CHAPTER 2.0 LITERATURE SURVEY

2.1 Introduction

In chapter 2, we will review the journals, papers and other current on-going research and development activities related to the scientific and systematic approach in the designing of aluminum draw punch and dies.

2.2 Design Rules for Drawing

Aluminum has one-third the Young modulus of steel. Thus the final product stiffness will be reduced unless the product design is modified to account for this factor. Two possibilities are to increase the ribbing used in the product and to increase the part thickness.

In the year 2001, University of Ohio published a paper entitled 'Design rules for forming aluminum stampings' [1] on the optimization of design parameters in the design of aluminum stampings. Some of the key design rules discussed in this paper are reviewed here :

a. Die Clearance

Die clearance is the distance between punch surface and the die surface. In deep drawing, if the die clearance is too large, the component forms a cone instead of a cylinder. The forming of square bends and straight walls will not be possible. If the die clearance is too small, ironing can take place which increases the drawing load and the danger of cracking. Galling and scoring on products will be common failures and product quality will be significantly low.

Recommended clearance for deep drawing of aluminum cups without ironing is as stated below :

$$u_D = s_0 + 0.02\sqrt{10 s_0}$$

where s_0 = sheet metal thickness

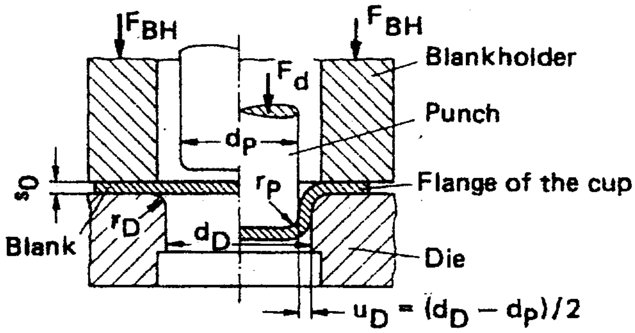


Figure 2.1:Punch radius(r_P),Die Radius(r_D), Sheet Thickness(s_0),Blank Diameter(d_B)

Die clearance is needed to allow room for the sheet metal thickness between the punch wall and die wall. Die clearances is determined by the tool and die engineer and is independent of the final product dimensions. This clearance must always be maintained by ensuring that continuos alignment between the punch and die is carried out by the preventive maintenance group.

b. Die radius

Die radius depends on the thickness of the workpiece. In order to lower the drawing load, a large radii is desired. Large radii, however, reduces the contact area between the blankholder and the flange and increases the tendency to form wrinkles in the region of die radius. The possibility of wrinkle formation is reduced if the die radius is selected small. Recommended values for die radii for aluminum stampings is $r_D = 5$ to $10\ s_0$. [1]

Die radius has a significant impact on the required punch force. As high as 35% reduction in punch force has been observed in many cases. However, die radius above $10s_0$ is not practical as there isn't any significant reduction in the punch force when the die radius is increased above $10s_0$.

c. Punch radius

It is important to select a proper punch radius, r_P in order to obtain a good quality part. For small components of large sheet thickness, it is advisable to use a gentle transition from the punch radius to the cylindrical portion of the punch to avoid wall thickness reductions in the transition zone from the bottom of the cup to the wall. Punch radius r_P must never be smaller than r_D or the punch might pierce the material. The recommended values for punch radii for aluminum stampings are in the range of $r_P = 8$ to $10\ s_0$. Punch radius greater than ten times the sheet thickness will cause wrinkling due to the high compressive stresses that occur while the sheet wraps around the punch radius.

The punch radius is normally related to the final product dimensions. If the punch radius on the final product is not critical for its functionality, then the stamping process engineer should be given the flexibility to determine the appropriate punch radius. However, currently this may not be possible in many cases as the stamping engineer and product engineer do not work for the same organizations. Product development and product manufacturing are being carried out independently at different sites globally. The impact of punch radius on the punch force is negligible due to the fact that the punch radius affects only the small initial bending force during the formation of the bottom of the cup.

d. Overhang Limit

Overhang limit is the limit of a certain amount of material that is not supported in the die. The maximum overhang for aluminum should not exceed $75s_0$ [1]. As shown in Figure 2.3, a overhang of $50s_0$ or less is desirable. When an overhang is too large, wrinkling will occur in the shrink flanging areas due to compression stresses.

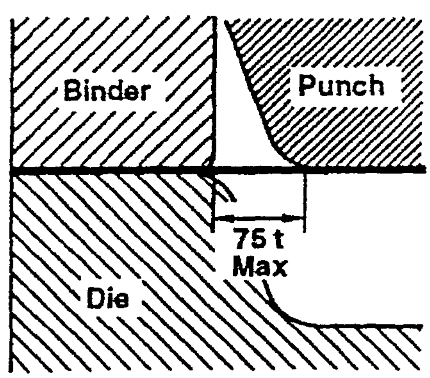


Figure 2.2 : Overhang Limit

The design rules established here will act as guidelines for the design of stamping tools. Thus, tool and die engineers involved in the design of these tools will be able to reduce the design cycle time as well as produce quality stamping products.

2.3 Friction in Drawing Process

In stamping operations, the friction at the tool-workpiece interface can significantly affect the quality of the stamped parts, the scrap rate and productivity because friction is the primary mechanism by which material flow within the die is controlled.

While lower friction is favoured in most stamping methods, other processes, such as deep drawing require that a blank be drawn in the gap between the punch and die to form the cup shaped part with a minimum amount of thinning. A certain level of friction on the punch base and radius therefore is essential to transfer stresses on the punch and allow the stretching of the blank.

During the deep drawing process, the static force between the blank and the die surface must be overcome. Continuo force must be applied to overcome the dynamic force to be able to pull the sheet metal towards the draw punch. This frictional force is closely linked to blankholder force and lubricants which are two important aspects in the deep drawing process.

As a result, knowing that the friction at the tool-workpiece interface for a particular stamping process is important. Furthermore, precise coefficient of friction values can greatly improve process design and analysis, numerical process simulations and process controls of the forming process. The increasing number of lubricants, coatings and specialty materials underscores the need for a practical approach to determining friction in stamping activities.

The most reliable way to evaluate lubricants for a metal forming process is to test the lubricant during the actual stamping operation where all the relevant process variables such as press speed, stroking rate, die and sheet materials correspond to real conditions. However, testing a lubricant under production conditions require the measurements of a large variables such as punch load, sheet thickness distribution, amount of galling, surface topography, surface coatings etc. and taking all these measurements at the plant level could be difficult and expensive. In addition, if the tested lubricant does not perform well, it may have detrimental effect upon the product quality and the tooling. Thus, lubricants should be tested in production only if they have been proven to be effective in laboratory tests that emulate production conditions.

Because of the many interacting variables at the tool-workpiece interface, it is difficult for a single test to emulate all conditions occurring in a stamping operation eg. press speed, interface pressure, tool temperature, etc. A practical approach is to select a test that takes into the account the most significant variables in a specific stamping operation.

In the year 2000, Ohio State University published a paper entitled 'A practical approach to evaluate friction' [2] which explored scientific and systematic approach in evaluating the friction factor in a practical stamping or drawing environment.

They pioneered the Limiting Dome Height (LDH) test to evaluate lubricants for stamping processes. In this test, a round blank is held firmly around the periphery while a spherical punch stretch forms the blank as shown in Figure 2.4. The dome height depends on the material's ability to distribute strain and on the limiting strain level. The strain distribution depends largely on friction which makes this test suitable for evaluating friction.

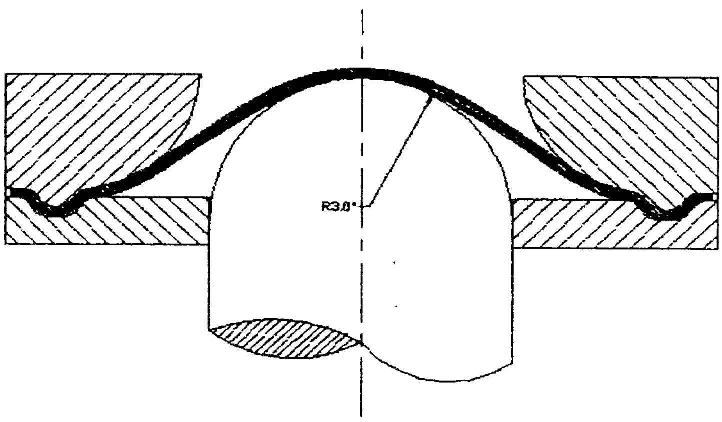


Figure 2.3 : Limiting Dome Height Test

The blankholder design can be further optimized using the method mentioned above to ensure that the common 'over-design' phenomena can be eliminated.

This systematic approach will allow the stamping engineers to be able to select the appropriate lubricants based on the responses of the Limiting Dome Height tests. Data obtained from these tests can also be crunched statistically to provide the engineering data to confirm the selection of the suitable lubricants. Most importantly, the effectiveness of the lubricants can be quantified.

Expensive lubricants which were purchased based on the influence of advertisements which do not significantly reduce the frictional force can be replaced with cost effective lubricants.

These actions will have a positive impact on the reliability of the tool as the punch force on the draw punch will be reduced and life span of the punch extended.

2.4 Formability in the Drawing Process

In stamping operations, the formability of the incoming material(sheet blank or coil) affects the quality of the stamped parts, the scrap rate and productivity. Coils from different suppliers or different heats may not exhibit the same formability even though the material composition and tensile properties maybe similar. The k and n values of the sheet material (obtained from the true stress vs true strain curve) determines the metal flow and fracture behaviour. Tensile data and Forming Limit Diagrams(FLDs) are used, in general, for evaluating formability. However, tensile data are not fully representative of the biaxial deformation conditions that exists in deep drawing and FLDs are expensive and time consuming to obtain for each material lot. Thus, it is desirable to have a practical formability test that represents the true conditions of the deep drawing process.

The Engineering Research Center for Net Shape Manufacturing (ERC/NSM) in University of Ohio published a paper entitled 'Practical determination of formability using the viscous pressure bulging (VPB) test' [3]. They further developed the well known hydraulic bulge test using a viscous material as a pressure medium and a double action tooling as shown in Figure 2.5

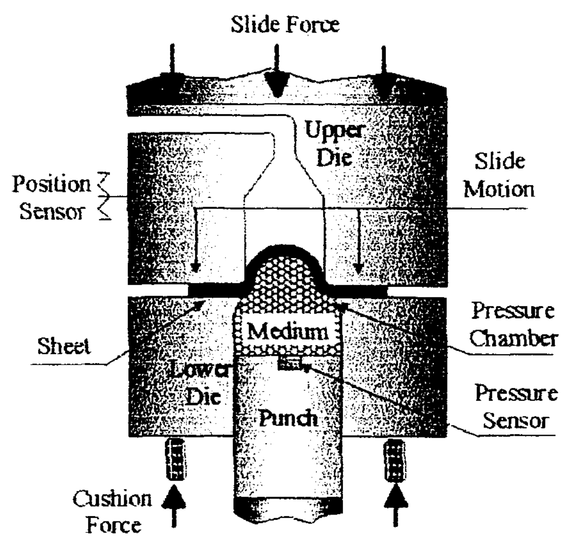
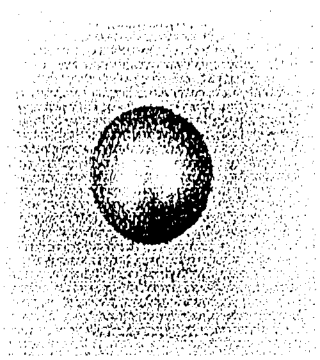


Figure 2.4 : Sketch of the Sheet Metal Bulge Test Tooling

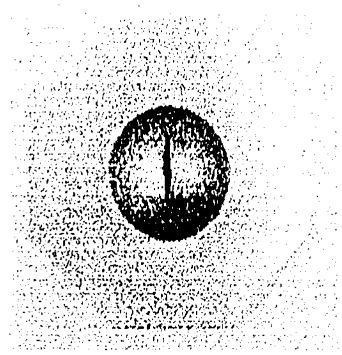
The tooling for this Viscous Pressure Bulging test can be installed in any hydraulic press equipped with a die cushion. The viscous medium is filled into the chamber between the punch and sheet blank. The blank is clamped around its periphery between the upper and lower dies through the cushion force provided by the cushion pins or nitrogen cylinders. Thus the material is allowed to stretch but not draw-in. When the ram moves down, the punch pushes the medium in the lower die chamber upwards and pressure is generated within the medium, acting on the sheet blank. As the sheet bulges, the region in the vicinity of the dome becomes nearly spherical in shape.

The relative formability of materials is determined by measuring simply the dome height at fracture, Figure 2.6. The larger dome height at fracture, the more deformable is the sheet material, Thus, this test can be used for rapid determination of the formability of a new batch of material before it is released to production. Furthermore, with this test it is possible to investigate material related problems such sudden increase in scrap rate due to splitting.

The K and n values of the bulged material are determined, provided the bulge height versus the bulge pressure are measured. Using analytical or FEM based analysis of the bulge test that is available in ERC/NSM, these data allow to obtain the true stress versus true strain curve under biaxial stretching conditions that exist in deep drawing process. The material data obtained in this manner are more reliable than that obtained from conventional tensile tests and can be used as input to FEM based computer programs used for process simulations.



(a) Bulged sheet (without fracture)



(b) Bulged sheet (with fracture)

Figure 2.5 : Using VPB to Evaluate Material Formability

This systematic approach will ensure that the incoming raw material are within the allowable specifications. This is critical in ensuring the successful mass production of deep draw products as these variations have a direct impact on the product quality and overall production efficiency. Some of the related issues are as stated below :

a. Surface finish

The level of surface finish has an impact on the frictional forces involved in the deep drawing process. The lesser the surface roughness, the higher is the formability of the product.

b. Impurities

The level of impurities called fibers may differ from batch to batch. These fillers can cause changes in material strength at different angles in the sheet metal.

c. Thickness

Variation in the sheet metal thickness will have an impact on the wrinkling severity and required punch force. The formability due to variations in thickness can be determined conclusively using the VPB test.

2.5 FEM in Simplification and Optimization of Draw Tool Designs

In the Y2000, Cao J, Li Shunping, Xia ZC and Tang SC from Northwestern University Ford Scientific Research Laboratory published a paper entitled 'Analysis of An Axisymmetric Deep Drawn Part Forming Using Reduced Forming Steps' [4] on the reduction of re-draws required in a deep drawing process of an axisymmetric part with a complex geometry. The existing practice required a 10 step drawing process. The new approach combines optimization scheme, design rules and numerical tests using finite element analysis. As a result, the 10-step drawing process was reduced to a 6-step drawing process. Additionally, the new process design yields a lower maximum void volume fraction in the sheet, meaning a more formable process and slightly higher press load.

Finite element methods have been successfully utilized to reduce the number of redraws from 10 to 6. This underscores the importance of reviewing all the current conventional ' rule of thumb' and personal/previous experiences in design methodology. FEM will significantly improve the product manufacturing cycle time and also reduce the tool and die maintenance cost.

2.6 Mechanical Properties of Sheet Metal

We often observe that many production problems may be due to lot to lot variation. A producer of automotive stampings may purchase coils of the same material whereby all the material specifications are acceptable. However, during production significant differences in performance from coil to coil may be observed. For example, the splits and scrap rate with a specific coil may be unusually high although nothing has changed in the process. The tooling, press strokes, lubrication etc have remained as before. In cases where tensile data is used for process simulation, the predictions may not agree with the observations made during die development or in production.

It is necessary to use a test that emulates the strain and stress that occur in the stamping process i.e the deformation in bi-axial deformation condition. The test to be used is the Viscous Pressure Bulge(VBP) test. This test allows to determine the stress strain behavior of the sheet metal providing more reliable material data and to evaluate formability by measuring the bulge height at fracture. Consequently, this bulge test can be used in a factory as a quality control test for incoming sheet metal or coils.

The tensile test is being used for years as a major test to determine the properties of sheet metal. Maybe it is time now to use the bulge test that gives more accurate and reliable information on material properties.