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ANALYSIS OF DEEP DRAWING PROCESS FOR VARIOUS PARAMETERS USING FINITE ELEMENT ANALYSIS

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ABSTRACT

The main objective of this paper is to find the most effective parameters in deep drawing process to produce a cup of required shape and size. Limit Drawing Ratio is one of the parameters that indicate the drawability of material. It is defined as the ratio of blank diameter to punch diameter at the onset of tearing. Deep drawing products in modern industries usually have a complicated shape, so these have to undergo several successive operations to obtain a final desired shape. In this work the effect of various parameters like die and punch corner radii, clearance, friction coefficient between die and punch, punch diameter on limit drawing ratio is investigated and presented by using an explicit finite element code LS-DYNA 3D.

KEYWORDS: Deep Drawing, Limit Drawing Ratio (LDR), Die, Finite Element Analysis (FEA), Metal forming, Modelling. Blank diameter, Punch diameter.

I. INTRODUCTION

Metal-forming processes are used in many manufacturing areas, such as in the production of components for cars, aircraft and household appliances. The efficiency of the metal components will depend on the precision with which they are made, which in turn depends on the effects of metal-forming processes on the properties of the metal used [1]. There are many different metals that can be made into sheet metal, such as: Aluminum, brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold and platinum. The direct design method and its theoretical basis which is called ideal forming theory to get an initial blank shape [2]. But real forming conditions such as blank holder forces, friction forces, tool geometry, etc. are not considered so the calculated blank shape had some shape errors. No effort was also made to simulate the earing. The sequential design procedure to optimize sheet-forming processes based on ideal forming theory, FEM analysis and experimental trials. They used this procedure to design a blank shape for a highly anisotropic aluminum alloy sheet that resulted in a deep draw circular cup with minimum earing [3]. Gea and Ramamurthy [4] have proposed a numerical scheme to maximize the drawability and to determine the optimal starting blank design for square cupping operations. Fracture failure and draw-in failure have been studied to maximize the drawability [5]. The outcome of this analysis is then used to determine the optimal blank geometry assuming the sheet metal as isotropic. Various experimental analysis on FEM which describes the magnitude of friction is dependent on the absence or presence of lubricant and its characteristics, the presence of coatings of impurities on the sheet metal blank, surface roughness of the tool and the blank, blank holder pressure and process velocity [6], [7]. The Finite Element Method is a mathematical tool for solving ordinary and partial differential equations. Because it is a numerical tool, it has the ability to solve the complex problems that can be represented in differential equations form. The applications of FEM are limitless as regards the solution of practical design problems [8]. The metal forming processes generally highly non-linear and history dependent, many researchers have used the direct differentiation method for the calculation of sensitivity [9]. The authors used FEM analysis to determine the plate thickness and the location of support elements holding the binder. They performed experiments at various binder force values to estimate the safe working area [10]. Metal-forming processes are used in many manufacturing areas, such as in the production of components for cars, aircraft and household appliances. The efficiency of the metal components will depend on the precision with which they are made, which in turn depends on the effects of metal-forming processes on the properties of the metal used [11]. There are many different metals that can be made into sheet metal, such as: Aluminum, brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold and platinum [12].

The Deep drawing involves many types of forces and deformation modes, such as tension in the wall and the bottom, compression and friction in the flange, bending at the die radius, and straightening in the die wall. Usually Drawing is a process of forming a flat, pre-cut, metal blank into a hollow shape, either cylindrical or box-shaped, by pressing it into a die cavity without excessive wrinkling, thinning, or fracturing [13]. Typical parts produced by drawing include beverage cans, containers of all shapes and sizes, and automobile and aircraft panels. Deep drawing process is influenced by some parameters like residual stresses, Blank holding force etc.

In this proposed work, effect of various parameters like die and punch corner radii, clearance, friction coefficient between die and punch, punch diameter on limit drawing ratio is investigated and presented by using an explicit finite element code LS-DYNA 3D.

II. METAL FORMING AND DEEP DRAWING PROCESS

Metal forming is a significant manufacturing process for producing a large variety of automotive parts and aerospace parts as well as consumer products, about 90% of all metal production starts off as cast, however a very large proportion of this is then processed by a bulk plastic deformation process, either to improve the structure and properties and / or to give the desired final shape (or close to that) required. Sheet metal is simply metal formed into thin and flat pieces, which are usually less than 6mm. There are different metals that can be made into sheet metal. Aluminum, brass, copper, cold rolled steel, mild steel, tin, nickel and titanium are just a few examples of metal that can be made into sheet metal. Sheet metal forming refers to various processes used to convert sheet metal into different shapes for a large variety of finished parts. The typical forming processes include stretching, drawing, cutting, bending and flanging, punching and shearing, spinning, press forming and roll forming. In this research we will primarily focus on the sheet metal drawing process. A sheet metal forming system comprises all the input variables relating the blank(geometry and material), the tooling (geometry and material), the conditions at the tool-material interface, the mechanics of plastic deformation, the equipment used, the characteristics of the final product, and finally the plant environment in which the process is being conducted. The basic mechanisms in sheet metal forming are stretching, drawing, and bending. Depending on the shape and the relative dimensions of the blank and the tool, one or more basic mechanisms is predominantly involved. The thickness of the sheet metal is called its gauge. The gauge of sheet metal ranges from 30 gauge to about 8 gauge. The higher the gauge, the thinner the metal is. As the gauge number increases, the material thickness decreases.

Metal forming processes can be classified under two major groups. Bulk deformation processes Sheet metalworking processes. Bulk deformation is characteristic in that the work formed has a low surface area to volume ratio. In sheet metalworking the metal being processed will have a high surface area to volume ratio. Metal forming processes are characteristic of high pressures between two contacting surfaces. In hot forming processes these high pressures are accompanied by extreme temperatures. For these reasons friction is a serious consideration in metal forming processes. A certain amount of friction will be necessary for some forming processes, but excessive friction is always undesirable. Friction increases the amount of force required to perform an operation, causes wear on tooling, and can affect metal flow creating defects in the work.

The most common sheet forming techniques are Blanking and piercing, Bending, section bending, stretching, Hole extrusion, Stamping or draw die forming, Deep drawing, Tube forming, Fluid forming, Coining & Ironing. Since sheet metal is formed using tensile or tensile-pressure forming, tools used are less loaded than during bulk forming. Product accuracy, especially for thick sheet metal, is not great, since surfaces are partially free and material is formed along the easiest natural path. However, product accuracy can be significantly increased using ironing and fine blanking. In general, formability depends on the material and the process involved. It can be defined as the ability of a material to deform without the occurrence of fracture or any other defect in a forming process.

III. DEEP DRAWING

Deep drawing of sheet metal is used to form parts by a process in which a flat blank is constrained by a blank holder while the central portion of the sheet is pushed into a die opening with a punch to draw the metal into the desired shape without causing wrinkles or splits in the drawn part. This generally requires the use of presses having a double action for hold-down force and punch force. It also involves many types of forces and deformation modes, such as tension in the wall and the bottom, compression and friction in the flange, bending at the die radius and straightening in the die wall. The process is capable of forming beverage cans, sinks, cooking pots, ammunition shell containers, pressure vessels, and auto body panels and parts.

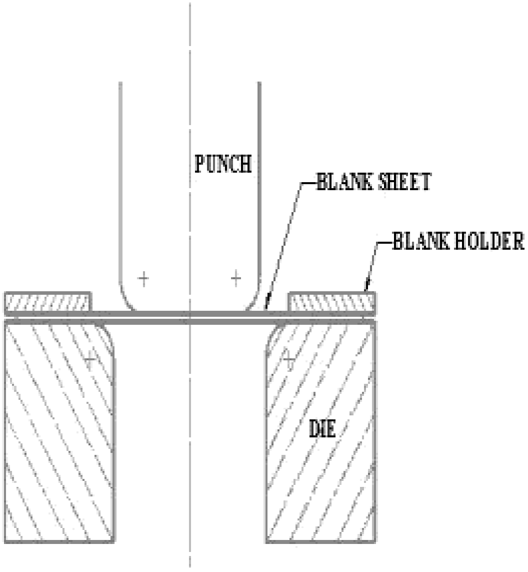

Fig.1 schematic view of Deep drawing process

The term deep drawing implies that some drawing-in of the flange metal occurs and that the formed parts are deeper than could be obtained by simply stretching the metal over a die. In most deep-drawing operations, the part has a solid bottom to form a container and a retained flange that is trimmed later in the processing. In some cases, the cup shape is fully drawn into the female die cavity, and a straight-wall cup shape is ejected through the die opening. To control the flange area and to prevent wrinkling, a hold-down force is applied to the blank to keep it in contact with the upper surface of the die. Presses used for deep-drawing operations can be either hydraulic or mechanical, but hydraulic presses are preferred because of better control of the rate of punch travel. Any metal that can be processed into sheet form by a cold-rolling process should be sufficiently ductile to be capable of deep drawing. Both hot- and cold-rolled sheet products are used in deep-drawing processes.

The majority of the applications using finite element methods has been deterministic, in which a set of design parameters is given and simulation results are interpreted by users. Additional simulations need to be performed if the results are not satisfactory. The determination of those design parameters is again mainly based on users experience and interpretation. Such design process usually requires enormous amount of time and cost to determine the optimal process parameters.

Limit Drawing Ratio is one of the parameters that indicate the drawability of material. It is defined as the ratio of blank diameter to punch diameter at the onset of tearing. The drawing ratio, DR, gives an indication of the severity of the drawing operation: the higher the ratio, the greater the severity.

Therefore

$$DR = \frac{D_b}{D_p}$$

Where, D_b = blank diameter and D_p = punch diameter. This value is dependant upon punch and die corner radii, friction conditions, draw depth, and material properties of the sheet metal.
The drawing force required to perform a drawing operation can be roughly estimated by the following form where
F = Drawing force, t = Original blank thickness, TS = Tensile strength, D_b = Blank diameter, D_p = Punch diameter
Increasing the DR will increase the punch force, and this will result in excessive thinning or even fracture in the cup wall.

$DR < LDR$;

Where LDR = Limiting Drawing Ratio.

IV. FINITE ELEMENT ANALYSIS

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal points”. Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement within the element in terms of the displacement at the nodes of the element. In the recent years, FEA has been universally used to solve structural engineering problems. The departments, which are heavily relied on this technology, are the automotive and aerospace industry. Due to the need to meet the extreme demands for faster, stronger, efficient and lightweight automobiles and aircraft, manufacturers have to rely on this technique to stay competitive. Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of simple shape within each element, the variation of displacement is assumed to be determined by simple polynomial shape functions and nodal displacements. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. This is a numerical solution for obtaining solution to many of the problems encountered in engineering analysis.

LS-DYNA is an advanced general-purpose multi-physics simulation software package developed by the Livermore Software Technology Corporation (LSTC). While the package continues to contain more and more possibilities for the calculation of many complex, real world problems, its origins and core-competency lie in highly nonlinear transient dynamic finite element analysis (FEA) using explicit time integration. LS-DYNA is being used by the automobile, aerospace, construction, military, manufacturing and bioengineering industries

V. ANALYSIS AND MODELING

The finite element simulation was carried out on LS-DYNA. The pre-processing was done with HYPERMESH. The rigid tooling of deep drawing consists of Die, Blank holder and Punch.

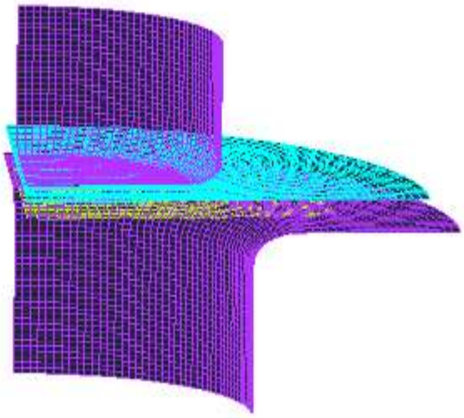

Fig. 2 Finite element model

The entire pre- processing process can be divided into four steps: Creating geometry & meshing, Creating material collectors, Applying boundary condition, Applying control cards. Initially an FEA Model as shown in Fig.2 is created replicating the existing experimental set to validate the model. Based on the symmetry boundary condition, a quarter of the geometry is modeled by using Hypermesh with LSDYNA template. The punch presses the sheet into die cavity. In sheet metal forming generally, membrane elements or continuum elements or shell elements are employed.

VI. RESULTS

The limit drawing ratios for various trials are presented in Table 1. The analysis is being carried out by column effect method. Summation at level 1 (S1) and at level 2 (S2) are computed and difference (S2-S1) is found out. According to column effect method higher the difference between the two sums, higher is the effect of that parameter.

Table 1 limit drawing ratios for various trials

Trial No	**Column Number**					
	R_p (mm)	**R_d (mm)**	**C (%)**	**M**	**D_P (mm)**	**β_{max}**
1	2	3	7	0.015	10	
2	2	3	20	0.45	40	2.1
3	2	10	7	0.45	40	1.2
4	2	10	20	0.015	10	1.6
5	5	3	7	0.45	10	2.5
6	5	3	20	0.015	40	1.5
7	5	10	7	0.015	40	1.8
8	5	10	20	0.45	10	1.4
S1	7.4	6.6	6.6	7.8	8.4	2.3
S2	7.0	7.8	7.8	6.6	6.0	
S2-S1	-0.4	+0.8	+0.8	-0.8	-2.4	

From Table 1, it is clear that the cup diameter has a pronounced effect on LDR and the effect of die profile, friction factor and % clearance is considerable. Plotting method is used to find out the combined effect of the parameters considered above taking two at a time.

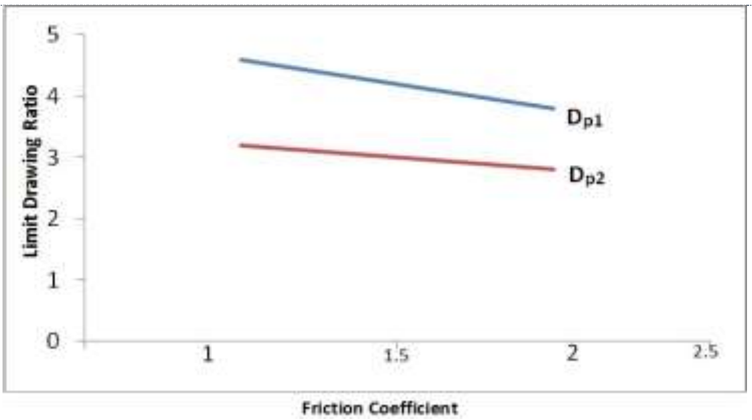

Fig 3. variation of punch diameter againest friction factor on the Limit Drawing Ratio

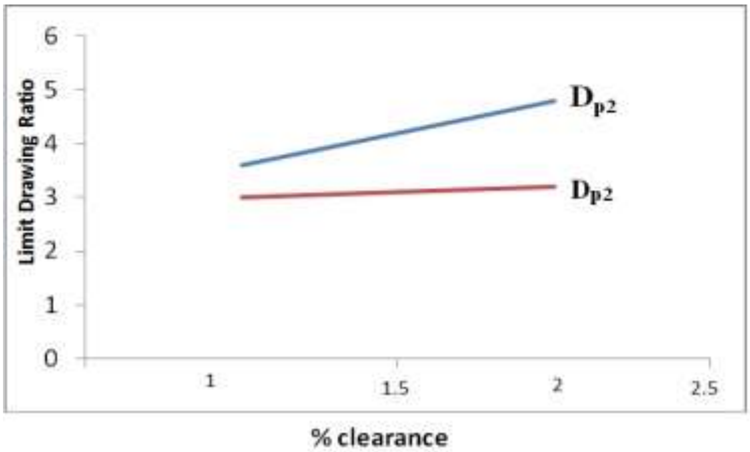

Fig 4. variation of punch diameter againest % clearance on the Limit Drawing Ratio

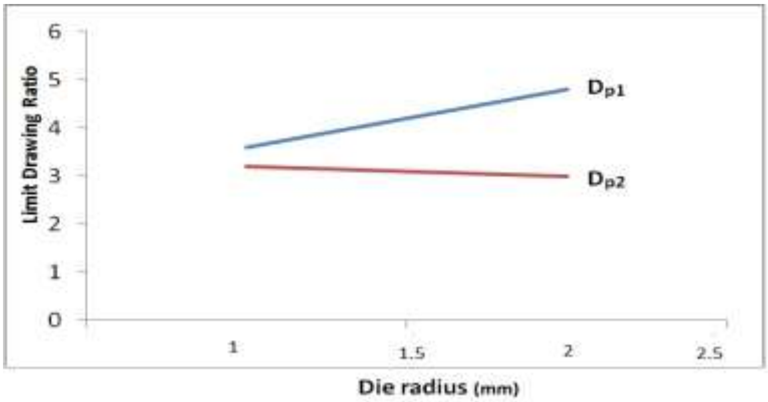

Fig 5. variation of punch diameter againest die radius on the Limit drawing ratio

For this, each pair of parameters at levels 1-1, 1-2, 2-1, and 2-2 are summed up and plotted as shown in Fig. 3 to 7. According to plotting method, higher the difference in slope, higher is the interaction between the two parameters chosen.

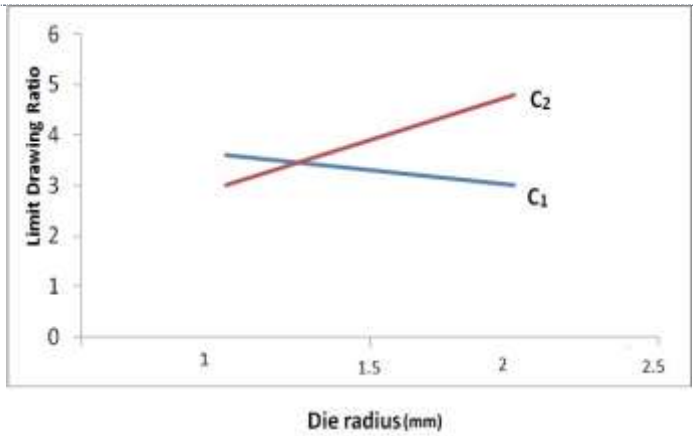

Fig 6. variation of die profile radius againest % clearance on the Limit drawing ratio

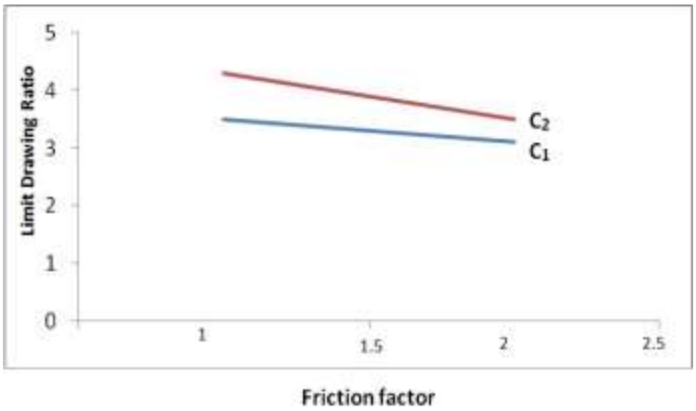

Fig 7. variation of the friction factor againest % clearance on the Limt Drawing Ratio

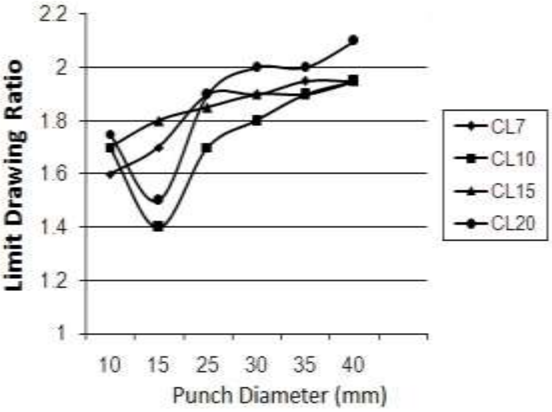

Fig 7.Variation of clearance with punch diameter (mm) on the Limit Drawing Ratio

From the Figure 6, it is evident that there is inter-dependency of die profile and % clearance in effecting the Limit Drawing Ratio. There is a little interaction of punch diameter with die profile and % clearance as presented in Fig. 4 and Fig 5. The Friction factor independently affects the LDR as reflected in Fig 4 to Fig 7. From the Fig 8, it is observed that the Limit Drawing Ratio increases with the increase of punch diameter. A small deviation to this is observed for clearance 10% and 20% where the Limit Drawing Ratio decreases first and then increases.

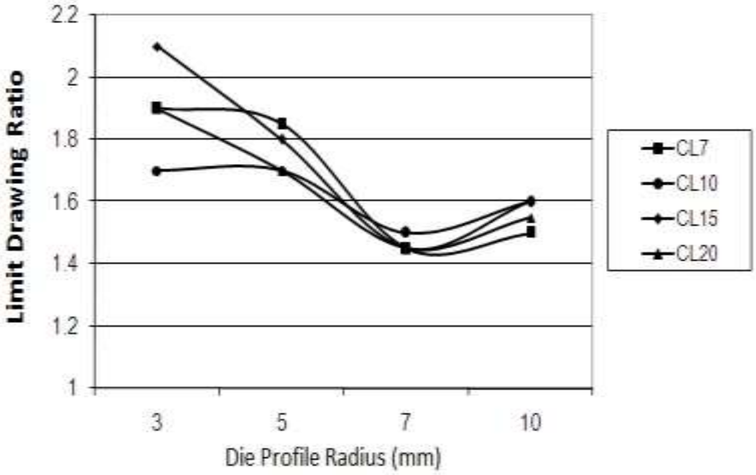

Fig 9. Variation of Limit Drawing Ratio with punch diameter at various die profiles

From the Fig 9, it is observed that Limit Drawing Ratio decreases with the increase in die profile radius.

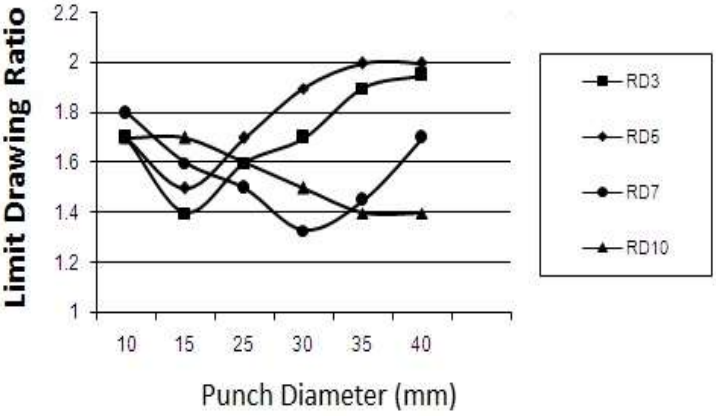

Fig 10. Variation of die profile radius with punch diameter

From the Fig. 10 it is observed that the Limit Drawing Ratio increases with the increase of punch profile radius. A small deviation to this is observed for punch profiles 3mm and 5mm where the Limit Drawing Ratio decreases first and then increases.

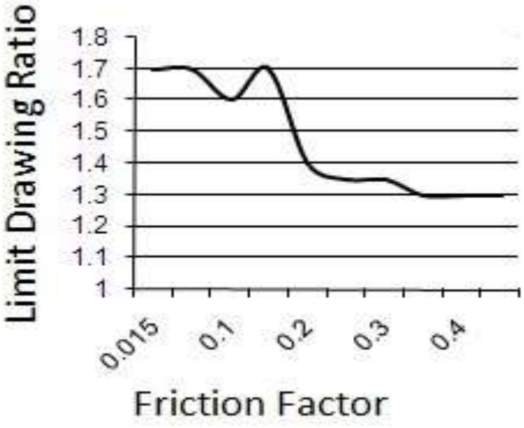

Fig 11. Effect of friction factor

From the Fig. 11, it is observed that the Limit Drawing Ratio decreases with the increase of friction factor.

VII. CONCLUSIONS

The deep drawing process is applied with the intention of manufacturing a product with a desired shape and no failures. An incorrect design of the tools and blank shape or an incorrect choice of material and process parameters can yield a product with a deviating shape or with failures. The most significant parameter which effects the Limit Drawing Ratio is punch diameter, There is a considerable effect of die profile, friction factor and % clearance on LDR and the cup diameter has a pronounced effect on LDR, The friction factor independently effects the LDR, the LDR decreases with the increase in die profile, LDR increases with the increase of punch diameter and the LDR decreases with the increase of friction factor.

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