Experimental Researches regarding the Forming Limit Curves Using Reduced Scale Samples

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Abstract

In this paper, an alternative solution to Haşek method, named conventional, for forming limit curves determination is proposed. New types of samples, for the experimental research, were used, which dimensions are reduced three times in comparison with the conventional ones. These samples were used for a thicker material. The experimental work assumed the manufacturing of a new dies, for cutting and forming, the manufacturing of the new sample and a lot of experimental tests. The obtained results are in concordance with the ones that correspond to conventional method. Next improving, in control of the material restraint and binder force, must be considered for refining the results.
Keywords: *forming limit curve, deep drawing, FLD, circle grid analysis*

1. Introduction

The deep drawing process is applied with the intention of manufacturing a product with a desired shape and no failures. The tools, the blank and the process parameters define deep drawing final product shape. 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.

In the deep drawing the most common defects are presented in figure 1 [1]. In figure 1, the notations are: 1. flange undulation; 2. side undulation; 3. piece wrinkling; 4. circular traces; 5. scratches; 6. orange peel; 7. Luders bands; 8. cracking of piece flange or piecebottom; 9. edges crackings; 10.- disalignment; 11. contour disalignment; 12. festoons; 13. delaminations; 14. edge festoons [1]. Some of these are the result of the dies (5, 9, 10, 14), another are due to friction conditions (1, 4, 13), others are as the result of the material composition (6, 13) and of the mechanical properties of the material (1, 2, 3, 6, 7, 8, 11) and others are as the result of the piece form (12, 14). For deep drawing by stretching only defects of types 3, 6 and 8 are common [1].

The forming limit curves, FLDs, is one of the method in examining the failure potential, which include a good representation of material's stretchability and the easiness when used for trouble shooting.

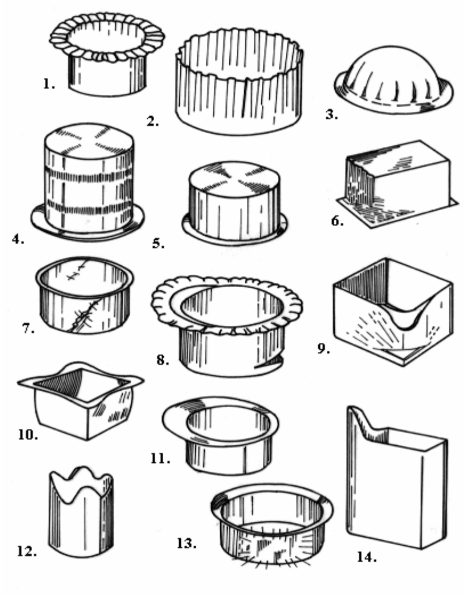

Fig. 1. - Types of defects in deep drawing [1]

The forming limit curves (FLDs) is derived from the circle grid analysis. Circle Grid strain analysis (CGA) is a technique employed during die tryout, and sometimes during production, to analyze and quantify plastic deformation in sheet metal. Analysis of the grids can suggest methods for reducing forming severity, making die tryout more of a science and less an art. From practical point of view, the use of FLD assumed to know both the maximum deformations of the piece and the material FLD curve. By putting the value of the piece maximum deformation on the curve, it will result if it possible to obtain a sound product or not, because the FLD curve divide the regions of deformations in two parts, respectively: all the points which are downstairs the curve are in the safe zone and all the points which are placed upstairs the curve are in the crack zone.

The Haşek method, from referred to as the conventional large method, to make FLCs steel sheets with a thickness around 1 mm used a specific tool arrangement. A new method, referred to as the small method [2], to measure strains on steel sheets with a thickness of 0.6 mm and smaller will have to use another set of tools. The idea was to shrink the conventional toolset, along with the test specimens, with one third and make FLCs on steel sheets three times thinner, hopefully receive the same results, according to [2]. If a scaling factor exists between the curves or if they obtain the same FLC-level it will be convenient.

Using these new types of specimens, in the paper, are presented some results of the researches, made for strain distribution determinations and for the visualization of the critical areas of strains in the material.

2. Experimental work

The material used was A3k made by MITAL STEEL, which have 0,6 mm thickness and next composition: C – max. 0,08 %; Si – max. 0,03 %; Mn – 0,20 - 0,40 %; S – max. 0,035 %; P – max. 0,030; Ni – max. 0,08 %; Cu – max. 0,08 %; Cr – max. 0,06 %.

The average mechanical properties for the material A3k are presented in table 1.

Table 1. A3k Average mechanical properties

Material	$R_{p0,2}$, [MPa]	R_m, [MPa]	A_{50} [%]
A3k	184.7	342.5	Min. 34

The tool arrangement for the hemispherical dome test was based upon the Haşek conventional toolset to create FLCs but scaled with one third.

Table 2 contains the dimensions.

Table 2. - Tool dimensions used to determine FLCs

Tool	Dimension, (mm)
Punch diameter	33
Die aperture	35
Die radius	3

The tools for deep drawing were manufactured in the Department of Manufacturing, Dunărea de Jos University of Galați, and are showed in figure 2 along with a setup of these.

Specimen design and preparation

This initial design was used to evaluate the idea if it was possible to keep the original shaped specimens downsized with a third. The steel sheets used for these tests had a thickness of 0.6 mm, as already was mentioned. They were prepared in the rolling direction, to force the crack transverse to this direction.

Fig. 2. - Tool arrangement and setup for Press 200 KN

The specimens were punched using the equipment presented in figure 3.

They were cutting because it this method didn't gave a heat-influenced zone to the edge of the material that could affect the test result. It also provides a somewhat good edge that acquires a relatively small grinding effort. The test samples were shaped according to figure 4. The arrow indicates the rolling direction of the sheet.

Fig. 3. - Tool arrangement for cutting

The dimensions of A and R are constant. A is equal with 70 mm and R is equal with 50 mm. B is varying according to table 3. All values in the table are scaled with one third from the original sized specimens.

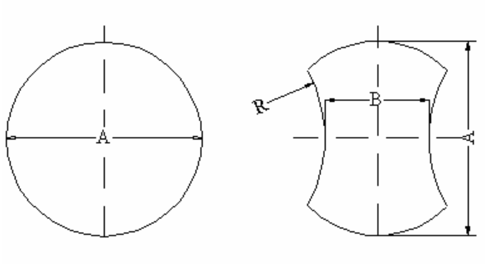

Fig. 4. - Shape of the initial test specimens

All specimens used were grinded on the edge in the length direction of the specimen before being etched and tested. It is essential to provide a good edge surface to avoid initiation of fracture that will lead to a non-accepted test result. The square grid pattern used was 2 mm and etched with the electrochemical process.

Table 3. - Initial test specimen’s dimensions

Number of specimen	**1**	**2**	**3**	**4**	**5**	**6**	**7**
B(mm)	0	63	40	33	20	13	7

Figure 5 shows a photograph of the etched samples.

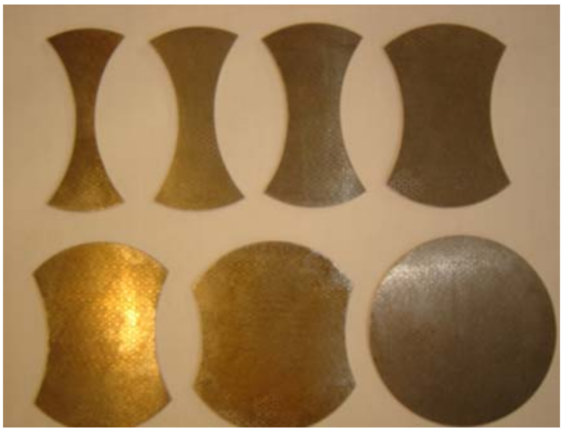

Fig. 5. - The specimens used for FLD determination

Before any testing was performed, the samples were lubricated with deep drawing oil. The testing was performed with a clamp force of 50 kN and a punch speed of 5 mm/s. Also, the necking of a specimen must start from the centre and transverse to the rolling direction otherwise it is a no correct test.

In a second attempt for the complete series, a thin film of polymer and oil was interlaid between binder and piece.

3. Experimental results

The specimens were formed till the cracks become visible. When testing this samples, some of the test specimens failed. The failed specimens got ripped apart in the edge of the die instead of cracking in the centre as they were supposed to. Figure 6 illustrates a correct test and a failed one. Figure 7 presents a success samples.

Fig. 6. - Failed specimen to the die edge to the left and a correct specimen on the right.

Fig. 7. – Success samples: Specimens 7, 6 and 1 from left to right

The specimens were measured by using the circle grid method as mentioned upwards. Due to the presence of curvature in the specimen surface after deep drawing procedure, it was chosen to print ellipse’s principal axis points over a scotch with a thin marker. Then the scotch was stuck into a sheet to measure the points by means of an optical traveling microscope equipped with two right angle slides on which work is mounted. The work is positioned under the microscope. Cross wire is aligned at one end and the measurement is taken. The cross wire is then aligned on the other end by moving the work table and the measurement is taken. The difference between the two readings gives the absolute measurement. The major and minor diameter values were obtained by that simple and accurate method. Once the measurement stage is finished, the readings are collected in an Excel worksheet.

In the following tables are presented the results of the measurements for three samples.

Tables 4. – Readings for Specimen 1 (mm)

Ellipse Number	Major Diameter (d_{max})	Minor Diameter (d_{min})	Original Circle Grid Diameter (d_0)	d_{max}/d_0	d_{min}/d_0
1	3.195	2.873	2.000	1.598	1.437
2	2.934	2.652	2.000	1.467	1.326
3	2.782	2.516	2.000	1.391	1.258
4	2.716	2.317	2.000	1.358	1.159
5	2.592	2.190	2.000	1.296	1.095

Table 5. – Readings for Specimen 6 (mm)

Ellipse Number	Major Diameter (d_{max})	Minor Diameter (d_{min})	Original Circle Grid Diameter (d_0)	d_{max}/d_0	d_{min}/d_0
1	3.171	1.599	2.000	1.586	0.799
2	2.652	1.781	2.000	1.326	0.890
3	2.602	1.857	2.000	1.301	0.929
4	2.535	1.879	2.000	1.268	0.940
5	2.361	1.965	2.000	1.181	0.983

Table 6. – Readings for Specimen 7 (mm)

Ellipse Number	Major Diameter (d_{max})	Minor Diameter (d_{min})	Original Circle Grid Diameter (d_0)	d_{max}/d_0	d_{min}/d_0
1	3.276	1.900	2.000	1.638	0.950
2	2.814	1.962	2.000	1.406	0.981
3	2.631	1.978	2.000	1.316	0.989
4	2.462	1.990	2.000	1.231	0.995
5	2.070	1.992	2.000	1.035	0.996

The deformations ε_1 and ε_2 are calculated with the formulas:

$$\varepsilon_1 = \ln\frac{d_1}{d_0}\ ;\ \ \varepsilon_2 = \ln\frac{d_2}{d_0}\ ;\ \ \varepsilon_3 = \ln\frac{t}{t_0} \qquad (1)$$

where: ε_1 and ε_2 are the major and minor strains; d_1 and d_2 – major and minor axes of the ellipses; d_0 – diameter of the initial circles; ε_3 – thickness strain; t_0 - initial thickness; t – final thickness.

Total strain ε is calculated with the following expression:

$$\bar{\varepsilon} = \left[\frac{3}{4}\left(1+\beta+\beta^2\right)\right]^{\frac{1}{2}} \qquad (2)$$

where β is the strain ratio given by:

$$\beta = \frac{\varepsilon_2}{\varepsilon_1} = \frac{\ln(d_2/d_0)}{\ln(d_1/d_0)} \qquad (3)$$

The obtained results for the strains are presented in tables 7.- 9.

Table 7. – Specimen 1

Ellipse Number	ε_1	ε_2	ε_3	β	$\bar{\varepsilon}$
1	0.468	0.362	-0.831	0.773	1.334
2	0.383	0.282	-0.665	0.736	1.307
3	0.330	0.230	-0.560	0.484	1.278
4	0.306	0.147	-0.453	0.231	1.133
5	0.259	0.091	-0.350	0.123	1.051

Table 8. – Specimen 6

Ellipse Number	ε_1	ε_2	ε_3	β	$\bar{\varepsilon}$
1	0.461	-0.224	-0.237	-0.486	0.750
2	0.383	-0.116	-0.166	-0.411	0.754
3	0.330	-0.074	-0.189	-0.282	0.773
4	0.306	-0.062	-0.175	-0.263	0.778
5	0.259	-0.018	-0.148	-0.106	0.824

Table 9. – Specimen 7

Ellipse Number	ε_1	ε_2	ε_3	β	$\bar{\varepsilon}$
1	0.493	-0.051	-0.442	-0.104	0.825
2	0.340	-0.019	-0.321	-0.056	0.843
3	0.274	-0.011	-0.263	-0.040	0.849
4	0.208	-0.005	-0.203	-0.024	0.856
5	0.034	-0.004	-0.030	-0.117	0.820

4. Conclusions

For the experimental research were used new types of samples which dimensions are reduced three times in comparison with the original ones. These samples were used for a thicker material (0.7 mm).

The informations obtained from samples deformations, modeled different strains states in material, from a biaxial state for the sample 1 to a uniaxial state for the sample 7. A concordance with the real strains states in deep drawing could be made.

However the experimental work must be improved in the case of using thicker materials. This improving must consider the obtaining of a higher binder force or a new system for material restraint.

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Cercetări experimentale privind curbelor limită de ambutisare utilizând epruvete de dimensiuni reduse

Rezumat

În această lucrare se prezintă o soluție alternativă la metoda convențională Haşek de determinare a curbelor limită de ambutisare. Pentru cercetarea experimentală s-au folosit noi tipuri de epruvete ale căror dimensiuni sunt micşorate de trei ori în comparație cu cele convenționale. Aceste epruvete au fost folosite pentru un material cu o grosime mai mare. Cercetarea experimentală a presupus construcția stanței de decupare şi a matriței de deformare, fabricarea epruvetelor şi numeroase încercări experimentale. Rezultatele obținute sunt în concordanță cu cele care corespund metodei tradiționale. Pentru obținerea unor rezultate mai exacte vor trebui făcute câteva îmbunătățiri, legate de modul de reținere a semifabricatului şi de forța de reținere corespunzătoare.

Experimentell Erforscht Betreffend die Formsbegrenzung Kurven mit eine Verringerten Skala-Proben

Zusammenfassung

In diesem Papier wird eine Ausweichlösung zu den herkömmlichen Methoden für die Formung von von Begrenzung Kurven Ermittlung vorgeschlagen. Neue Arten der Proben, für die experimentelle Forschung, wurden benutzt, die Maße dreimal im Vergleich mit den ursprünglichen verringert werden. Diese Proben wurden für ein stärkeres Material benutzt. Die experimentelle Arbeit nahm die Herstellung von neue Würfel, für Ausschnitt und Formung, die Herstellung der neuen Probe und eine Menge experimentelle Tests an. Die erreichten Resultate sind in der Übereinstimmung mit den, die herkömmlicher Methode entsprechen. Zunächst, verbessernd, in der Steuerung der materiellen Begrenzung und der Mappe Kraft, muß für das Verfeinern der Resultate betrachtet werden.