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PRODUCTION OF COMPLEX PARTS BY DEEP DRAWING - DEFORMATION ANALYSIS

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ABSTRACT

The object of this paper is the deformation analysis aimed to determine the stability of the technological process of deep drawing complex steel sheet parts. The forming limit diagram is described. Analysis of the forming limit curves is made, whereas criteria for limit deformation are considered the moment when the maximum of even deformation is accomplished and the moment when crack occurs in the material. A procedure for determination of forming limit curves is elaborated. Forming limit curves are experimentally determined the according to the both criteria for the steel sheet Č0147 (RSt 13 according to DIN 17006). Finally, it is presented how this can be used practically.
Key words: *Deformation analysis, Forming limit diagram, Forming limit curve, Deep drawing of steel sheet.*

1. INTRODUCTION

One of the most practical methods for estimating the possibility of making specific complex parts using drawing processes and also estimating the stability of those processes is the deformation analysis which is based upon the use of the forming limit diagram (FLD). Forming limit diagram is used to determine the ability of a specific metal sheet workpiece to endure plastic deformation when exposed to certain stress – deforming conditions. The main deformations (strains) $\varphi 1$ and $\varphi 2$ in the dangerous section (the critical spot) are received by measuring the axes of the ellipses - the deformed circles on the circle grid that was previously graved on the workpiece. Knowing the dimensions of the diameter of the starting circle and the dimensions of the ellipse's axis, the main

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deformations φ1 and φ2 can easily be defined. Through to the values of φ1 and φ2 in the critical section (the critical spot) the limit of deformability of the sheet metal for the accurate operation can be established in terms of occurrence of a local deformation or a breakage.
Forming limit diagram has wide use: in the analysis of the reasons for local deformation and breakage in the dangerous section during drawing complex parts, in the selection of the sheet metal with a quality that will fit best the production of a specific product with drawing in terms of a reliable (safe) technological process, in defining the optimal form for the work piece, for making corrections in the tools for drawing complex parts, for making new tools etc.

2. FORMING LIMIT DIAGRAM

Forming limit diagram represents the ratio between the maximum of the major logarithmic deformations in the sheet metal plane φ_1(the major relative deformations ε_1 or the percentage deformations δ_1, depending on how the major deformations are given) that appear at the moment of local deformation or breakage (depending on the chosen criteria for limit deformation) and the corresponding deformations in the perpendicular directionφ_2 (ε_2 or δ_2). The forming limit diagram is given in the Figure1.

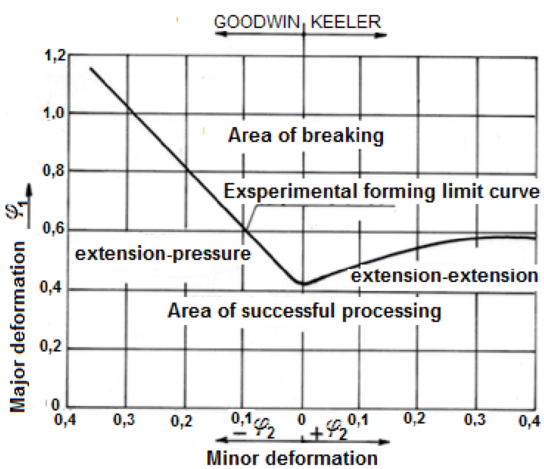

Fig.1 - Forming limit diagram

The forming limit curve divides the diagram in two areas: the area under the forming limit curve represents the area of a successful and reliable plastic processing and area above the forming limit curve that represents area of an unreliable plastic processing, area where it comes to breakage in the dangerous section of the drawn part.
The left part of the diagram (Goodwin's) is specific for the ratios of the deformations that are in the wreathduring typical deep drawing. It shows that if the perpendicular deformation ($-\varphi_2$) grows by its absolute value, and that happens if the appropriate negative stress grows ($-\sigma_2$), then the value of the limit deformation φ_1 grows as well.

The right part of the diagram (Keeler's) is specific for the ratios of the deformations during drawing. Its basic characteristic is the growing possibility of accomplishing relatively bigger limit deformations φ_1 with the growth of the normal deformations φ_2.
The forming limit diagram is constructed using the values of the limit deformations received experimentally, although there are some procedures to do that analytically. When the experimental procedure is used, grid composed of small circles with diameter d_0 is graved on the workpiece. After the deformation the circles turn into ellipses with axes: d_1-maximum and d_2-minimum diameter.
The directions of the principal stresses and the principal deformations for a basic or a proportional stress condition overlap the dimensions d_1 and d_2 of the ellipses' axes. In case the deformation is not monotonous phased examination is performed so that in each stage of it the deformation should be monotonous or nearly monotonous.
In the right part of the forming limit diagram the stress scheme isaplane, both principal stresses are positive, so the dimensions of the ellipses' axes after the deformation are larger than the starting diameter of the circle.
The left part of the forming limit diagram corresponds to the plane stress condition with opposite stresses. One of the major stresses is positive, while the other is negative. The axe of the ellipse in the direction of the positive stress is bigger than the diameter of the starting circle, while the axe in the direction of the negative stress is smaller from the starting diameter of the circle.

3. FORMING LIMITS CURVE

The forming limits curves are experimentally obtained by different procedures. Each of them has to insure obtaining different limit ratios of the major deformations φ_1 and φ_2.A grid of small circles of diameter d_0 is applied on the workpiece, most often electrochemically, and then deforming of the workpiece is performed until limit deformation is reached. There are two criteria to determine the limit deformation of the metal sheet:

- Criteria that defines the limit deformation as the maximal straight deformations, which are the deformations at the moment before local deformation appears.
- Criteria that defines the limit deformation as the maximal deformations at the time of breaking of the metal sheet.

According to the first criteria smaller values are received for the limit deformations of the metal sheet compared with the second criteria, which includesirregulardeformations as well. The first criteria is considered to be more specific because the local necks first form at the critical place which means bigger decrease of the thickness of the metal sheet, something that is not acceptable in terms of strength, and at the same time precedes the breaking at the critical place.

4. EXPERIMENTAL DETERMINATION OF THE FORMING LIMIT CURVES

The forming limits curves for the sheet steel Č0147 (RSt 13 according to DIN 17006) with thickness of 1 mm are experimentally obtained, by drawing sheet strips with different widths by using rough hemispherical punch.
To define the forming limit curve two circular sheet plates with diameter 179 mm are used and five sheet bands cut from the circular plate with diameter of 179 mm and width 116, 110, 100, 92

and 80 mm. On the circular sheet plates and bands electrochemical grid composed of small circles with a diameter of 5 mmis applied.Scheme of the tools used for drawing is shown on Figure 2.

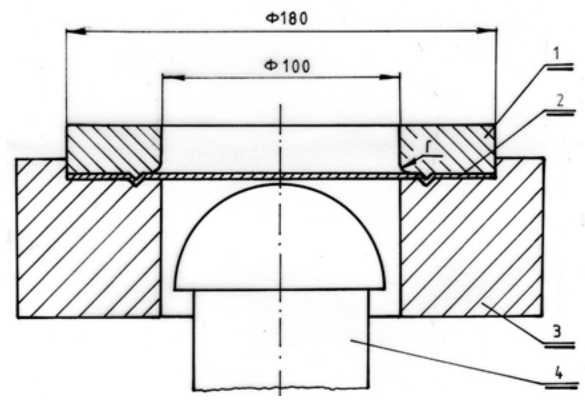

Fig. 2 - Scheme of the tools used for drawing

Tools consist of a rough hemispherical punch (position 4) with the ball diameter of 90 mm, die (draw ring) with an internal diameter of 100 mm (position 3) and Blank holder (position 1).
Drawing was carried out until the emergence of a crack. Figure 3 shows a photograph of the drawnworkpieces.

Fig. 3 - Photograph of some of the drawn workpieces

After drawing the circles from the grid with diameter d_0 are deformed into ellipses with axes d_1-major and d_2-minor. The measurement of the ellipses´ axes was performed with mobile measurement tool to the nearest 0,1 mm. The axes of two ellipses are measured as follows: ellipse passing through the crack and the crack's nearest ellipse. The ellipse passing through the crack is treated as an area in which localized deformation occurred earlier and caused tearing, while the crack's nearest ellipse is treated as an area with a maximum straight deformation.
Logarithmic deformations are determined by the following equations:

$$\varphi_1 = \ln\frac{d_1}{d_0}\text{and}\varphi_2 = \ln\frac{d_2}{d_0} \tag{1}$$

The couple of logarithmic deformations φ_1 and φ_2 for an ellipse through which passes a crack, defines one point on the forming limit curve where as a criterion for the limit deformation are taken the deformations generated during the tearing of the metal sheet. While the of couple logarithmic deformations φ_1 and φ_2 determined for the crack's nearest ellipse defines a point on the forming limit curvewhen as a criterion for the limit deformation are taken deformations generated uniformly at a maximum even deformation.

Figure 4 shows forming limit diagram with forming limit curvedetermined by both criteria for a Č0147 material, thickness 1mm. The forming limit curve marked as curve 2 is the one that defines the maximum straight deformations as limit deformation. The forming limit curve marked as 1 is the curve which as limit deformation criterion takes the maximum deformations at the time a crack in the steel sheet occurred.

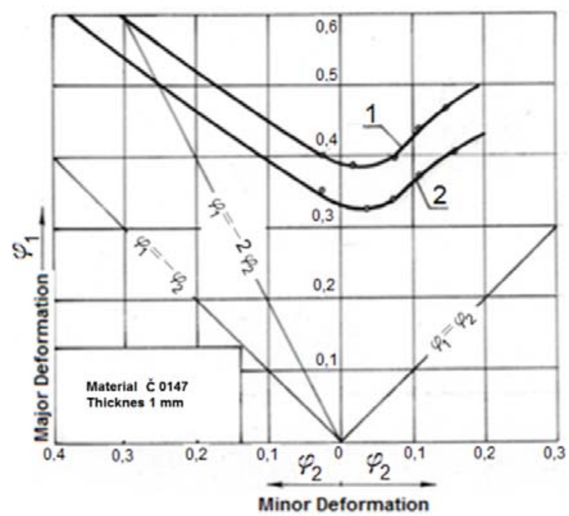

Fig. 4 -Forming limit diagram for the steel sheet Č 0147 with thickness of 1 mm. 1- Limit curve at the time a occurred, 2 – Limit curve for maximal straight deformations

5. APPLICATION OF THE FORMING LIMIT DIAGRAM (FLD)

Grid of small circles of diameter d_0 is applied on the workpiece, on the parts made of steel sheet Č0147, following already known procedure (preferably by electrochemical method). The workpiece with an applied circles grid is drawn using the drawing tools. After the drawing, the circles from the grid on the workpiece are deformed into ellipses. The ellipses´ axes d_1 and d_2 are measured on the critical place. After determining the dimensions of the axes, deformations φ_1 and φ_2 are calculated. They are applied onto the forming limit diagram shown in Figure 4, which determines one point. The location of the point is analyzed considering the forming limit curves 1 and 2. The point obtained under curve 2 provides a reliable technological process of drawing without a local deformation occurring on the critical place. A point positioned between curves 1 and 2 means that the technological process takes place with the emergence of a local deformation. This technological process is unstable. A point positioned above the curve 1 means that the technological process is not stable and on the critical place cracks appear.

If a particular point lies much under the forming limit curve 2, this means that the material used for preparation of the corresponding part has very high quality and a material of lower quality can be selected.

If a particular point lies above the forming limit curve 1, this means that the material used for preparation of the corresponding part has an unsatisfactory quality and should be selected a higher quality material or to make adjustments of the tools for drawing in order to reduce deformations on the critical place.

6. CONCLUSION

- The deformation analysis is among the most practical methods to estimate the possibility of making some complex parts using drawing as a technological process.
- It provides insight for the deformation state of the critical place and allows assessment of the stability of drawing as a technological process.
- It gives an opportunity to correct the tools used for drawing and eases the selection of appropriate material in terms of quality.
- The defined forming limit diagram can be used for analysis of the technological processes of drawing sheets´ parts (pieces) that are made by drawing a sheet steel Č 0147, thickness 1mm.

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DEFORMACIONA ANALIZA PROCESA DUBOKOG IZVLAČENJA DELOVA KOMPLEKSNE GEOMETRIJE

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REZIME

Cilj ovog rada je da analizira i odredi stabilnos tehnološkog procesa dubokog izvlačenja kompleksnih delova od lima. Elaboriran je dijagram granične deformabilnosti (DGD), kao i analiza krive u DGD. Detaljno je analiziran postupak dobijanja DGD dijagrama. Izvršeno je i eksperimentalno određivanje krive u DGD za lim od čelika Č0147 (RSt 13 prema DIN 17006). Ispitivanje je vršeno na limovima čelika prečnika 179, 116, 110, 100, 92 i 80 mm. Elektrohemijskim procesom su na limove naneseni krugovi prečnika 5mm. Kao žig je koriščena polusfera prečnika 90mm. Zaključeno je da je deformaciona analiza jedna od najpraktičnijih metoda za procenu mogućnosti za izradu kompleksnih delova putem dubokog izvlačenja. Ova analiza pruža uvid u deformaciono stanje na kritičnim mestima i omogućava procenu stabilnosti samog procesa dubokog izvlačenja. Takođe je na ovaj način moguće vršiti i korekciju alata za izvlačenje i pojednostavljen je izbor odgovarajućeg alata.

Ključne reči: d*eformaciona analiza, dijagram granične deformabilnosti, DGD krive, duboko izvlačenje.*