EFFECT of SOME GEOMETRICAL PARAMETERS on the MAXIMUM FORCE, ENERGY and THICKNESS STRAIN DISTRIBUTION in the DEEP DRAWING PROCESS

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 radial clearance percentage, punch profile radius, and die profile radius on the force, energy requirements and the quality of the deep drawing of steel cylindrical cups are investigated. The quality is assessed by the reduction in thinning and the encountered defects.The maximum drawing force and the consumed work are also determined. The obtained results are presented and discussed.

Index Terms— Effect, Geometrical parameters, Maximum force, Consumed work, Thickness strain, Deep drawing, Steel.

◆

1 INTRODUCTION

DEEP drawing process is one of the most widely used manufacturing process among the sheet metal forming processes particularly in the automobile and aircraft industries. For example, it is used for manufacturing a large number of the body and spare parts. In its simplest form it may be defined as a secondary forming process by which a cylindrical shape or alike, e.g. cone, frustum, is produced from a thin sheet metal. As early as 1939 when Swift published his first paper on deep drawing of flat ended cylindrical cup which is known as Swift cup, [1, 2] and followed by the deep drawing of hemispherical end cup; [3]. Researchers of metal forming engaged in investigating the process and optimize the parameters affecting it, [4- 14].

1.1 Mechanism of deformation

The deep drawing mechanism is a complicated process regarding the different types of stresses which exists on each region in the blank. To facilitate the understanding of the mechanism, the blank is divided into three regions X, Y and Z. The outer annual region X is sandwiched between the die at its bottom part and the blank holder at its top part. Region Y, the inner annular region is not in contact with either the punch or the die and Z the central region of the blank is only in contact with the punch as illustrated in Figure 1. When the compressive force is applied to the punch, the draw proceeds the material in region X starts to draw progressively inwards towards the die profile under the effect of the applied tensile stress resulting in continuously decreasing the radii in this region which causes induced compressive hoop stress which causes an increase in the material thickness at the outer part of region X. Unless holding down pressure is applied, the induced hoop stress will cause the blank to fold causing wrinkling. When the material in region X passes over the die profile it is thinned by plastic bending under the effect of the tensile stress. The net effect of the outer part of region X is increase in thickness of the material. Regarding the material in region Y, it can be readily seen that it is subjected to bending and sliding over the die profile; part to stretching in tension in the clearance region, part to stretching between the die and punch in the clearance zone and part to bending and sliding over the punch profile. Finally, zone Z is subjected only to stretching and sliding over the punch head. The above mechanism can be summarized in accordance with the above division of the blank and the type of stresses which each region is subjected to:
(i). Pure radial drawing between the die and the blank holder.
(ii). Bending and sliding over the die profile.
(iii) Stretching between the die and the punch in the clearance zone.
(iv). Bending and sliding over the punch profile radius.
(v). Stretching and sliding over the punch head.
Various parts of region X may go through some or all of the processes (i), (ii) and (iii); while parts of region Y may go through some or all of processes (ii), (iii) and (iv); finally, parts of region Z may go through some or all of processes (iii), (iv) and (v).
It should be noted that process (i) causes thickening of the blank whereas processes (ii), (iii), (iv) and (v) causes its thinning.
Figure 1 shows the variation of the thickness along the wall of a drawn cylindrical cup for a flat headed and hemi-spherical punches.

- *Adnan I. O. Zaid is currently a professor in Mechanical and Industrial Engineering Department, Applied Science Private University, Amman 11931 Jordan. E-mail: adnan_kilani@yahoo.com*
- *Fadhil A. Hashim is currently Materials Engineering, University of Technology, Baghdad, Iraq. E-mail: hashembsb@yahoo.com*

In hemi-spherical punches, making allowance for bending over the punch profile radius is not essential, whereas in the more general case of drawing with a flat-headed punch, making allowance for bending over the die and punch profiles, has not yet been solved. The punch load at any phase of drawing is determined by the forming region. If the blank is held rigidly at the die to prevent radial drawing the process becomes one of pure stretch-forming. Extensive and detailed experimental and theoretical investigations of cup-drawing have been carried out by different researchers, aiming at reducing the different encountered in the process and improving the quality of the produced parts, [3]. Since then the researchers in the metal forming were engaged in investigating the parameters involved in the process, the defects in the process and how to treat them, Refs.[4-14].

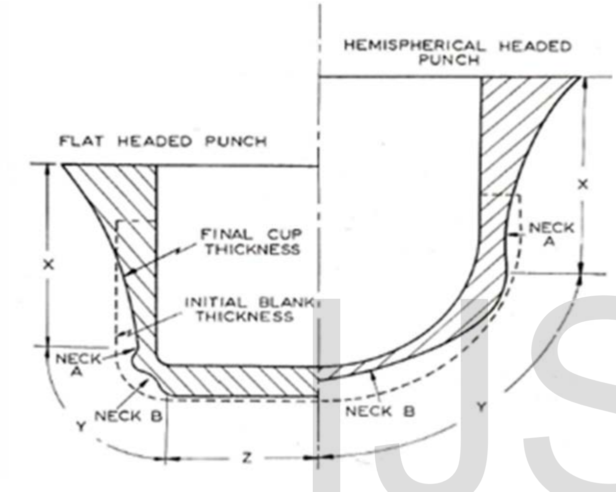

Fig. 1 Sections through deep drawn flat ended and hemi spherical cups with flat and hemispherical-headed punches

Recent experimental investigation on the effect of radial clearance percentage, punch and die profile radii on their autographic records (punch load- punch displacement curves) and on quality of the produced blanks is carried out and the results are presented and discussed.

Recently, the area of research in this field has extended and covered different aspects such as:.

1). Warm and hot deep drawing. Nowadays, considerable effort is being devoted to warm or hot deep drawing due to its effectiveness for enhancing formability e.g. [5–7], while less attention has been given to the investigation of deformation behavior during cold deep drawing, [16-19].

2). Surface texture and grain size, [16,20].

3). Friction and lubrication, [20-26].

4). Simulation using finite elements, FE, [24-26].

[5]. Controlling 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.parts.

Several methods for application of variable blank holder force in the deep drawing process have been presented. However, the main aim remained the same optimizing the parameters and producing cost effective, clean and non-defected parts.

The available literature on these areas is voluminous and reviewing it is beyond the scope of this paper, [15-26].

2 MATERIALS, EQUIPMENT AND EXPERIMENTAL PROCEDURES

2.1 Materials

The specimens were circular discs of 180 mm diameter and 0.42 mm thickness made from carbon steel with the following wt. percentages: 0.22% C and 0.5 Mn and the remainder is Fe. They were annealed before being used. Their mechanical behavior in the annealed condition is shown in Fig.2.

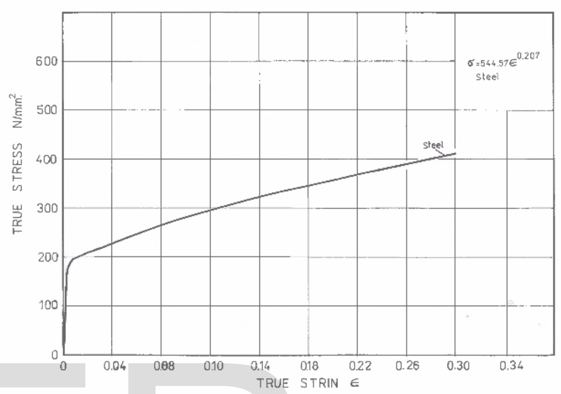

Fig. 2.The true stress - true strain curve of the work piece material

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.

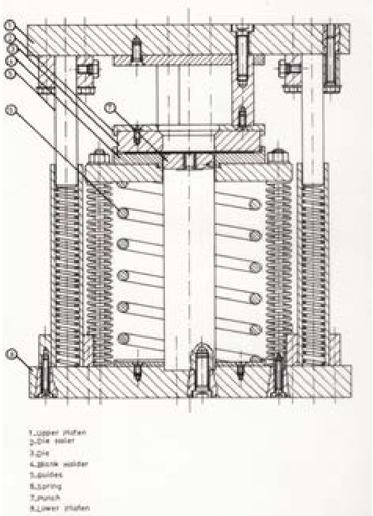

Fig. 3. Schematic drawing of the deep drawing die

The compression spring, the punch, die and all the punches and dies used in this investigation were all made of X12M tool steel of the chemical composition shown in Table 1.

The deep drawing tests were carried out using the die shown in figure 4 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. The sleeves and the blank and die holders. All were made from galvanized carbon steels. Compression springs and the punch and die which were made of X12M die steel of the chemical composition shown in Table 1.

TABLE 1
CHEMICAL COMPOSITION OF X12M DIE STEEL

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

All the punches and dies which were used for investigating the different parameters in this paper were all made of the same material, X12M and heat treated in accordance with the heat treatment cycle which was recommended by the suppliers. The obtained hardness, as measured by Rockwell Hardness, is RC 65. Their diameters were measured using the Tool Makers travelling microscope and their profile radii were determined using the shadow graph at magnification X20. The values of the radial clearance percentages are shown in Table 2 and the five punches and five dies with the different profile radii were machined and ground under the same cutting conditions and their dimensions are shown in Tables 3 and 4 respectively.

All the tests were carried out on the Universal testing machine, Instrun type, of 250 KN at cross head speed of 10 mm / minute, from which the autographic record, (punch force – punch travel) was obtained and used for determining the required values.

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
THE VALUES OF PUNCH PROFILE RADIUS, (MM)

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
THE VALUES OF DIE PROFILE RADIUS, (MM)

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 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 the deffects encountered in the process 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. It was found from the the autographic record,(punch load versus punch travel) for different blank diamet 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 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 Radial clearance between punch and die

Radial clearance between punch and die throat may affect the drawing process directly by controlling the freedom of the walls either to thicken or to taper and pucker. It can be seen from figure 6 that the maximum drawing force is greatly influenced by the radial clearance particularly when its value is less than the blank thickness i.e. the case known as ironing condition where it increased more than three folds. As the clearance increases above the blank thickness it becomes less affective until it reaches a constant value e.g. it can be seen that the best radial clearance percentage for the steel used material was the difference in the maximum drawing force all C / to % above 100 % within the tested range does not exceed 10 %, however at 130 % the produced cups have least wrinkling and ears height. This is in agreement with the results reported in reference [3] for mild steel. Hence a net radial clearance of about 30 per cent is suitable for general purposes, with free drawing and a reduction of 50 per cent, and this has the sanction of practical experience. 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 re-drawing operation. A more important feature than the drawing force is the local strain in the blank, which may lead to local necking and finally to cracks and fracture. Radial stresses tend to thicken the blank at its rim, while bending and sliding over the die profile and the punch head tends to thin it. The most serious thinning arises from the stretching over the punch head and particularly between the punch head and the die.to reduce the thinning as much as possible to avoid cracks which will lead to fracture.

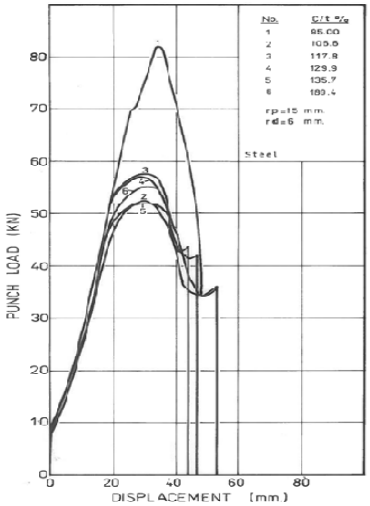

Fig. 4. Effect of radial clearance percentage on the autographic record of the deep drawing process

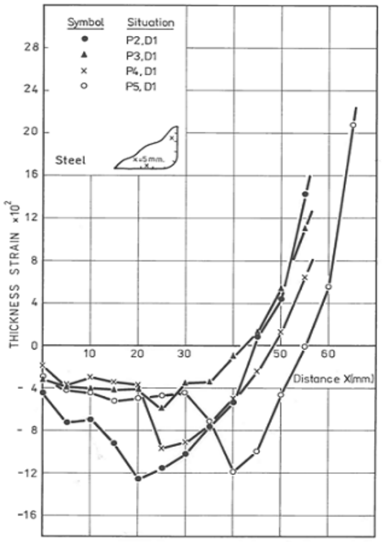

Fig. 5 Thickness strain distribution for the Combination of P2 with D2. D3. D4 and D5

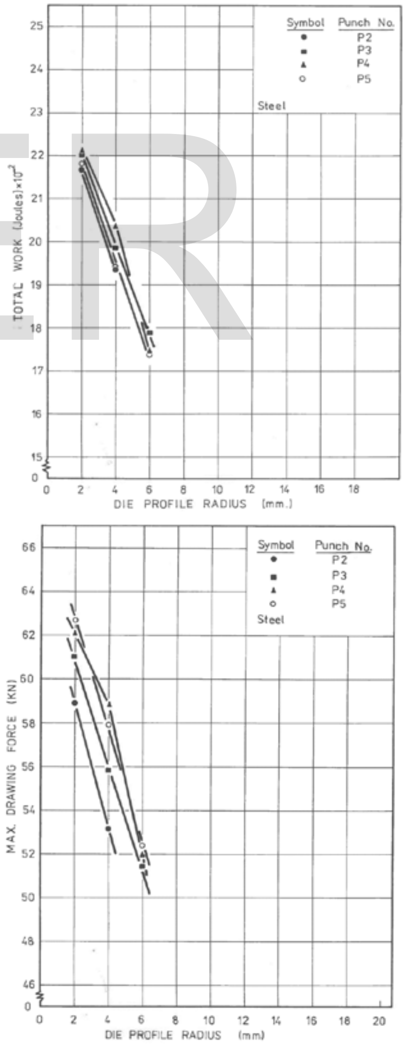

Fig. 6. Effect of die profile radius on the consumed work and maximum drawing force

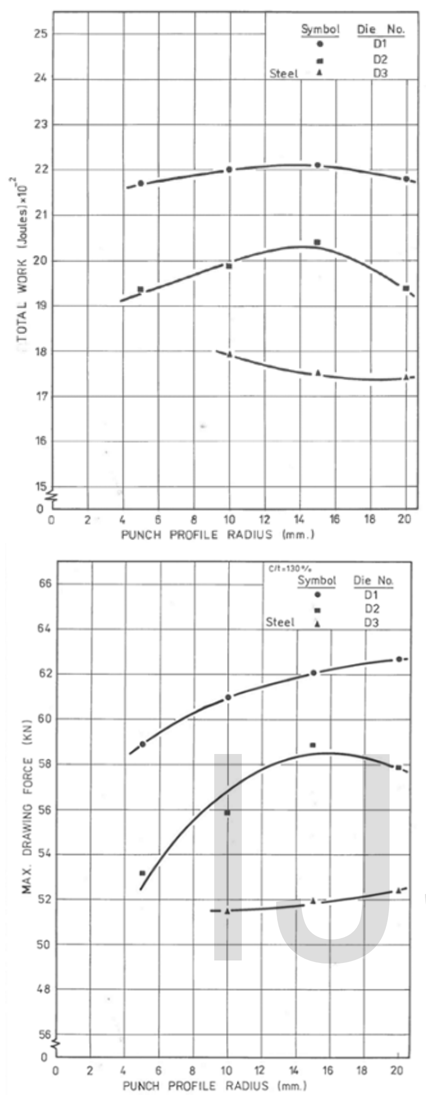

Fig. 7. Effect of punch profile work on the work consumed and maximum drawing force

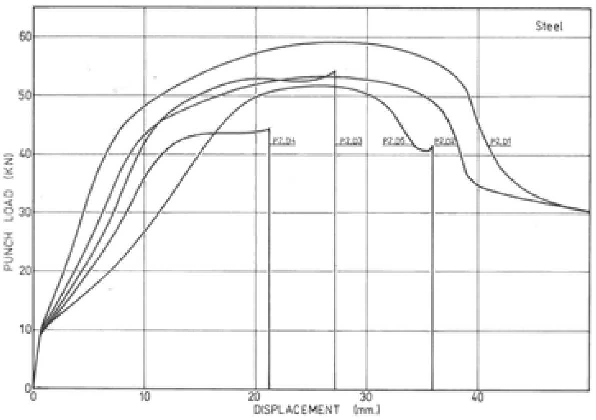

Fig. 8. Autographic records, (punch force – punch travel) for P2 with the five dies

In general, there is not a great difference between the values of thinning among the investigated values of C / to %. It is worth noting from figure 5 that all the thinning occurs at punch profile zone of the blank which is subjected to bending and tension as much as possible it is required to maintain high frictional condition on the punch while maintaining low friction everywhere else similar to mandrill drawing.

The effect of radial clearance percentage on the thickness strain distribution on the used steel is shown in figure 3. It indicates that the maximum thinning is 6 % which occurred at 106 % radial clearance percentage. In general, there is not a great difference between the values of thinning among the investigated values of C / to %. It is worth noting from figure 3 that all the thinning occurs at punch profile zone of the blank which is subjected to bending and tension.

4 CONCLUSION

Within the experimental limitations, regarding the investigated geometrical errors the following points may be 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 more than three folds the clearance increases above blank thickness it becomes less affective until it reaches a constant value. The best radial clearance percentage for the steel used in this work was found at 130 % which 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 maximum drawing force increases with increase of the punch profile radius, rp up to rp = 15 mm then it starts to decrease. However, it was less affected by rp as compared to 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 cost effective.

ACKNOWLEDGMENT

The author is grateful to the Applied Science Private University, Amman, Jordan for the financial support granted to this research (Grant No.DRGS-2015).

REFERENCES

[1] Swift H W 1939-1940, Proc. Inst. Of Automobile Eng.,34, 361.
[2] Swift H W 1948, Engineering, 166, 333 and 357.
[3] Chung S Y, Swift H W 1951 Cup-drawing from a Flat Blank, Proc. Inst. Mech. Engrs.165. 199.
[4] Hesenberg W C F 1954 A simple Account of some of Professor Swift Work on Deep Drawing, B.I. S.R.A. Report MW/1954.

[5] Johnson W, Mellor P B 1980 Engineering Plasticity, The Camelot Press Ltd., Southampton, U.K.

[6] Alexander, J M 1960, Metal Review 5, No 19.

[7] Chiang D C, Kobayashi 1966, J. Engng. Industry, 88, 443.

[8] El-Sebaie M G, P B Mellor 1972, Int. J. Mech. Sci.,14, 535.

[9] El-Sebaie M G, P B Mellor 1973, Int. J. Mech. Sci., 15, 485.

[10] Panknin W 1976 , Sheet Met. Ind. 53, .

[11] Gransow W G 1979, Sheet Met. Ind., 56, 561.

[12] Gotoh M 1980, Int. J. Mech. Sci., 1980, 22, 367.

[13] Yu X T, Johnson W 1982, Int. J. Mech. Sci., 24.

[14] Fukui S, Hansson, Analytical Study of Wal Il Ironing, Considering Work-hardening. Annls of C.I.R.P., 18, 593.

[15] Freeman P, Leeming H, Ironing of Thin-walled Metal Cups-the Distribution of the Punch Load, B.I.S.R.A. Report No.MW/E/46/53.

[16] Ehsan Afshin, Mehran Kadkhodayan, An experimental investigation into the warm deep-drawing process on laminated sheets under various grain sizes, Materials and Design 87 (2015) 25–35.

[17] S. Yoshihara, K. Manabe, H. Nishimura, J. Mater. Process. Technol. 170 (2005) 579–585.

[18] M.H. Lee, H.Y. Kim, H.K. Kim, G.D. Kim, S.I. Oh, Mater. Trans. 49 (2008) 1120–1123.

[19] L. Li, X.M. Zhang, C.P. Tang, Y.L. Deng, N. Zhou, Mater. Sci. Eng. A 527 (2010) 1266–1274.

[20] Xinsheng Huang, Kazutaka Suzuki Yasumasa Chino , Mamoru Mabuchi, Modelling mixed lubricaton for deep drawing processes, Wear, Vol. 294–295 (2012), pp.296–30

[21] S.J. Allen, S.M. Mahdavian, The effect of lubrication on during the deep drawing of axisymmetrical steel cups, Journal of Materials Processing Technology, 199 (2008).

[22] X. Roizard , J.M. Pothier , J.Y. Hihn , G. Monteil , Experimental device for tribological measurement aspects in deep drawing process, 199 (2008) pp. 102–107.

[23] Feng Gong , Zhi Yang , Qiang Chen , Zhiwen Xie , Dayu Shu , Jiali Yang, Influences of lubrication conditions and blank holder force on micro deep drawing of C1100 micro conical–cylindrical cup, Precision Engineering 42 (2015) pp. 224–230.

[24] X. Roizarda,∗, J.M. Pothiera,b, J.Y. Hihnb, G. Monteila, Experimental device for tribologicl measurement aspects in deepdrawing process, journal of materials processing technology, 209 (2009) pp. 1220-1230.

[25] Tom Walde *, Hermann Riedel, Simulation of earing during deep, Acta Materialia 55 (2007), PP. 867-874.

[26] T. Khandeparkar *, M. Liewald, Hydromechanical deep drawing of cups with stepped geometries,Journal of Materials Processing Technology, 202 (2008) pp.246-253.

[27] Søren Tommerup,Benny Ende Benny Endelt, Experimental verification of a deep drawing tool system for adaptive blank holder pressure distribution, Journal of Materials Processing Technology 212 (2012) 2529–2540