

Effect of Die Profile Radius on the Deep Drawing of Flat Ended Cylindrical Brass Cups

Adnan I. O. Zaid, Fadhil A. Hashim

Abstract— The geometrical parameters play an important role in the deep drawing process. In this paper, the effects of the die profile radius on the deep drawing of flat ended cylindrical brass cups on the autographic records, the thickness strain distribution, maximum amount of thinning, maximum drawing force, total consumed work and the quality of produced cups are investigated. The quality is assessed by the reduction in the thinning and the encountered defects in the produced cups. The obtained results are presented and discussed.

Index Terms— Effect, Die profile radius, autographic record, Thickness strain distribution, Maximum amount of thinning, Maximum drawing force, Total consumed work, Deep drawing cylindrical brass cups.

1 INTRODUCTION

DEEP drawing process is considered to be the most widely used forming process among the sheet metal forming processes particularly in automobile and aircraft industries. It is used for manufacturing a large number of body and spare parts. In its simplest form it may be defined as a secondary forming process by which a sheet metal is formed into a cylinder or alike by subjecting the sheet to compressive force through a punch with a flat end of the same geometry as the required shape of the cylinder end while it is held by a blank holder and the holding down force applied on it which hinders its movement but does not stop it, Fig.1.

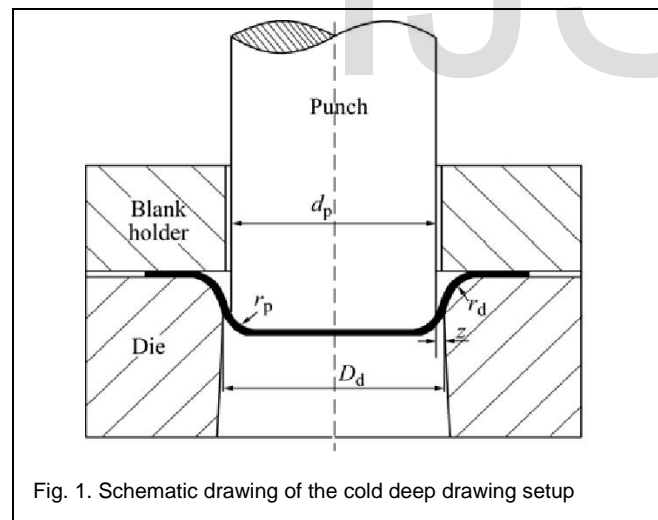


Fig. 1. Schematic drawing of the cold deep drawing setup

The first reported experimental work on cup-drawing seems to be that of Swift, published in 1939, [1, 2]. Since then, researchers in the manufacturing field got engaged in investigating the process under cold condition and a large number of publications were reported in the open literature regarding the mechanism of deformation, the parameters affecting the

process aiming at reducing the defects encountered in the products and to render the process cost effective, [3-27].

The literature reveals that the following parameter play an important role in the deep drawing process:

1). The Drawing ratio: it 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.

2). Blank holding down force: 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 psi of blank contact area 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). Radial clearance between punch and die, c , normally it is defined with respect to the original sheet thickness, c/t and referred to it as radial clearance percentage, c/t %. The experimental work and practical experience showed that a net radial clearance percentage of about 30 per cent is suitable for general purposes, with free drawing and a reduction of 50 per cent. However, increasing it beyond this value may allow a bell-mouth to persist near the rim of the cup, which would be practically objectionable if the deep drawn products are required to undergo a redrawing operation.

- Adnan I.O. Zaid is a full professor in Industrial Engineering in University of Jordan, Jordan, 11924. E-mail: adnan_kilani@yahoo.com
- Fadhil A. Hashim is currently a Mechanical Engineer

Recently, the area of research in this field has extended and covered different aspects of the process, e.g. warm and hot deep drawing. Nowadays, considerable effort is being devoted to warm and hot deep drawing due to its effectiveness for enhancing formability e.g. [5-7], surface texture and grain size, [16, 20], friction and lubrication, [20-26], simulation using finite elements, FE, [24-26] and the control of the distribution of the holding down force. The control of strain paths by means of variable blank holder force is used by many authors to enable successful drawing of parts with complex geometries, which could not have been drawn using a constant blank holder pressure. Brief description of these publication is summarized by the authors, [27].

The plastic instability of cup drawing is usually measured by the limiting drawing ratio (LDR). A new and practically applicable equation for estimating the LDR in the cylindrical cup drawing with a flat nosed punch using process parameters namely yield strength, strain hardening exponent, strain rate sensitivity, normal anisotropy value, friction coefficient, die profile radius and half die opening has been derived using an integral technique based on the load maximum principle for localization of plastic flow. The obtained results have shown that LDR increases with the increase of strain rate sensitivity. Furthermore, they showed that there is an interaction between the process parameters and the LDR which made possible to better understand and control the cup drawing behavior for optimum press drawability.

2 MATERIALS, EQUIPMENT AND EXPERIMENTAL PROCEDURES

2.1 Materials

The specimens were circular discs of 180 mm diameter and 0.387 thickness made from 70/30 brass of the mechanical behavior shown in Fig.2.

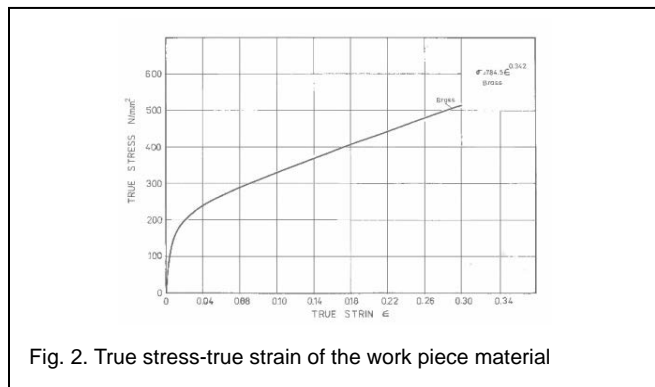


Fig. 2. True stress-true strain of the work piece material

2.2 Equipment and Experimental procedures

The deep drawing tests were carried out using the deep drawing die shown in Fig.3 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.

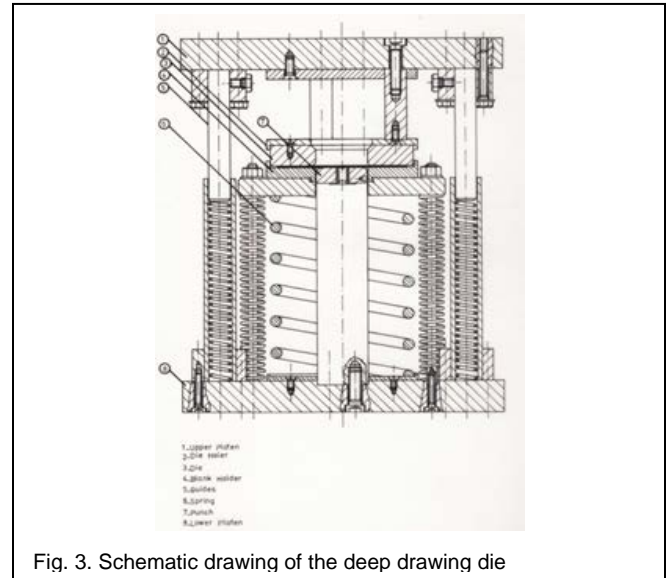


Fig. 3. Schematic drawing of the deep drawing die

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

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.

Tables 3 and 4 respectively.

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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	Die profile radius (mm)	Rdn/dr
rd1	2	4.77
rd2	4	9.53
rd3	6	14.3
rd4	10	23.84
rd5	15	35.75

3 RESULTS AND DISCUSSION

In this section, the main parameters affecting the deep drawing process discussed which include: the drawing ratio, holding down pressure, radial clearance percentage, punch and die profile radii, the thickness strain distribution, maximum amount of thinning and its location, maximum drawing force and the total consumed work are presented and discussed.

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 as 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 The 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 psi of blank contact area 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 Die Profile Radius on the Autographic Records

Figure 4 shows the autographic records for the combination of punch 2, P2, with the five dies: D1, D2, D3, D4 and D5 Whereas, Fig. 5 shows the autographic records for the combination of punch 4, P4, with the same five dies. It can be seen from these two figures that the general trend in both of them is similar except in the maximum drawing force and the value of the punch travel for the successfully drawn cups despite that the curves are sharper in case of Fig. 5 i.e. less distance in punch travel and of higher value of the maximum drawing force knowing that the punch profile radius in Fig.5 is 5 mm and in Fig.4 is 15 mm. Furthermore, it can be observed that the difference in the maximum force in case of P4 is more pronounced than in case of P2 unlike the expectations as it is expected that the maximum force will be sharper and higher in P2 as the strain hardening is higher for a sharper bend. This indicates that the maximum drawing force is more affected by the die profile radius as compared to the punch profile radius. This agrees with the previous findings for drawing of galvanized cylindrical steel cups, [27].

3.4 Effect of Die Profile Radius on the Thickness Strain Distribution

Figures 6 and 7 show the effect of die profile radius on the thickness strain distribution for the combinations of P2 with dies: D1 and D2 and P4 with D1, D2 and D3 respectively. It can be seen from these two figures that the general trend is the same in which the upper part of the cup thickens and the part around the punch profile radius suffers from thinning. Also it can be seen the two necks on each curve. These two necks are well established and repeatedly reported in the literature in the drawing of flat ended cylindrical cups, [8, 9, 22]. However their value and their location varies depending on the value of the die profile radius and the punch and die combination as illustrated in Fig.8. It is worth mentioning in this respect that if the amount of thinning in any of these two necks exceeds certain limit it will lead to fracture.

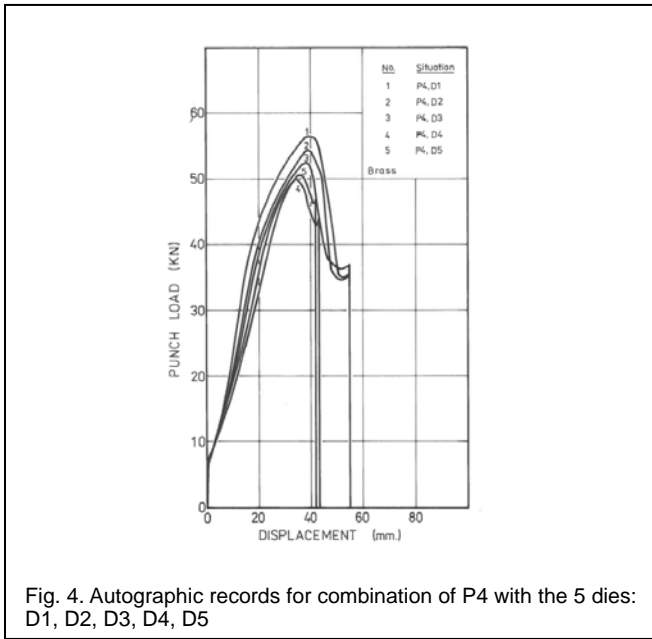


Fig. 4. Autographic records for combination of P4 with the 5 dies: D1, D2, D3, D4, D5

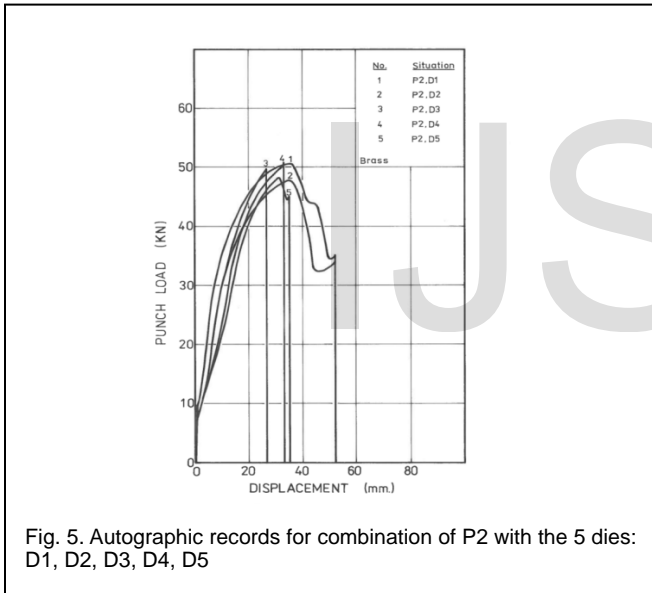


Fig. 5. Autographic records for combination of P2 with the 5 dies: D1, D2, D3, D4, D5

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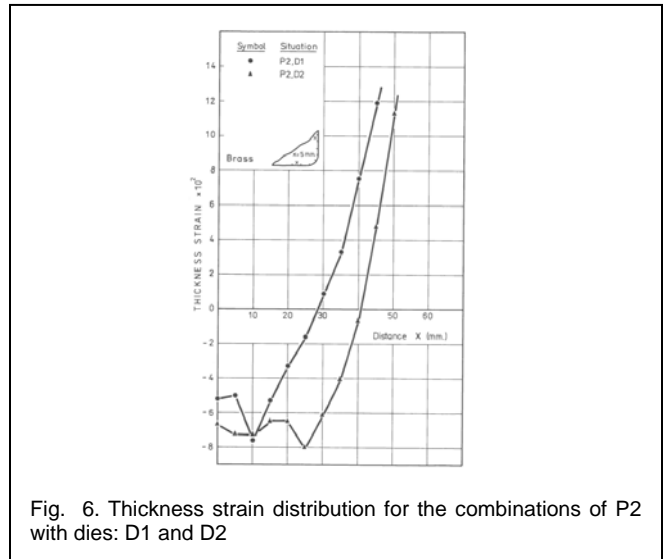


Fig. 6. Thickness strain distribution for the combinations of P2 with dies: D1 and D2

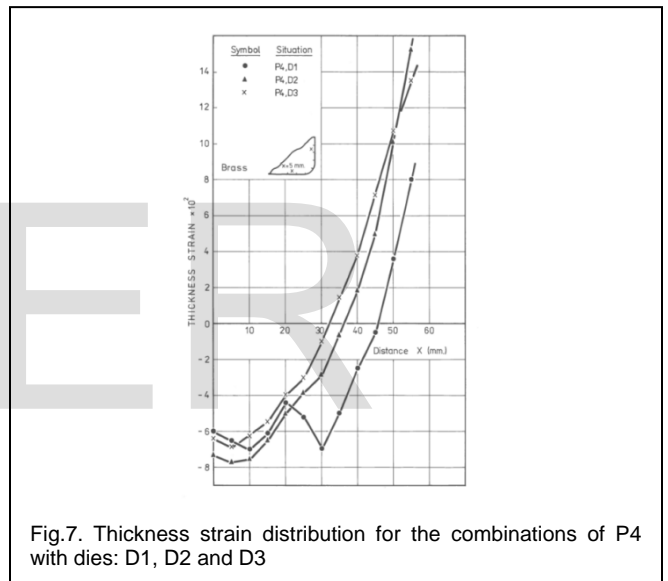


Fig.7. Thickness strain distribution for the combinations of P4 with dies: D1, D2 and D3

3.6 Effect of Die Profile Radius on the Maximum Drawing Force

It can be seen from Fig. 9 that the maximum drawing force decreases with the increase of die profile radius for successfully produced cups and for all punches and dies combinations. However, it was observed that its liability for wrinkling increased. Furthermore, it can be seen with reference for Figs 5 and 6 that the force also increases with the increase of the distance of the punch travel and it is not possible to produce successful cups for a die profile radius less than 2 mm irrespective of the punch profile radius which corresponds to five times the original sheet thickness. Similarly, it is not possible to produce successful cups if the die profile radius is larger than 6 mm which corresponds to 15 times the original sheet thickness. These values agrees with the same values found by the authors for galvanized steel, Ref. [27]. Regarding the effect of the punch profile radius, it is unlike the die profile radius as the maximum drawing force increases with increase of the punch profile radius up to 15 mm then it starts to decrease.

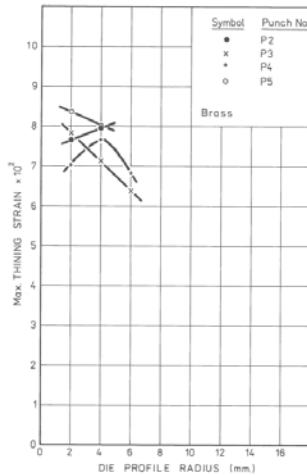


Fig. 8. Effect of die profile radius on the maximum thinning

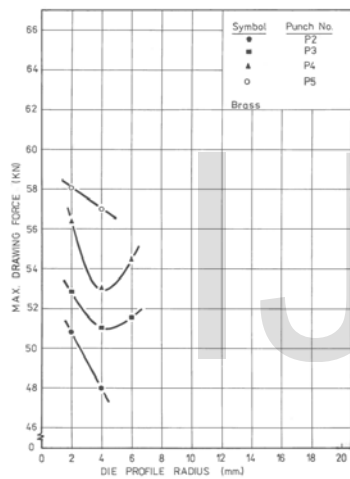


Fig.9.. Effect of die profile radius on the maximum drawing force

3.7 Effect of Die Profile Radius on the total consumed work

Examination of Fig. 10 reveals that the total consumed work represented by the area under the autographic record as measured by the plan meter decreases with increase of the die profile radius in a linear manner irrespective of the punch profile radius although the maximum drawing force was increased as explained in the previous section. Also, it can be seen from the figure that the total work is more affected by the die profile radius than the punch profile radius, this is attributed to the work consumed in the plastic deformation being much more in the case of the die profile radius the great majority of the sheet will be bent over the die profile radius (the part which forms the cup wall) as compared to a small part of the sheet which will bend over the punch profile radius which forms the cup corner.

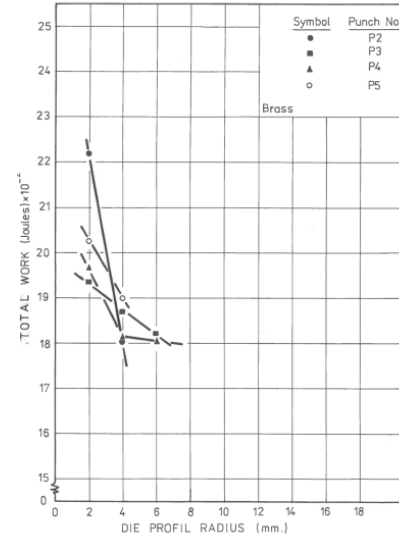


Fig. 10. Effect of die profile radius on the total consumed work

4 CONCLUSIONS

Within the experimental limitations and keeping all the parameters involved in the process constants at their optimal values except the punch and die profile radii the following points are concluded;

- i). The maximum drawing force is greatly influenced by the punch and die profile radii in the following manner: it decreases with increase of the die profile radius, whereas its liability for wrinkling increases. The optimum value of die profile radius for the used brass material was found at 6 mm which equals about 15 times the original sheet thickness.
- ii). The maximum drawing force is less affected by the punch profile radius as compared to the die profile radius.
- iii). The total consumed work decreases with increase of die profile radius at all punch-die combinations.
- iv). Despite the fact that the research work on deep drawing has been going on since 1939, it is far from being complete and the parameters are still not optimized to get rid of the encountered defects in the produced parts and renders the process cost effective.

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