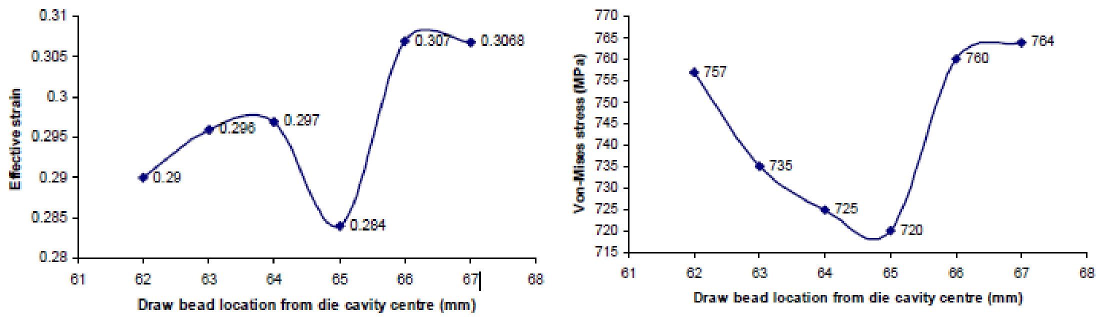


Figure 2-5: (a) Graph of effective strain against location draw bead from die cavity cantre
(b) Graph of Von-mises stress against location of draw bead from die cavity cantre

The results above shows that the effective strain increases from distance 62mm to 64mm and drop drastically at 65mm before raising again until 67mm. While the results for Von-misses stress shows that Von-misses stress decrease as distance increase from 62cm to 65cm but increases after 65cm. From this, 65cm is concluded as the optimum distance from the center of die cavity since effective strain is minimum, Von-Mises stress is minimum and thickness is maximum.[14] Experimental test had been conducted to justify the result. The press tool being used in the experimental test was designed according to standard press tool design procedure.[16]

Another study by Mohamed et al was done about numerical design optimization of draw bead position and experimental validation of cup drawing process. [17] This stud focus on effect of position of draw bead to the thinning and strain distribution of formed parts. This simulation test was carried out using rectangular draw bead and from distance 62mm to 68mm.

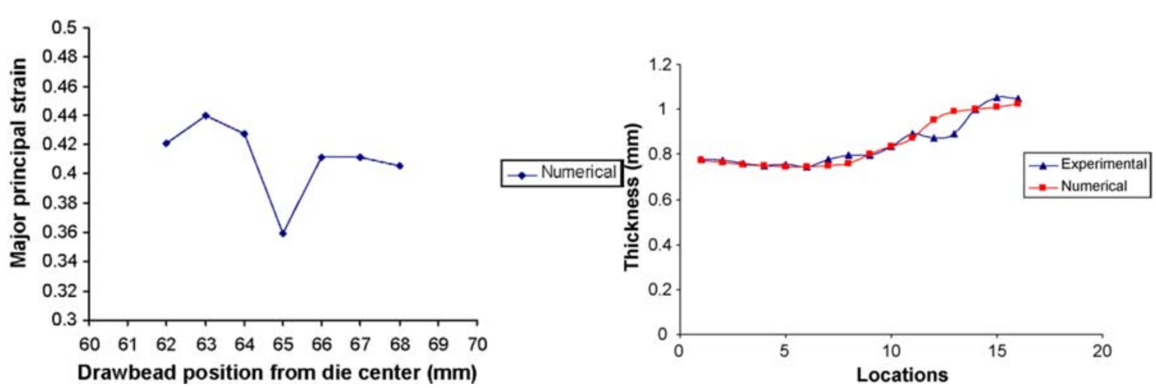

Figure 2-6: (a) Graph of Major principle strain against location draw bead
(b) thickness of product measure from center of product

From the results in figure 2.6 above, the result of principle strain exhibit same trend as the result in study done by by Murali, Gopal and Rajadurai. Distance 65mm from center of die would be best location to place the draw bead as it will result in lowest principle strain. While results of thickness distriubtion shows that as the further form the center of outcome product, the thicker it becomes. Both numerical simulation and experimental result shows the same trend.

## 2.4 Improved equivalent draw bead based on draw bead restraining force

Draw bead had been design and function to provide restraining force on the blank during deep drawing process. Providing optimum restraining force to prevent defect product had been the ideal function of every draw bead. Draw bead restraining force is a combination bending force as blank bend and unbend through the draw bead and friction force cause by the draw bead. [18] A finite element simulation study had been made to obtain correct different draw bead part geometries that will combine together and generate the required draw bead restraining force (DBRF). The figure below shows the label of geometry of draw bead.

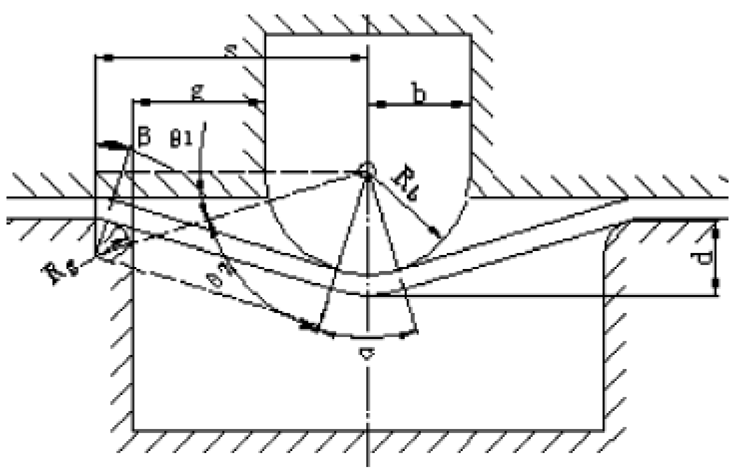


Figure 2-7: geometries of draw bead

The simulation was first done to obtain find out the suitable DBRF for a chosen product. The product is make sure to be perfect under this restraining force. After that, the bead radius (*Rb*), the groove shoulder radius (*Rg*) and the pressing depth (*d*) which are geometries of draw bead are being manipulated to obtain perfect combination to provide optimum DBRF. Table below show the optimization results of the draw bead geometry.[19]

Table 2-1: optimization results of the draw bead geometry

| DBRF (N/mm) | Rb (mm) | Rg (mm) | D (mm) |
|---|---|---|---|
| 118 | 5.71 | 3.99 | 7.34 |
| 65 | 6.06 | 4.05 | 6.13 |
| 40 | 6.51 | 4.86 | 4.45 |
| 25 | 7.28 | 5.11 | 3.64 |
| 6 | 10.00 | 5.00 | 2.00 |

Table 2.1 shows the combination different setting of bead radius (*Rb*), the groove shoulder radius (*Rg*) and the pressing depth (*d*) to achieve a desire draw bead restraining force of 118N/mm, 65 N/mm, 40 N/mm, 25 N/mm and 6 N/mm.

Other than the above study. Bae et al carried out a study on simulation-based prediction model of the draw-bead restraining force. [20] The model is constructed with Box-Behnken design are experimental designs used to generate higher order response surfaces using fewer required runs than a normal factorial technique.[21,22] Response surface methodology investigate the correlation between several explanatory variables and response variables.[23]

In this study, a circular draw bead was being selected for simulation to develop a predication model for draw bead restraining force (DBRF). The draw bead parameters such as bead height, shoulder radius and blank thickness are variables used to construct the simulation model.

Table 2-2: Range for design parameter of draw bead

| Range of design variables | | | |
|---|---|---|---|
| Design parameter | Bead height (h) | Shoulder radius (Rs) | Sheet thickness (t) |
| Range (mm) | 2 - 6 | 3 - 5 | 0.6 - 1.2 |

Table 2.2 show the range for parameters which was used to in simulation for prediction model. Finite element analysis were carried out for each design case. DBRF for each design case was measured with average value of the reading after the force reaches steady state.

Table 2-3: DBRF results measured for each design case

| Design | $h$ (mm) | $R_s$ (mm) | $t$ (mm) | DBRF (N/mm) |
|---|---|---|---|---|
| 1 | 4.0 | 3.0 | 0.6 | 103.81 |
| 2 | 4.0 | 5.0 | 0.6 | 75.28 |
| 3 | 4.0 | 3.0 | 1.2 | 303.92 |
| 4 | 4.0 | 5.0 | 1.2 | 239.53 |
| 5 | 2.0 | 4.0 | 0.6 | 76.16 |
| 6 | 6.0 | 4.0 | 0.6 | 88.21 |
| 7 | 2.0 | 4.0 | 1.2 | 212.58 |
| 8 | 6.0 | 4.0 | 1.2 | 281.64 |
| 9 | 2.0 | 3.0 | 0.9 | 155.61 |
| 10 | 6.0 | 3.0 | 0.9 | 208.13 |
| 11 | 2.0 | 5.0 | 0.9 | 126.62 |
| 12 | 6.0 | 5.0 | 0.9 | 154.00 |
| 13 | 4.0 | 4.0 | 0.9 | 168.72 |

$$DBRF\ (N\ mm^{-1}) = -26.93 + 24.87h - 15.98Rs + 159.09t - 314hRs + 23.75ht - 29.89Rs\ t - 2.95\ h^2 \ + 4.18R_s^2 + 85.95t^2$$

Formula 2.1: Formula for prediction model

Table 2.3 shows the simulation results of DBRF for different combination of design parameters based on Box-Behnken design. Formula 2.1 is used for construction of prediction model of DBRF for draw bead. The regression prediction model shows a correlation coefficient of 0.9977 with the simulation results.[20] Which means that the regression prediction model can be used to predict the DBRF of draw bead accurately.

## 2.5 Draw bead reduction strategy

Draw bead is a useful assisting tool for deep drawing process. But draw bead parameters must be set correctly to achieve a desire output. Current automotive industry uses manual optimization to obtain an optimum design of draw bead.[24] This method require complete 3D CAD modeling draw bead of different geometry for different simulation. Multiple 3D modeling of draw bead consume time.

A more efficient method call advanced adaptive line bead model can now be used to obtain a optimize draw bead. Unlike other simulation which require 3D modeling of draw bead, this method only required define of draw bead geometry profile.

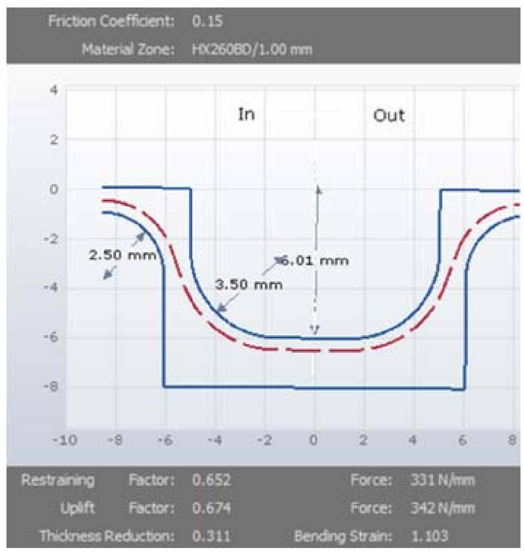


Figure 2-8 : construction of draw bead geometry profile for simulation

The above figure 2.8 shows the constructed adaptive line bead model. During the simulation process, the adaptive line bead estimates the restraining force on the sheet metal as if material were sliding through the bead profile.[25] But still like conventional ways of optimizing draw bead, multiple iteration of trial and error is needed to obtain a suitable draw bead. This is where draw bead reduction strategy comes in for use. The reduction strategy defines the order, the measures and the ranges in which draw bead geometries are simultaneously modified, including bead height, bead radius or groove radius.[26] Combination of draw bead reduction strategy and adaptive draw bead, potential combination of draw bead geometry can be known as strength of draw bead is reduced. Below shows sample of a draw bead reduction example.

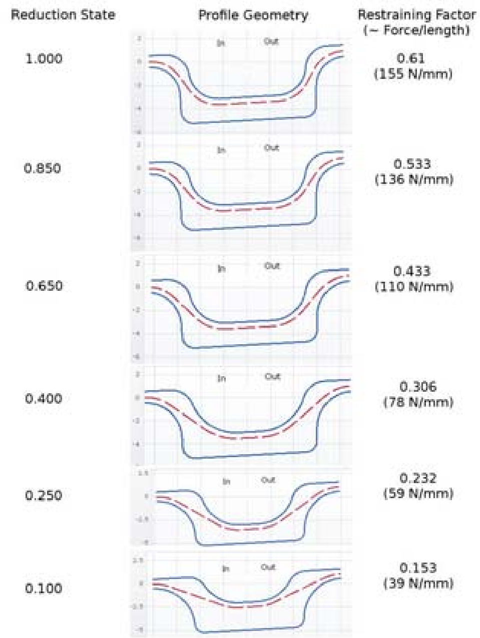


Figure 2-9: series of draw bead reduction process

Figure 2.9 above are a series of modification in draw bead geometries to reduce draw bead restraining force. In general to reduce draw bead restraining force, bead radius and groove radius can be increase while bead height is decrease.