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EXPERIMENTAL ANALYSIS FOR DEFINING FORMING LIMIT DIAGRAM FOR THICK SHEETS

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ABSTRACT

In this paper a combined procedure to determine the forming limit diagram (Keeler-Goodwin diagram) for thick sheets is proposed. It is defined for cold rolled steel sheet Č0147 (RSt 13 DIN 17006) with thickness of 5 mm using two different criteria: maximum uniform elongation and the criteria of tearing. For the area of one positive and one negative strain (the left part of the diagram) the curves of limit strain are determined using the method of inline stretch of test tubes with circular lateral clips of sheet with thickness of 5 mm. The curves of limit strain are gained by drawing using rough hemispherical punch of sheet strips with different widths for the same quality of the material, but with thickness of 1 mm. For the area of two positive strains (the right part), the curves of limit strain for sheet with thickness of 5 mm are determined so that, in continuation to the right end side of the limit curves, gained with stretching of the test tubes with circular lateral clips, the for material with thickness of 1 mm are drawn, retaining the same form in the process.
Key words: *strain, limit deformability, diagram of limit deformability, curves of limit strain.*

1. INTRODUCTION

Deformation analysis for evaluating the criticality of strains in the process of drawing on complex sheet metal parts is based on the use of the diagram of limit deformability. The determining of the curves of limit strain for thick sheets in the area of one positive and one negative strain (the left part of the diagram), obtained by using the method of stretching of the sheet test tubes with circular side clips, is relatively easy. The defining of the curves of limit strain for the area of two positive strains can be a problem though, because for receiving two positive strains powerful devices for drawing are needed. In lack of such devices, in this paper a combination is made by

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determining the curves of limit strain gained by using the method of stretching of the sheet test tubes with circular side clips and continuing it for the area of two positive strains with the curves of limit strain for the same quality of the material, but with smaller thickness.

2. CURVES OF LIMIT STRAIN

In the diagram of limit deformability the curves of limit strain are experimentally defined for sheet metal with quality Ļ.0147 (RSt 13 according to DIN 17006) and thickness of 5 mm. Curves of limit strain are drawn according to two criteria: when as criterion for limit deformability the maximum uniform elongation is taken and the criteria of tearing. For the area of one positive and one negative strain (the left part) curves of limit strain are determined using the method of inline stretch of test tubes with circular lateral clips of sheet metal with thickness of 5 mm, and for the area of two positive strains by drawing with rough hemispherical punch of sheet metal strips with different widths for the same quality of the material and thickness of 1 mm.

2.1. Curves of limit strain determined by stretching the test tubes with lateral circular clips

For receiving the curves of limit deformability experimentally, test tubes of sheet metal are made with thickness of 5 mm. Test tubes are made of strips of a width of 40 mm with laterally derived circular sections with radius: R-5, R-10, R-20, R-30, R-40 and R-60 and measuring width of 20 mm in the smallest cross section. Fig. 1 shows the drawing according to which the test tubes are made.

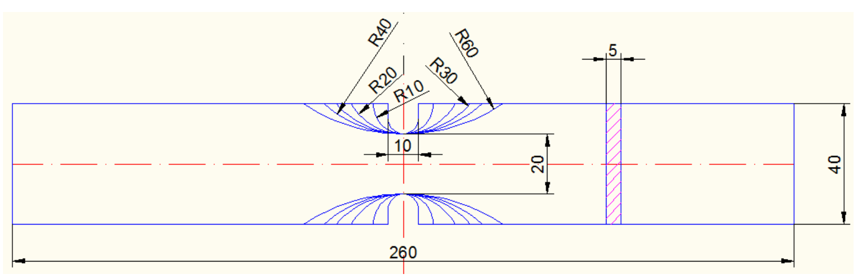

Fig.1 *- Dimensions of test tubes with circular lateral clips*

To determine the curves of limit strain of sheet metal 18 test tubes are used: six test tubes cut in rolling direction, perpendicular to the rolling direction and angle of 45° with respect to the direction of rolling. Test tubes are marked with a marker in the following manner: r-5-0° to r-60-0° test tubes cut in the direction of rolling, r-5-45° to r-60-45° test tubes cut in the direction angle of 45° in relation to the rolling direction and r-50-90° to r- 60-90° test tubes cut in the direction angle of 90° with respect to the direction of rolling. On all of the test tubes a round measuring grid with a diameter of 5 mm is done at the measuring point (on electrochemical way) by using the device ERICHSEN.

To determine the curves of limit strain when as criteria for limit deformability the maximum even elongation (maximum force) is taken, all test tubes are uniaxial (line) stretched to the point of maximum force.
In Fig.2 there is a photograph of the sheet test tubes stretched to the maximum force.

Fig.2 - *Photograph of test tubes stretched to the maximum force*

After stretching of the sheet test tubes to the point of maximum force, a measurement is performed of the median axes of the three ellipses of the deformed circle from the measuring grid that lies on the line of minimum cross-section. The larger axis is marked `by d_1, and the smaller axis by d_2. Measurement is performed with a magnifying glass to an accuracy of 0,1 mm. Logarithmic strains for the measured axes of the ellipses are calculated according to the equations

$$\varphi_1 = \ln\frac{d_1}{d_o}; \quad \varphi_2 = \ln\frac{d_2}{d_o}$$

where:

φ_1 - maximum equally logarithmic strain in the direction of stretching;

φ_2 - maximum equally logarithmic strain perpendicular to the direction of stretching;

d_0 - diameter of the circle of the measuring grid;

d_1 - greater axis of the ellipse for the test tube stretched to the maximum force;

d_2 - minor axis of the ellipse for the test tube stretched to the maximum force.

To determine the curves of limit strain using the criteria stretching until tearing, the previously stretched sheet metal test tubes to the point of maximum force are used, and this time they are stretched to tearing. After the tearing of the test tubes, again measurement is performed on the axes of the ellipse in the middle of the deformed circle from the measurement grid. The axes of the median eclipses on the minimum diameter are measured again, with larger axis marked by d_3, and the smaller axis d_4. Logarithmic deformations for the measured axes of the eclipses are calculated according to equations:

$$\varphi_{1k} = \ln\frac{d_3}{d_o}; \quad \varphi_{2k} = \ln\frac{d_4}{d_o}$$

where:

φ_{1k} - logarithmic strain after tearing in the direction of stretching;

φ_{2k} - logarithmic strain after tearing perpendicular to the direction of stretching;

d_3 - greater axis of the ellipse of sheet test tube stretched to tearing;

d_4 - minor axis of the ellipse of sheet test tube stretched to tearing.

In Fig.3 the diagram of deformability limit with curves of limit strain is shown, obtained by logarithmic strainns of sheet test tubes with lateral radius for the three characteristic directions 0°, 45°and 90° on which the circles of the measuring grid have centers lying on the line of minimum cross-sectional or are quite close to it.

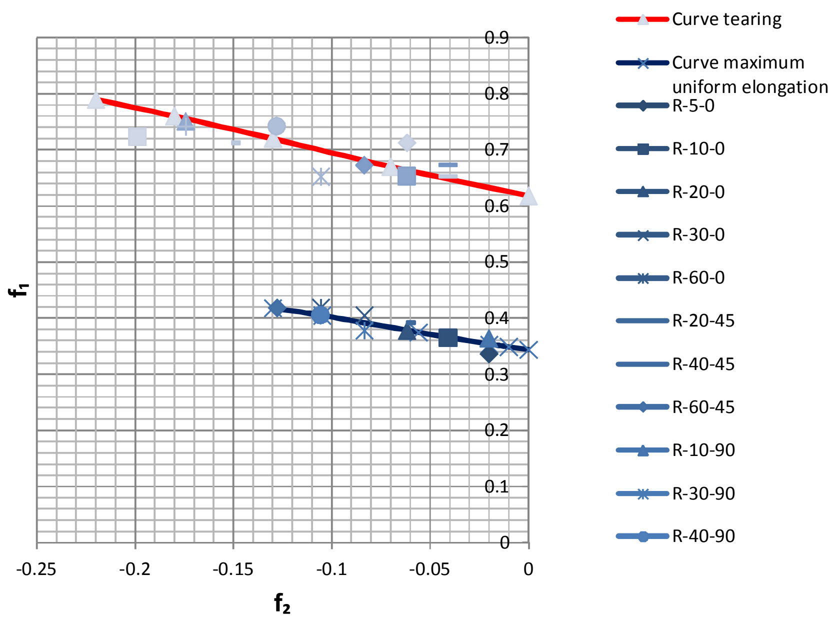

Fig.3 - *Curves of limit strain determined by stretching the test tubes with lateral circular clips*

By using this procedure the limit strains are determined only for curves of limit strain for the area of two positive strains. The lower curve represents curves of limit strain for maximum uniform strain and it is obtained by the maximum uniform logarithmic strain of sheet metal test tubes stretched to the point of maximum force. The upper curve represents curve of limit deformability in the case of tearing and is obtained by logarithmic strain of sheet metal test tubes stretched to tearing.

According to some authors (5) curves of limit strain given after this procedure lie somewhat lower when other procedures are used.

2.2. Curves of limit strain by drawing of sheet metal strips

To define the right side of curves of limit strain it is necessary to achieve the boundary terms with two positive strains. Because the material that is used for determining the curves of limit strain is with thickness of 5 mm, in order to be able to stretch it in two axes directions a strong device is needed. In absence of such a device, for defining the right part of the diagram, curves of limit strain are used for the same material quality and thickness of 1 mm. Curves of limit strain are then determined with the method of drawing using rough hemispherical punch of sheet metal strips with different widths. For their determination were used: two sheet metal plates with 179 mm diameter and four sheet metal strips with widths 116, 110, 100 and 92 mm cut from sheets with a diameter of 179 mm. On the previous pieces by electrochemical means a circular measurement grid with diameter of 5 mm is applied. The drawing is performed using a rough hemispherical punch with diameter of 90 mm and die with an internal diameter of 100 mm. As criteria for limit deformability the moment of occurrence of first crack is considered. In Fig.4 there is a photograph of part of the circular sheet metal plates and strips with a two axis stretching.

Fig.4 - *Drawn parts of circular plates and sheet strips to limit deformability*

After the drawing, the axes of two ellipses of the deformed circles from the measuring grid are measured: the ellipse passing through the crack and the nearest neighboring ellipse on the left or right of the crack. Ellipse passing through the crack is treated as an area where localized strain previously occurred and resulted to tearing, and the adjacent ellipse of the crack as a zone with maximum uniform elongation. The limit strains are determined using the two different criteria, and then a diagram is drawn with two curves of limit strain: one in the case of maximum uniform logarithmic deformation and one in case of tearing.
In Fig. 5 the diagram of limit deformability is shown by drawing using a rough hemispherical F punch on tin strips of varying width for sheet 1 mm thickness.

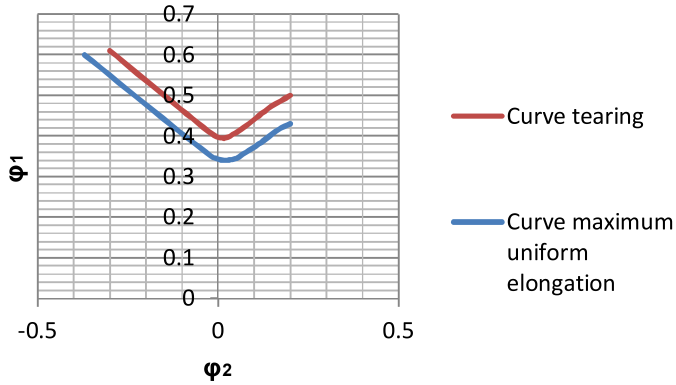

Fig.5 - *Diagram obtained by drawing on sheet strips of varying width (sheet 1 mm thick)*

3. DIAGRAM OF LIMIT DEFORMABILITY

In Fig.6 the diagram of limit deformability is shown for sheet metal with thickness of 5 mm. In this diagram curves of limit strain determined by logarithmic strains of stretched test tubes with lateral circular clips of sheet metal with thickness 5 mm and curves of limit strain determined by logarithmic strains of sheet metal strips drawn with different width of 1 mm thick sheet are presented.

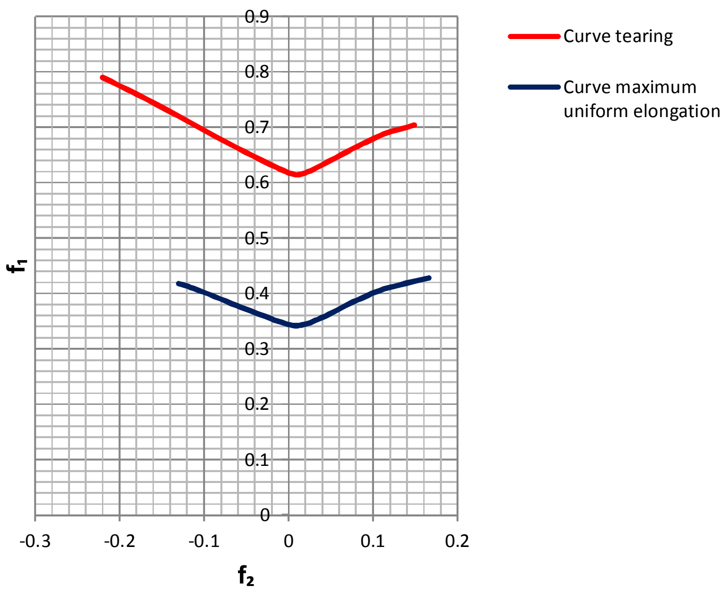

Fig.5. *Diagram of limit deformability for Č.0147 (RSt 13 DIN 17006) and sheet thickness of 5mm*

The construction of curves of limit strain for material with thickness of 5 mm for the area of the two positive deformations (right part) is made so that on the right end of curves of limit strain, determined by stretching the test tubes with lateral circular cuttings, in continuation with retained form, are imported curves of limit strain for material with thickness of 1 mm.

In the diagram of limit deformability the two curves of limit strain are drawn:

- Curve of limit deformability for the criteria of stretching test tubes to the point of maximum force (lower curve),
- Curve of limit deformability for the criteria of stretching until tearing (upper curve).

The diagram shows that curve of limit deformability obtained by the criteria of stretching until tearing lies well above the curve obtained by stretching to the point of maximum force. Authoritative curve of limit deformability for stable process of drawing is the curve obtained by stretching to the point of maximum force. The process of drawing will be stable only if the fields of logarithmic strains, determined by drawing of complex parts, lies below this curve.

If logarithmic strains occur which lie between the two curves, that would mean that the process of deformation will take place in the field of localized strain that is not allowed. If logarithmic strains occur over the border line of limit deformability of the curve obtained by tearing, the drawing process is unstable and on the critical areas cracks will occur

4. CONCLUSION

- For the area of one positive and one negative strains curves of limit strain for thick sheet metal can easily be determined by inline stretch of test tubes with circular side clips.
- In lack of appropriate equipment for the area of two positive strains, curves of limit strain for thick sheets can be determined by drawing after a procedure using a thin sheet of the same quality. Curves obtained for the thin sheet can be attached to the right end of the curves of limit strain given after the procedure of linear stretching of test tubes with thick side stripped material.

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EKSPERIMENTALNO ODREĐIVANJE DIJAGRAMA GRANIČNE DEFORMABILNOSTI ZA LIMOVE VELIKE DEBLJINE

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REZIME

U ovom radu je prikazana kombinovana procedura za određivanje dijagrama granične deformabilnosti (Keeler-Goodwin dijagrama) za limove veće debljine. Ova procedura je definisana za hladno valjan lim od čelika Č0147 (RSt 13 DIN 17006) debljine 5 mm i to upotrebom dve kriterijuma: maksimalno uniformno izduženje i kriterijum loma. Za područja od jedne pozitivne i jedne negativne deformacije (leva strana dijagrama) krive dijagrama su određene zatezanjem limenih epruveta debljine 5 mm, sa kružnim bočnim suženjima.
Krive granične deformabilnosti su određene izvlačenjem pomoću polu-sferičnog žiga sa različitim prečnicima. Za područja od dve pozitivne deformacije (desna strana dijagrama) i za limove debljine 5 mm, krive dijagrama su određene pomoću rastezanjem epruveta sa kružnim bočnim suženjima.
Ključne reči: *deformacije, granična deformabilnost, dijagram granične deformabilnosti, krive granične deformabilnosti*