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Review On Micro Deep Drawing Process For Thin Foil Materials

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Abstract-Micro Deep Drawing[MDD] process is a fundamental micro forming method with potential applications in forming of cups, hollows and boxes and has an edge over other micro manufacturing methods. There are numerous process parameters and other factors that affect product quality produced by deep drawing. This paper is highlighting recent research work and results in deep drawing. Deep-drawing operations are performed to produce a light weight, high strength, low density, and corrosion resistible product. These requirements will increase tendency of wrinkling and other forms of failure in the product. Parameters like as blank-holder pressure, punch radius, die radius, material properties, and coefficient of friction affect deep drawing process. A thorough knowledge of the overall process is required to produce a product with minimum defects. This review paper has given the attention to gather recent developments and research work in the area of micro deep drawing.

I. INTRODUCTION

Sheet-metal forming processes are technologically among the most important metalworking processes. Products made by sheet-forming process include a very large variety of different geometrical shapes and sizes, like simple bend to double curvatures even with deep recesses and intricate shapes. Typical examples are automobile bodies, aircraft panels, appliance bodies, kitchen utensils and beverage cans. Sheet-metal forming processes are widely used in the manufacturing industry. Greater productivity and low production cost can be expected for commercial scale production of sheet metal forming processes. As mentioned that the flat sheet of metal is formed into a 3-D product by deep drawing process. The basic tools of the deep drawing process are blank, punch, die and blank holder (or pressure plate). Deep drawing is affected by various factors such as material properties, tool geometry, lubrication etc. Owing to these factors, failures may occur during the process. Tearing, necking, wrinkling, earing and poor surface appearance are the main failure types that can be seen in deep drawing. Tearing and necking are caused by the tensile stresses and hence named as tensile instabilities. Another failure is wrinkling, caused by compressive stresses unlike to tearing and necking. When the radial drawing stress exceeds a certain value compressive stress in the circumferential direction becomes too high, plastic buckling occurs. The four major defects which can occur during deep drawing are fracture, wrinkling, earing and spring back .The phenomenon of wrinkling (flange instability) is specific to the process of deep-drawing . Instability in the work piece, also called wrinkling of the walls. In deep drawing process the main objectives are to obtain defect less or minimum defects in the product. Prediction of wrinkling is a very important process for a deep-drawing operation since wrinkled parts are treated as scrap. The factors affect the deep drawing process may be categorized into three categories.

(i) Process parameters
(ii) Geometrical Parameters
(iii) Machine parameters

Process parameters include blank holder force, coefficient of friction, drawing ratio, material properties. Geometrical parameters include blank diameter, cup diameter, blank thickness, and corner radii of cup. Machine parameters include die radius and punch radius. To achieve a successful deep drawing process, a study of the stress-strain and anisotropy behavior of the sheet metal to be used is inevitable. Before one begins to study the stress-strain and anisotropy behavior in sheet metals, a proper knowledge of the stresses that occur during the forming process needs to be established.

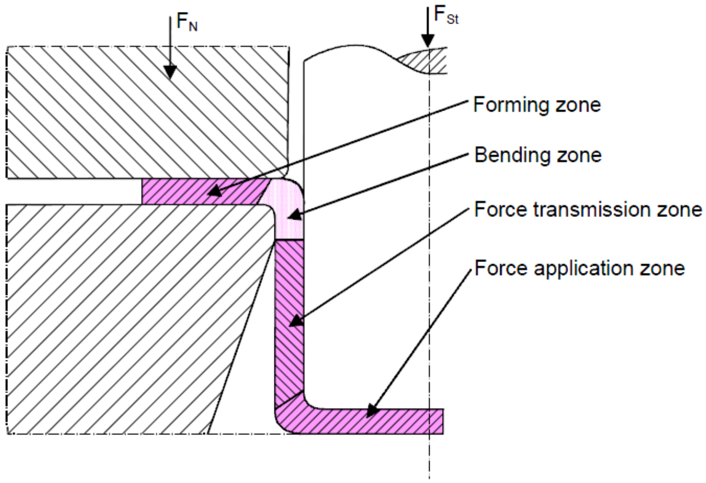

Figure 2. Stress zones in Deep Drawing

II. LITERATURE REVIEW

Literature review has been categorized on the basis of the parameters which control forming process, the quantities which decide successful execution of the process and the quality of the product. The important parameters and factors are:
(i) Blank holder force (BHF) and optimization BHF.
(ii) Punch force and punch speed
(iii) Friction
(iv) Blankshape
(v) Forming Limits
(vi) Stress and Strain Distribution
(vii) Thickness variation
(viii) Wrinkling

III. MICRO DEEP DRAWING PARAMETERS

3.1 Blank Holder Force

Higher BHF is always desirable to eliminate wrinkling in deep drawn cup shaped product, but attempts have made to predict a minimum BHF at which wrinkling cease to exist. Numerous research work have been reported to investigate the effect of BHF on product quality, material flow, strain path, stress distribution, thinning (at wall) and thickening (flange) of sheet metal, defects in product. Jaisinghet. al. (2004) has suggested that the blank holder force has the maximum impact on the thinning strain, the coefficient of friction, plastic strain ratio. The strain-hardening exponent depends on BHF. Tommerupet. al. (2012) has investigated the effect of blank holder pressure on strain path in the sheet during forming process.

Volk et. al. (2011) has simulated deep drawing process to investigate, optimized blank holder force (BHF) for an asymmetrical work piece from household appliances industry. In this research work the specific blank holder forces have been identified for minimum wrinkling and for the improve quality product. It has been suggested that a better holding system improves the quality of the workpiece. It is evident that even small changes in BHF can lead to failure during the process. These failures can be avoided if a variable BHF is applied, but the correct trajectories need to be chosen.

3.2 Punch Force

Zhao et. al. (2007) has presented hydro-mechanical reverse deep drawing of cylindrical cups with axial pushing effect. The axial pushing force is exerted on the brim of the blank by a pushing ring, this reduces radial tensile stress at the sidewall and the probability for the occurrence of fracture can be minimised. The radial stress at punch-die zone increases with friction and bending, this reduces tangential stresses and hence reduces wrinkling. The loading capacity of sidewall was observed to be improved due to strain hardening effect. The finite element simulation for hydro-mechanical reversed deep drawing process has been completed successfully with DYNAFORM-PC code combining with modifying load mask keyword manually. The experimental results doesn’t deviate to a greater extent from numerical simulation results. Sanieeet. al. (2003) has investigated the required drawing force by analytical, numerical and experimental techniques. FE simulation has been performed to study the effect of element type on the forming load and the variation of the thickness strain. The influence of the friction coefficient on the drawing load has also been investigated and maximum drawing force has quantitatively been investigated for both the analytical and FE methods. Among different analytical relationships, Siebel's formula provided the most accurate maximum drawing force for the process under consideration.

3.3 Friction

Friction is one of the major factor that influences deep drawing process. Surface quality of finished product, tool life and draw-ability of sheet depends highly on presence of good lubricating film between contact surfaces. Friction is considered as major influencing parameter in the strain distribution at tool blank interface and drawability of metal sheet during metal forming process. Tool wear is affected by drawability of metal sheet. Yang (2010) has analyzed friction coefficient and strain distribution by combining an elastic-plastic FEM code with a friction model by simulating a deep drawing process. Numerical results are in good agreement with the experimental results for the film thickness and the strain distribution. Liu Qiqianet. al. (2012) has simulated micro multi point forming process with cushion. To simulate micro multi point forming process, a finite element model with the effect of size has been developed

3.4 Blank Shape

Sound knowledge of the process and material variables are required, to minimize the process defects and optimize the process. Blank shape is an important parameter in deep drawing process as the quality of deep drawn product, thickness distribution, forming limits, minimizing the defects can be improved by having an optimum blank shape, also the material cost of product reduced, if proper blank shape is selected. Molotnikovet. al.(2012) has investigated the size effect on maximum load and limit drawing ratio for deep drawing of copper. To study the effect of ratio of blank thickness to grain size on blank thickness, numerical and experimental investigations has been carried out. Through mathem1atical modelling and experimental work it has been proposed that size effect plays a crucial role in deep drawing process when grain size kept constant and dimensions of work-piece get reduced.

3.5 Forming

Forming limit is dependent on process parameters. Numerous investigations have been carried out to find forming limits and forming curves. The forming limit of an HDD process depends highly on component physical shape. Kandil Anwar (2003) has presented experimental investigation on drawability of different metals to find the effect of hydro-forming deep drawing parameters. An experimental test rig to produce symmetric and non-symmetric cups has been developed. Wrinkling is a very severe failure in case of hydro-forming deep drawing as compared to conventional deep drawing. During the cup forming process, failures occurred and by adjusting initial pressure these failures were eliminated. It has been found that the maximum pressure ranges between 0.15-0.3 of the mean flow stress of sheet metals.

3.6 Stress and Strain Distribution

Assempour Ahmad et. al. (2011) has studied the effect of normal stress on hydrodynamic deep drawing process. By considering classical theory of plasticity and geometrical relationships, analytical model has been developed. In this study, the influence of normal stress on the variation of blank thickness, stress and strain fields and punch force has been studied. The differences have been observed in thickness distribution, in stress and strain in both radial and circumferential direction and also in punch force with and without the normal stress. Higher thickness has been observed in the 2D stress state than in the 3D stress state.

3.7 Thickness Variation

In deep drawing, the sheet metal thickness vary throughout the process. Process parameters influences thickness variation. Several research works have been reported to evaluate thickness variation. Claudio et. al. (2006) has simulated deep drawing process for steel sheets to evaluate the values of maximum punch force, in-plane principle deformation and thickness distribution in the sheet. Erichsen test was used to assess the performance of the model and the deep drawing of a cylindrical cup. Experimental validation of numerical prediction has been achieved for punch force, final value for the in-plane deformations and thickness distributions on the sheet.

3.8 Wrinkling

Wrinkling is the most severe defect in deep drawn product. Wrinkling may be defined as the formation of waves on the surface to minimise the compression stresses. Kadkhodayanet. al. (2011) has investigated flange wrinkling in deep drawing process. In this research, an analytical approach with the help of bifurcation and Tresca yield criterion is used to study plastic wrinkling of flange in deep drawing. The proposed analytical approach predicts more accurate results for large width flange and explains effect of blank holder pressure on wrinkling.

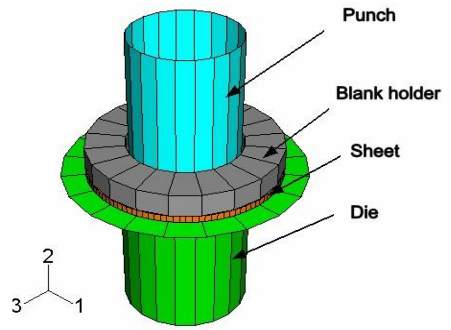

Figure 2. The mould assembly scheme in FEM

VI. NUMERICAL SIMULATION

According to the scheme of the experiment, the finite model of the blank was built with solid elements. The finite element model of the punch assembly is shown in Fig. 2. The punch, die and blank holder were built as rigid parts.According to the experimental conditions, the contact between blank and mould was treated as follows: the inner surface of the die contacted with lower surface of the blank; the punch contacted with the upper surface of the blank; the blank holder contacted with the upper surface of the blank; we defined the contacting surfaces as contact pair. Following the Coulomb frictionconcept, we set the tangential friction condition by giving suitable frictional coefficient μ. As no lubrication existed between punch and blank, assume μ=0.3, whereas there were good lubrication used between die-blank pair and blank holder-blank, thus μ=0.1. The blank holder pressed against the blank with 100N constant force, which could increase the blank rigidity and prevent wrinkling. As no accurate experimental data about friction and blank holder force were obtained, the corresponding data applied in the FEM was estimated empirically by referring to Rabbe, Zhao and Roters (2001), Raabe and Roters (2004), Zhao, Mao et al (2004). The deep drawing process was accomplished through punch moving downwards 5mm, then the blank was drawn as a micro-cup.

V. MDD EXPERIMENTS

Liang Luo et al[2005] ,figure 3(a) displays the whole MDD machine, and key parameters of the MDD machine and drawing process are listed in Table 3. The drawing forces of 10 times experiments for each material group were recorded and their average values are shown in Fig. 3(b). The drawing force has a relatively slow increase initially, and a fast yet constant increase until reaching a peak value. After remaining this peak value for short time, drawing force of each group decreases to a non-zero value at the end of process. Initially, the resistance of bending dominates the drawing force while other forces are small. As the process continues, large deformation causes high flow stress, and simultaneously friction force increases due to increased contact forces. Therefore, the drawing force rises significantly at the later period. Further, Group 1 has higher force increase and decrease speeds and smaller residual force than that of the other two groups. High elastic modulus and plastic modulus are in accordance with the high force increase speeds in the first half drawing process. Moreover, high tensile strength corresponds with the large peak drawing force. Large strain hardening index represents good formability and indicates weak springback behaviourcharacterised by small residual force at the end of drawing process.

Table 1, lists the average e geometrical values of drawn cups in each group. The difference between outer and minimum inner diameters was defined as the maximum distance, and the deviation between outer and maximum inner diameters was defined as minimum distance. Then, their relative difference was employed as a judgement of wrinkles. With the increase of grain size, wrinkling phenomenon becomes significant. That is because that a few grains on the thickness direction decrease deformability and, consequently, compression stability on the flange of blank is weak. Therefore, the blank is easy to wrinkle and needs great wrinkles to compensate this compression instability.

VI. CONCLUSION

This paper has crictically reviewed the important process parameters and its effects on micro deep drawing. It is found that the important process parameters are material thickness, coefficient of friction, thermal properties, stress

and strain concentration, wrinkling. It is determined that micro deep drawing of thin foil materials are commercially suitable for automobile, electrical applications. The following are the major conclusion of the review:
[1] When the cups drawn by the same punch,the thicker (larger T/D) material has largerLDR.
[2] When the cups drawn by the same punch,the thinner (smaller T/D) material has moreuniform cup heights. In other others, lessportion of cup needs to be trimmed off.
[3] For drawing same inner diameter cups, thethinner material has better material utilization efficiency.

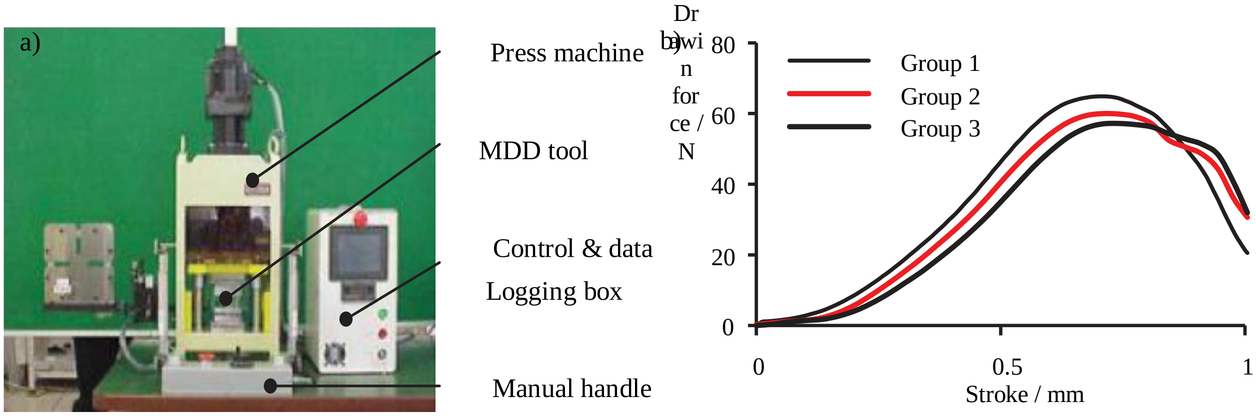

Figure 3.(a)Micro deep drawing machine and (b) Drawing forces of each material group.

Group	Min inner diameter/m	Max inner diameter/m	Outer diameter/m	Max distance/m	Min distance/m	Wrinkles/%
1	787.083	816.645	941.092	77.004	62.223	24.546
2	780.558	814.277	938.137	78.789	61.930	27.334
3	789.532	831.042	950.033	80.251	59.496	35.091

Table 1. Key Parameters Of MDD Process And Formed Cups.

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