Effect of Punch and Die Profile Radii on Deep Drawing of Galvanized Steel

Adnan I. O. Zaid, Fadhil A. Hashim

Abstract— Deep drawing process is one of the most widely used metalworking processes among the sheet metal forming processes in general and among the sheet metal forming processes in particular. It is used in the automobile and aircraft industries for manufacturing a large number of parts. Since the publication of Swift paper on the deep drawing of cylindrical cups the researchers of sheet metal forming got engaged in investigating the different parameters involved in the process. Despite the large number of publications on different parameters involved in the process they are still far from being optimized and work is still required to render the deep drawing process efficient, free from defects and cost effective. In this paper, the effect of radial clearance percentage on the autographic record (punch load—punch travel, thickness strain distribution, the maximum amount of thinning and the maximum deep drawing force and the total consumed work were invested and the obtained results are presented and discussed.

Index Terms— Different parameters, Deep drawing, Autographic records, Thickness strain distribution, Maximum thinning, Maximum drawing force, Total consumed work, Galvanized steel.

1 Introduction

DEEP drawing process is one of the most widely used process in metal working processes in general and in sheet forming in particular. It is performed to produce a very large variety of different geometrical shapes and sizes, like simple bend to double curvatures even with deep recesses and very complex shapes. Typical examples are automobile bodies and aircraft panels of good strength and light weight i.e. high strength-to-weight ratio and corrosion resistible products. Also it is used in producing appliance bodies, kitchen utensils and beverage cans.

The deep drawing process is affected by many parameters; these can be categorized into four groups:

i). Parameters related to the forming machine: type a). Presses which may be either a). Mechanical, hydraulic or servomotor all of them provide a quasi-static strain rate ranging from 10^-4 to 1 / s. b). Hammers: free falling type, hydraulic, leaf spring or petro-forge type all these provide an intermediate strain rate ranging from 1 / s to 100 / s. iii). High strain rate i.e. (dynamic, impact): high energy rate forming, HERF, gas forming, electro-magnetic, electro- hydraulic or explosive forming providing strain rate from 10^2 – 10^4 / s.

ii). Parameters related to the die set, (punch and die). These include: their design, mechanical behavior radial clearance percentage, punch and die profile radii, their surface roughness and out of roundness).

ii). Parameters related to the blank: its material type, dimensions, geometry, chemical composition, mechanical and physical properties.

iv). Parameters related to the process: dry or lubricated, lubricant type, lubrication system, holding down pressure, friction, Punch Force, the total consumed work, drawing ratio and the limiting drawing ratio. One should differentiate between the drawing ratio and the limiting drawing ratio as the first is a geometrical parameter and the latter is a mechanical property of the material.

These parameters have engaged the metal forming researchers after the publication of Swift paper in 1939, [1] till now aiming to optimize these parameters to obtain products with minimum or no defects, [1-27]. Because of these factors, some 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 they are types of tensile instabilities. Another failure is wrinkling, caused by compressive stresses unlike to tearing and necking. When the radial drawing stress exceeds a certain value of induced compressive stress in the circumferential direction becomes too high, so plastic buckling occurs. The major defects which bound to occur in deep drawing process will be dealt with in the following section.

1.1 Defects Encountered in the Deep Drawing

The above mentioned variables in the previous section might cause several defects which will be discussed in detail in this section. In deep drawing process the main objectives are to obtain less or minimum defects in the products. The following defects may occur in the produced cups:

1). Wrinkling: The phenomenon of wrinkling (flange instability) is specific to the deep drawing process. It occurs in the upper part of the produced cylindrical cups. It is caused by the induced compressive stress when it exceeds a certain critical value and the holding down pressure or force, HDF, is less than the required value. It can be avoided by increasing the holding down pressure or force. Higher blank holding down pressure or force is always desirable to eliminate wrinkling in the deep drawing of cylindrical cups or alike. taking into consideration that if increased above the required value it will cause necking followed by crack initiation which might lead to

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fracture, [ ]. There have always been attempts to predict a minimum BHF which can lessen or avoid the occurrence of wrinkling. It was found experimentally that 400 lbs. force is enough to avoid it in steels.

2). Earing: it occurs on the upper part of the produced cup due to the planar anisotropy which exists in the sheet from the rolling process. Its number is even and depends on the degree of anisotropy in the sheet. It cannot be avoided and is treated by trimming. Planar anisotropy should not be confused with normal anisotropy as the latter is structural property.

3). Orange Peeling : it occurs if the grain size of the sheet material it can be avoided by reducing the grain size either by heat treatment or by addition of the proper grain refiner to the melt of the sheet material prior to solidification during its manufacturing.

4). Bell shaped cup: it occurs if the radial clearance percentage exceeds the optimum value. The optimum value was found to be about 130 % which agrees with the same value was obtained by the authors for 70 / 30 brass, [27].

2 Materials, Equipment and Experimental Procedures

2.1 Materials

The specimens were circular discs of 180 mm diameter and 0.378 mm thickness made from galvanized steel of the mechanical behavior shown in Fig.1. It can be presented mathematically by the following general equation: 6 = 544.57 E^207.

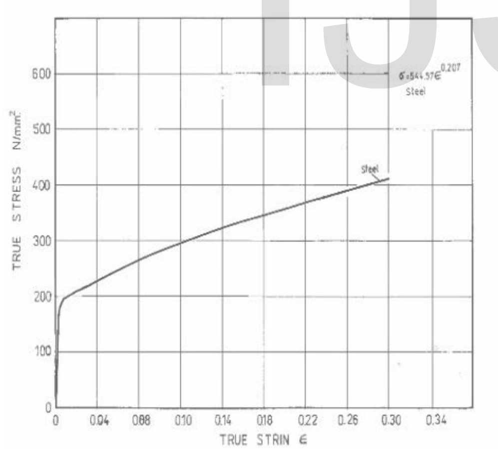

Fig. 1. The true stress – True strain of work piece material

The main deep drawing die and all the other punches and dies which were used for investigating the different parameters were all made of the same material, X12M of the chemical composition shown in Table 1. They were all heat treated according to the treatment cycle provided by the suppliers to achieve a hardness of RC58.

Five punches and five dies with different diameters and different profile radii were machined and ground under the same cutting conditions. Their diameters were measured using the Tool Makers travelling microscope and their profile radii were determined using the shadow graph at a magnification X20. The values of the radial clearance percentages for the different combined punches and dies are shown in Table 2. The values of the punch and die profile radii are shown in Tables 3 and 4 respectivly.

TABLE 1
Chemical composition of X12M

Element	Wt. %
C%	1.70%
Mn%	0.35
Si%	0.4
Cr%	0.12
V%	0.3
Fe%	Bal.

TABLE 2
THE VALUES OF RADIAL CLEARANCE AND RADIAL CLEARANCE PERCENTAGES

Symbol	Radial clearance mm	Radial Clearance %
C1	0.3976	94.8
C2	0.4473	106.6
C3	0.4943	117.8
C4	0.545	129.9
C5	0.5695	135.7
C6	0.7947	189.4

TABLE 3
Values of punch profile radii

Symbol	Punch profile radius (mm)	Rpn/pr
rp1	2	3.34
rp2	5	8.34
rp3	10	16.67
rp4	15	20
rp5	20	33.34

TABLE 4
Values of die profile radii

Symbol	Punch profile radius (mm)	Rpn/pr
rp1	2	3.34
rp2	5	8.34
rp3	10	16.67
rp4	15	20
rp5	20	33.34

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2.2 Equipment and Experimental procedures

The deep drawing tests were carried out using the deep drawing die shown in Fig.2 which was designed and manufactured for this purpose. It consists of the following main parts: the upper and lower platens which are concentric and held in line together, the sleeves the blank and die holders were all made of galvanized steel.

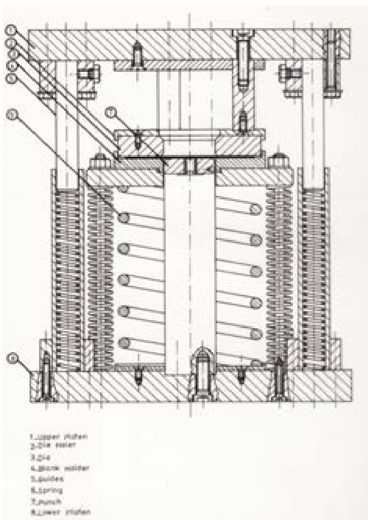

Fig. 2. Schematic drawing of the deep drawing die

3 RESULTS AND DISCUSSION

In this section, the main parameters affecting the deep drawing process are given and discussed which include: the drawing ratio, holding down pressure, radial clearance percentage, punch and die profile radii and their effect on the maximum drawing force and total consumed work. All the presented results are taken for the successful completed cups.

3.1 The Drawing ratio

Drawing ratio is defined as the ratio of blank diameter to the throat diameter of the die. It was found that for any given drawing conditions the punch load increases with blank diameter in an approximately linear manner, over the whole of the useful range with slight tendency to drop near the limiting drawing ratio. It was found from the autographic records, (punch load versus punch travel) for different blank diameters. It is worth mentioning in this respect that one should differentiate between the drawing ratio which is a geometrical parameter and the limiting drawing ratio which is a material property.

3.2 Blank holding down pressure

Normally, two types of blank-holding down pressure are commonly used: clearance blank-holding and pressure blank-holding; the object in each case is to prevent wrinkling of the blank during radial drawing, but with the minimum of interference with free drawing. In the early work of reference, [10] on mild steel blanks it was shown that with clearance blank-holding, an initial clearance of 5 per cent was sufficient for this purpose. With pressure blank-holding the medium pressure necessary to prevent wrinkling was 400 lbs. and a clearance of 0.002 in when clearance blank–holding were used. The same was adopted in this research work. It was also found that increasing the force beyond this amount had little effect on the maximum punch load or on the final thickness in the base or on the profile radius of the produced cups, though the walls were thinner with the higher loads.

3.3 Effect of radial clearance percentage, C/to on the autographic record

Fig. 3 shows the autographic records for the successful cups and the combination of punch P4with die D3, where rp =15mm and D3 = 6mm. It can be seen from this figure that the general trend is the same with little or no difference in the maximum drawing force values and radial clearance percentages except for the case when the value of the clearance is less than the blank thickness. This is referred to as an ironing process. The value of C/to = 95%. The force has increased by 54.7%. This is attributed to the high friction between the blank and the punch and die profile radii.

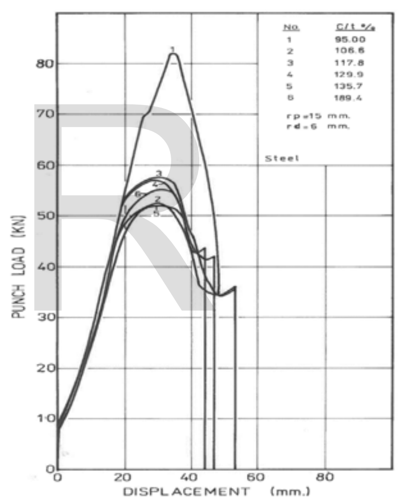

Fig. 3. Effect of radial clearance percentage on the autographic record

3.4 Effect of Radial Clearance Percentage on the Thickness Strain Distribution

Figs. 4 and 5 show the thickness strain distribution along the wall of a galvanized steel cup. It can be seen from these figures that the base of the produced cups has suffered little amount of thinning for all punches and die profile radii and for all punch and die combinations with little difference among their values which range between 2 and 6.2%, i.e. -2 and -6.2% thickness strain. This occurred at the combination of P5 with D1as indicated in Fig. 5. This is attributed to stretching along the projectile radius.

Furthermore, it can be seen from these figures that the maximum amount of thinning occurred at the region in the blank which falls between the punch and die profile radii which has no contact either with punch or die at the start of the deep drawing process. This maximum value is 12% at the same

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combination of P5 with D1, Fig. 5. This is attributed to bending and stretching in this region both of which causes thinning. Normally this thinning leads to neck formation which forms two necks in this region for flat ended cylindrical cups. Those necks were repeatedly reported in the literature, [6, 8, 9, 22 27] and have occurred in this research work. After neck formation which is a tensile plastic instability it will lead to crack initiation and finally to fracture. It is worth mentioning in this respect that the part of the blank which was located between the upper surface of the die and the bottom surface of the blank holder has suffered thickening with a maximum value of 13% as illustrated in Figs. 4 and 5.

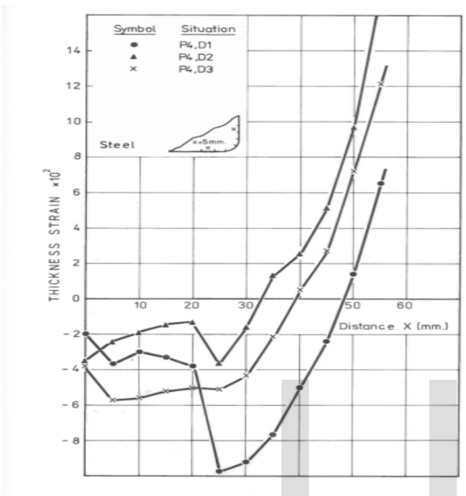

Fig. 4. Effect of die profile radii on the thickness strain distribution for the combination of punch 4, (P4), with Di, D2 and D3

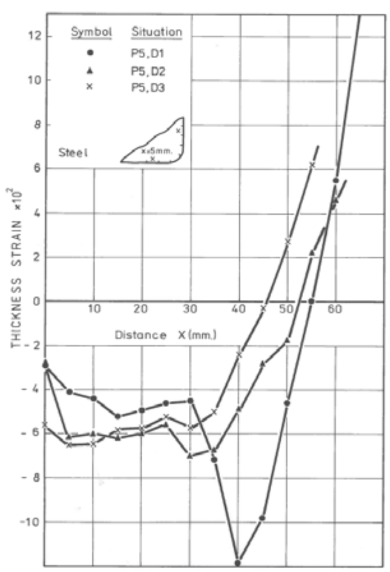

Fig. 5. Effect of die profile radius on the thickness strain distribution for the combination of P5 with D1, D2 and D3

Fig. 6 summarizes the maximum amount of thinning fer the different punch and die combinations.

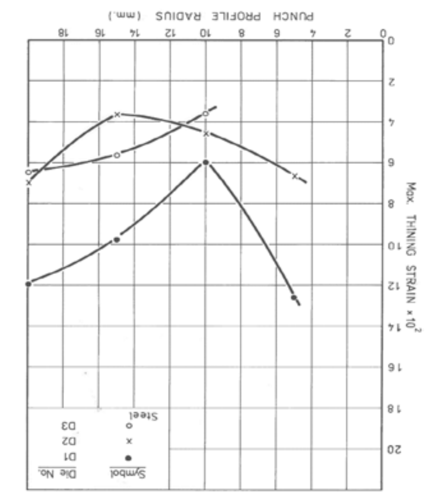

Fig. 6. Effect of punch and die profile radii on the maximum amount of t

3.5 Effect of Radial Clearance Percentage on Maximum Drawing Force and Total Consumed Work

It can be seen from Fig. 7 that the maximum drawing force decreases with the increase of radial clearance percentage within the ironing range i.e. when the clearance value is less than or equal to the sheet thickness, i.e. C < to or=to, almost in a linear manner then it starts to increase up to the optimum value of the radial clearance percentage ,130%, then it remained practically constant. The maximum increase in it is 58%, which is attributed to the heavy friction between the blank and the die.

Regarding the effect of radial clearance percentage on the total consumed work; it can be seen from Fig.8 that in general it follows the same trend of the maximum drawing force with a maximum increase of 300%.

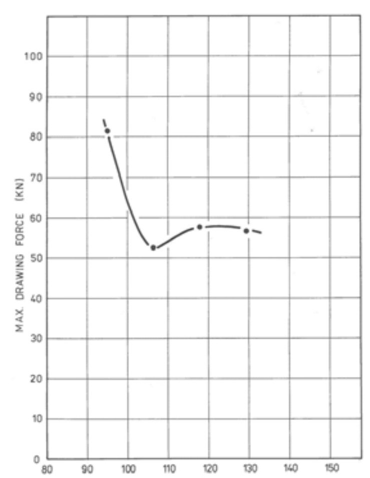

Fig. 7. Effect of radial clearancer pecentage on the maximum deep drawing force

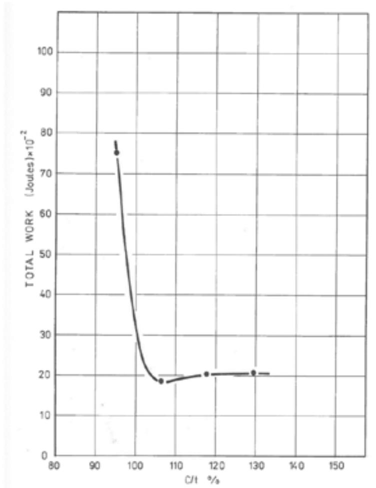

Fig. 8. Effect of C/to% on the total consumed work of galvanized steel cups

4 CONCLUSION

Within the experimental limitations, the following points are concluded:

i). The maximum drawing force is greatly influenced by the radial clearance between the punch and the die, particularly when it is less than the blank thickness i.e. the case known as ironing condition, it increased in a linear manner to a maximum value of.. . When the clearance increases above blank thickness it becomes less affective until it reaches a constant value near to the optimum value of radial clearance percentage. The best radial clearance percentage for the galvanized steel which is used in this work was about130 % where it produced least wrinkling and ears height. However, increasing it beyond this value caused a bell shaped cup.

ii). The maximum drawing force decreases with increase of the die profile radius, rd, whereas its liability for wrinkling increases. The optimum value for the used steel material was found at rd = 6 mm which equals about 15 times the original sheet thickness.

iii). The total consumed work in drawing the galvanized cups was also influenced by the radial clearance percentage following the same trend as the maximum drawing force but to a higher degree. The. maximum increase was three folds of the constant value at C/to= 130%. Similarly, like the maximum drawing force it was less affected by the punch profile radius, rp, as compared to die profile radius, rd.

iv). Although the research on the deep drawing process has been going on for more than seven decades; it is far from being complete and further work is required to get rid of the defects encountered in the process and renders it efficient and cost effective.

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