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EXPERIMENTAL INVESTIGATIONS OF FORMING LIMIT CURVE IN SHEET STEEL

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Abstract: Forming blanks during the deep drawing process by exceeding certain limits leads to cracks in pieces and as a result damaging them. Different methods are used to determine these limits. One of these methods consists in obtaining limit deformations by determining the forming limit curves. This paper presents the determination of forming limit curves at material cracks for steel A5 STAS 10318-80.

1. INTRODUCTION

In order to assess the capacity of deformation of blanks a frequently used method is the forming limit curve (FLC) method. The plastic deformations which can be applied on a blank during a deep drawing process are limited by thinning and cracking. Knowledge of limit deformations and characterization of the capacity of blank deformation represent important issues for those who use them. In order to solve these issues, the notion of forming limit curve, FLC, was introduced by Keeler (1965).

The main theories used to determine analytically the forming limit curves are synthesized in paper [1].

Forming limit curves, in the system of axes ε_1-ε_2, represent the limit deformation obtained either when the blank becomes thinner, or when cracks appear. Generally, both are forming limit curves: FLC at necking and FLC at breakage. For ductile materials, where breakage is preceded by necking special attention is paid to FLC at necking because it acts as an accentuated thinning of the blank, which cannot be accepted because it has low resistance.

These curves are important for the deep drawing process because if by a computing method deformations ε_1 and ε_2 which appear at deep drawing can be determined, then with the position of the point with coordinates ε_1 and ε_2 to the forming limit curve we can know whether the deep drawing process is possible or not.

This paper presents the forming limit curves obtained at breakage for material A5 A5 STAS 10318, produced by Mittal Steel Romania, by using as a deep drawing test the Marciniak test and as a method to determine deformations the image correlation method.

2. EXPERIMENTAL PROCEDURE

2.1 MATERIAL

In this study, A5 sheet steel of deep drawing quality, 0.73 mm, 1 mm and 1.23 mm thick, supplied by Mittal Steel, Galati, Romania is used. The chemical composition is given in Table 1.

Table 1. Chemical composition (weight percentage)

Element content	C	Mn	Si	P	S
%	0.08	0.40	0.10	0.025	0.03

2.2 SPECIMENS AND EXPERIMENTAL EQUIPMENT

The Marciniak test consists in using a flat bottom punch and an intermediate piece (with a circular hole), fig. 2.
The specimens used have a rectangular shape with the dimensions presented in table 1.

Table 2. Dimensions of the specimens used

Thickness mm	Length mm	Width mm	Stress-states
0.73	200	80	uniaxial tension
		140	plane deformation
		200	biaxial tension
1	200	80	simple traction
		200	biaxial tension
1.23	200	80	biaxial tension
		140	plane deformation
		200	biaxial tension

The tests were made by using a driving plate placed between the specimen and the punch. The driving plate has width similar to that of the specimen tested, fig. 2. The driving plate is meant to avoid breakage in the area connecting the punch.

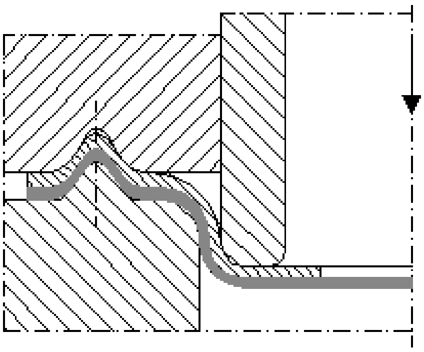

Fig. 1 Marciniak test

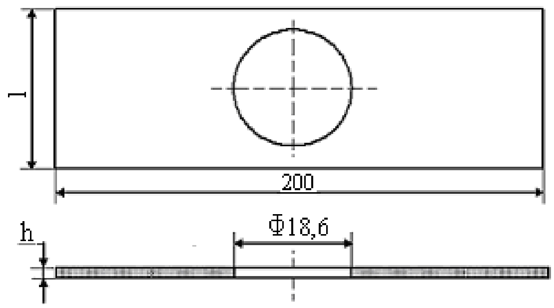

Fig. 2 Driving plate dimensions

For the specimens with widths bigger than 100 mm the pieces were holed at Φ15-Φ20.4 for the breakage to take place in the centre of the specimen.

The equipment used for the Marciniak test is made of a traction-compression machine, controlled by a computer, and a deep drawing modulus.

The traction machine used for the deep drawing test, fig. 3, is a Zwick machine with a maximum force of 200 KN (20tf).

In order to achieve the deep drawing test the machine is equipped with the deep drawing modulus. It is placed under the mobile cross for the machine to develop the compression force required by the deep drawing. During the deep drawing the punch is fixed, while the active plate and the blank holder are mobile. The specimen tested is placed between the active plate and the blank holder which are fixed with six screws. During their descending movement, the blank is deep drawn on the punch which is attached to the fixed part of the traction machine. The mobile part is guided with three (superior) columns. The fixed part is guided on the three inferior columns. The dimensions and shape of the punch are presented in fig. 4.

The equipment utilized in the deep drawing process with cylindrical punch with flat bottom is composed of traction - compression machine, controlled with a computer, and the drawing device.

The traction machine used for the drawing assay, fig. 3, is the Zwick machine having a maximum force of 200 KN (20tf). In order to realize the drawing assay the machine is equipped with the drawing device. This one is placed under the arm of the sleeper for the machine to develop the compressive force necessary to the drawing. At the drawings the punch is fixed, and the die and the blank holder are mobile. The sheet submitted to assay is placed between the die and the blank holder, which are screwed up with six screws. During the descent motions, the sheet is drawing on the punch, which is attached to the fixed part of the traction machine.

The mobile part is guided with the help of three (superior) columns. The fixed part is guided by the three inferior columns. The dimensions and the shape of the punch are presented in figure 4.

Fig. 3 Traction machine

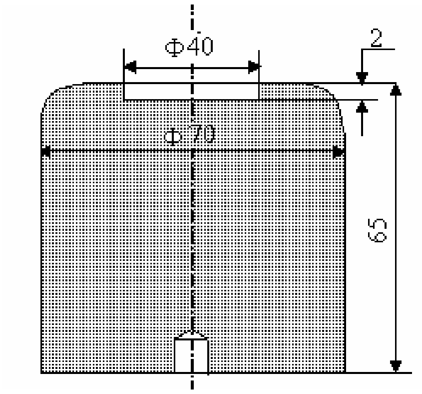

Fig. 3 Punch used

Between the punch and the driving plate Teflon foil is placed in order to reduce friction. The tests are filmed with the help of a camera placed in front of the experimental device.

2.3 MEASURING THE DEFORMATIONS WITH THE IMAGE CORRELATION METHOD

This method consists in overlapping some images corresponding to different states of material deformation. Before starting the deep drawing process, random spots of paint of different sizes are applied to the specimen. With the help of a camera and a programme which analyses images the deformations of the piece can be measured during the deep drawing process.

The image correlation method developed by Brunet et al. [1] eliminates the disadvantages of measuring the deformations with the help of networks.

The measuring of the network strains are done by correlating two images: the initial image of the specimen and the deformed image, fig. 3. In order to perform this correlation, acquisition of images by using a video camera connected to a computer, an image acquisition program and an image correlation program are necessary.

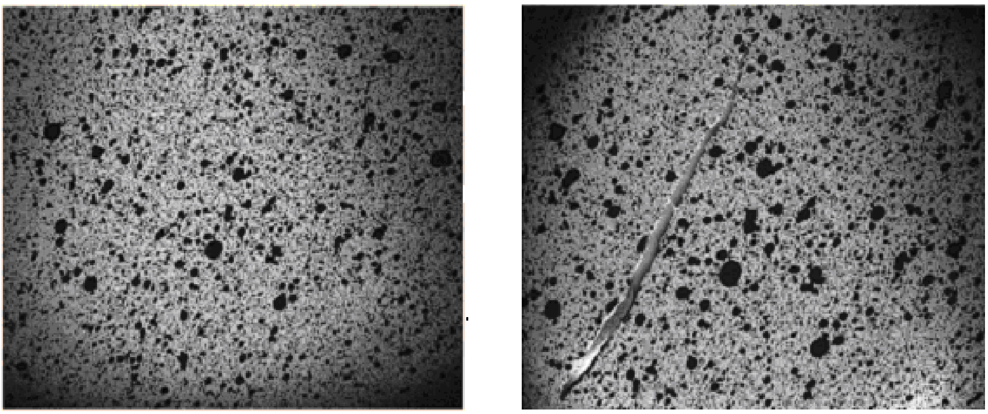

Fig. 3. Speckle aspect at the beginning and at the end of a Marciniak test

Therefore, a good accuracy at the calculation of the forming limit diagrams through the image correlation method results.

3. RESULTS AND DISCUSSIONS

In order to determine the real deformation on direction 3 (ε_3) the thickness of the deep drawn specimen was measured near the crack for the three types of stress: uniaxial traction (l = 80 mm), plane deformation (l = 140 mm) and biaxial stretching (l = 200 mm). Deformation on direction 3, perpendicular on the surfaces which delimit the thickness of the material, was calculated function on the thickness of the deep drawn specimen. This thickness was measured with a microscope at breakage and at 2.5 and 10 mm from the breakage [2].

In order to determine the forming limit curve at breakage we shall proceed as follows, knowing that:

$$\varepsilon_3 = -(\varepsilon_1 + \varepsilon_2) \tag{3.1}$$

and that after material necking appears ε_2 is constant, ε_1 increasing a lot, it results:

$$\varepsilon_{1r} = -(\varepsilon_2 + \varepsilon_{3r}) \tag{3.2}$$

where: ε_{1r} is deformation on direction 1 at material breakage;

ε_2, deformation on direction 2 when necking appears;

ε_{3r}, deformation on direction 3 at material breakage;

In tab. 3 there are presented the deformations at breakage for a thickness of specimen of 0.73 mm and in tab. 4 for a thickness of 1.23 mm. Deformation on direction 3 ε_{3r} is determined by measuring the thickness of the specimen at breakage, tab. 3 and 4, and ε_{1r} is determined with relation (3.2).

Based on these the forming limit curves at breakage can be traced (fig. 4, g = 0.73 mm; fig. 5, g = 1.23 mm).

Table 3. Deformations obtained at material crack, g=0.73mm

Stress	ε_{1r}	ε_2	ε_{3r}
uniaxial traction	0.648	-0.238	-0.41
plane deformation	0.568	-0.0228	-0.54
biaxial stretching	0.551	0.279	-0.83

Table 4 Deformations obtained at material crack, g=1.23mm

Stress	ε_{1r}	ε_2	ε_{3r}
uniaxial traction	0.677	-0.257	-0.42
plane deformation	0.474	0.0062	-0.48
biaxial stretching	0.50	0.28	-0.78

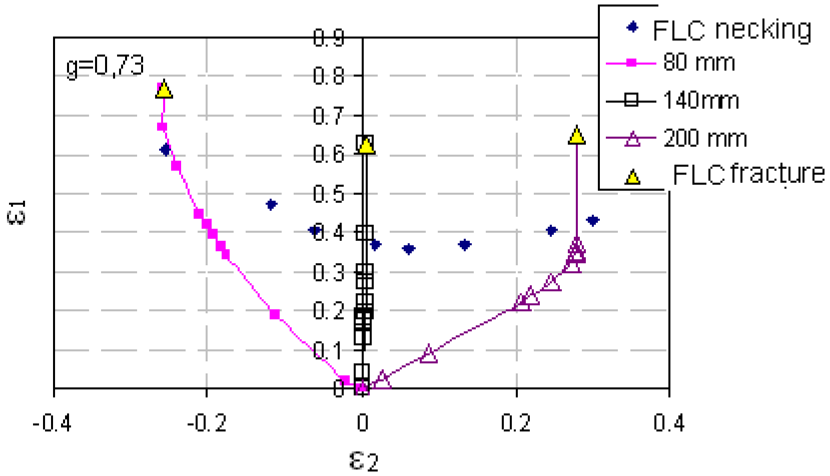

Fig. 4. Forming limit curve at material crack, g=0.73mm

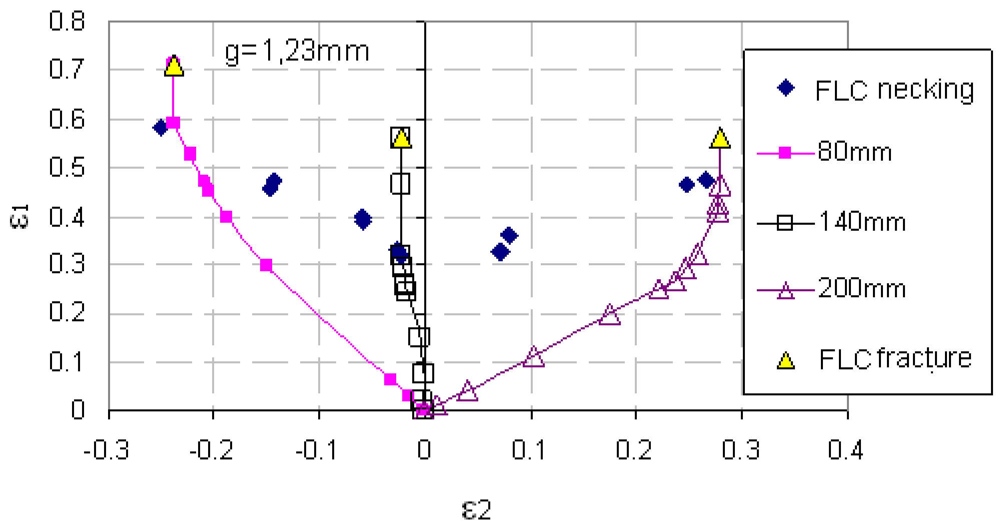

Fig. 5. Forming limit curve at material crack, g=1.23mm

CONCLUSIONS

Tracing the forming limit curves required performing some deep drawing tests during which the deformation state of the specimen varied from uniaxial traction to biaxial stretching and accurately measuring the deformations at breakage. The Marciniak test (deep drawing with a cylindrical flat bottom punch) was used as a deep drawing test and the image correlation method was used a method to measure deformations.

From the analysis of forming limit curves at breakage the following conclusions can be drawn:

- the maximum deformation is obtained for uniaxial traction and the minimum deformation is obtained for plane deformation.

- determining the forming limit curves of material through the image correlation method is achieved in a short period of time.
- the stress applied to the specimen (uniaxial traction, plane deformation and biaxial stretching) is maintained regardless of the depth of deep drawing.

Forming limit curves are used to determine whether a piece with a given configuration can be obtained through deep drawing. In order to do so, the maximum stress applied to the material during the deep drawing process is calculated. If the point where the maximum stress appears is placed under the curve the piece can be obtained without any risks.

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