A SOFTWARE SYSTEM FOR DETERMINATION OF FORMING LIMIT DIAGRAMS

Georgi Stoilov, Jordan Genov, Vasil Kavardzhikov, Jordan Kovachev

Abstract: Forming limit diagrams (FLD-s) deliver quantitative, graphical information concerning the ultimate ductility material my display under various strain conditions and boundary criterion of material failure in a deep drawing process. FLD-s are commonly obtained by usage of special samples – the so-called Nakazima's bands. This method is realized in general as a circle grid is printed on the sheet surface and its deformation is measured after the forming. Different deformations transform the circles to ellipses, exhibiting a different eccentricity. A software system for quantitative determination the changes in lengths of both major and minor axes of ellipses, is presented in this report. The grid deformed images are captured in computer memory by a digital camera, equipped with a mechanical piece, allowing the camera optical axis to maintain orthogonal upon each local area of specimen surface. An interactive way of operator-computer work is proposed for ellipses geometry analysis. The two axes of each ellipse of interests are measured and data derived are presented graphically, and recorded in a data base as well. Using this information the main deformations of samples are calculated after that.

Keywords: deep drawing, plastic deformations, forming limit diagrams.

ACM Classification Keywords: C.4 Performance of systems- Measurement techniques

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Introduction

The forming limit diagrams contain basic information necessary for design plastic forming technological processes of sheet metals blanks. This information determines in a highest degree the effectiveness of respective production. FLD-s provide data which lay in the ground of methods, defining technological transition number and type, as well as the related to them expenses for both energy and instrumental equipment.

The forming stability loss depends on the plastic forming limit of sheet metal blanks, revealing in two fundamental phenomena: - strain localization and unacceptable bifurcation of the deformed body form [Goloveev, 1974], [Shevelev and Yakovlev, 1972].

The forming stability limit value is a function of the strain-stress state characteristics of each sheet forming technology operation. At a most complicated deep drawing processes the stress state in different areas of processed blank changes from two-dimensional tension in the bottom through one-dimensional stress at the wall to tensile and compression at the flange [Material Factors]. Experimental investigations of deriving the limit form change are directed to improvement of instrumental and measure equipment [Nikolov et al, 2006], [Кавърджиков et al, 2008] and creation new tools for determining strain distribution in the deformed samples [Hadjikov et al, 1987], [gov], [gom]. Most complete information about the limit stable plastic forming of a sheet metal material as a function of different strain state schemes can be delivered by forming limit diagrams [aluminium matter].

Forming limit diagrams

Forming limit diagrams contain graphical information upon the limit combination of linear logarithmic deformations (e_1 and e_2) at specimens' surface, limited by appearing of a localized strain. Keler and Bechofen in 1963 and Goodwin in 1969 established an experimental relation between linear deformations (e_1 and e_2) at special strain conditions. This dependence demonstrates that at conditions of a two-dimensional tensile stress state and positive deformations (e_1 >0 and e_2 >0), the limit form change of a sheet metal blank is significantly larger than this one obtained at one – dimensional tensile stress state (e_2 = 0).

Samples possessing a special form (the so called "Nakazima's bands) (fig.1) have to be used for FLD-s deriving.

Different relations of the width *h* to the length *l* of the samples zone of interest ensure different stress-strain state $\beta = e_2/e_1$ when these samples are subjected to a forming process. Before the beginning of the experiment a coordinate grid, composed by equal circles with diameter 2mm ÷ 5mm or squares (fig. 2) [Hedrick] is printed on the specimen surface. During the specimens plastic deformation the initial circles transform to ellipses.

The purpose of this work is a software system to be created, assisting the measurements of different major and minor axes lengths of the ellipses, caused by different strain degrees.

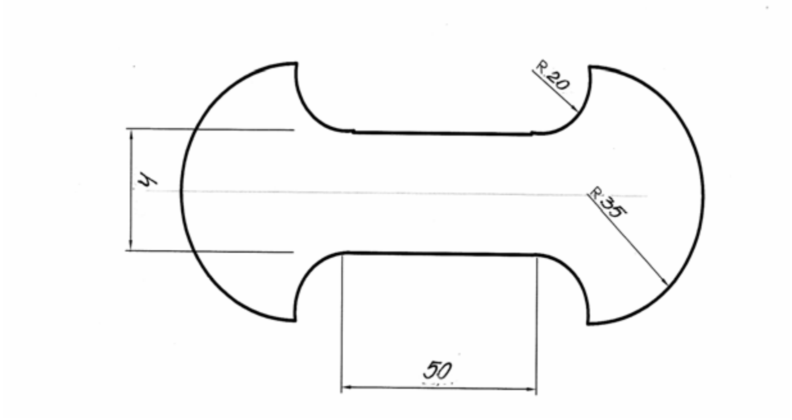


Fig. 1. Form and dimensions of Nakazima's bands

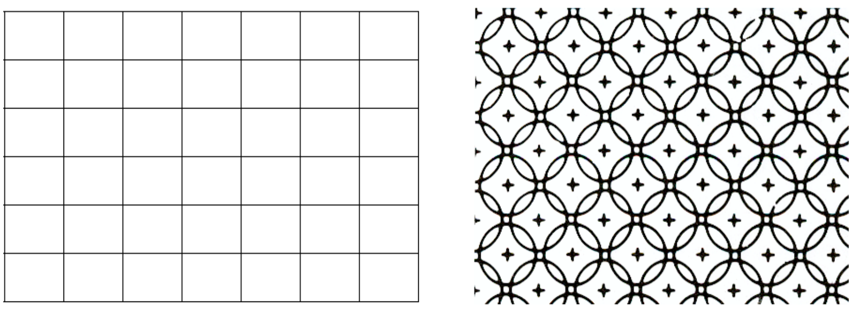


Fig. 2. Coordinate grids composed by squares and by circles

A proportional loading is applied to the samples at which monotone strain conditions (e_2/e_1 = *const*) are maintained. Forming limit curves (FLC-s), allowing the FLD-s to be derived, are obtained at different relations of the limit combination e_1 to e_2 of a sheet metal, after measurement coordinate grid deformations. An area is defined under the forming limit curve as a result, at which the strains appearing at the concrete deep drawing process, do not lead to sheet metal destroying – fig.3. [Hedrick].

The purpose of this work is a software system to be created, that can assist measurements of coordinate grid deformations.

After the samples plastic strain the images of deformed circles (ellipses) are captured in computer memory by a digital camera, equipped with a mechanical piece, allowing the camera optical axis to maintain orthogonal upon each local area of specimen surface by an operator. The recognition of ellipses geometry is carried out when the computer and operator work in inter-active way and the main axes of each ellipse are presented in a vector form. Using the obtained data base, the main local strains of the surface are calculated and presented graphically.

The measurements of ellipses axes start from the ellipse, localized at the near vicinity of the crack, which appears when specimen failure has begun and the loading has been stopped – i.e. at the zone of local strain concentration. Different deformations result in different ratio values of the minor and major ellipse axes that are related to two orthogonal strain components (fig. 4):

main strains $\varepsilon_{max} = \ln(\frac{a}{d_0})$ и $\varepsilon_{min} = \ln(\frac{b}{d_0})$; (1)

relative strains $\varepsilon_{max} = \ln(\frac{a-d_0}{d_0})$ и $\varepsilon_{min} = \ln(\frac{b-d_0}{d_0})$. (2)

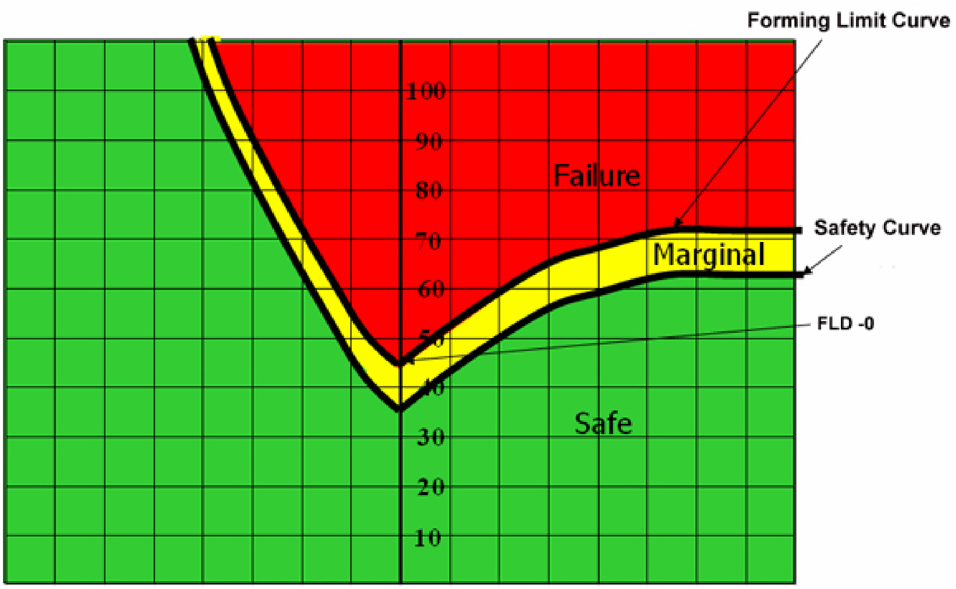
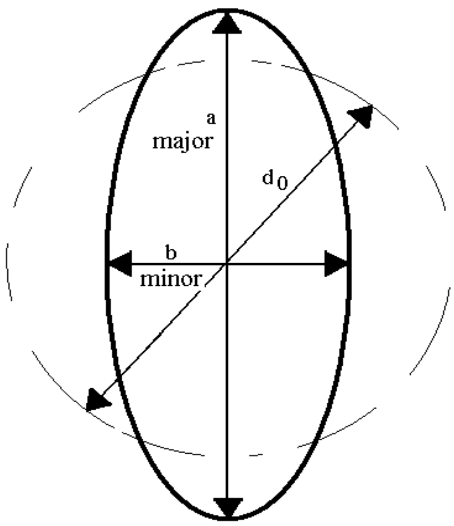


Fig. 3. A forming limit diagram



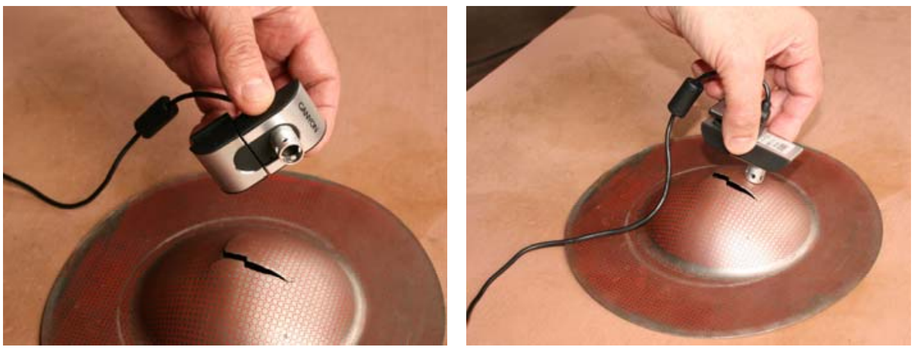
Фиг.4. The initial grid circle and resultant ellipse obtained after deformation.

A software system for deriving of forming limit diagrams

Several methods for deriving of FLD-s are in usage at present. Performing the respective methods an operator can measure ellipses axes using measurement strip, measuring magnifying glass or microscope [gom]. The grid is scanned in direction orthogonal to the crack orientation and measurements are carried out. Software packages for simulation tree-dimensional forming of metal sheet materials based on finite element method are commonly used. Software „DYNAFORM" is a power tool for simulation of such processes [DYNAFORM]. The information obtained after FLD-s deriving can be add to the other material characteristics needed for numerical simulation of the deep drawing process by „DYNAFORM".

Modern automated systems for measurement of ellipses axes, independently of their orientation in the space, use two digital cameras observing the specimen surface through appropriate angles. Recently another optical strain measurement system was developed, working also with two digital cameras [gom]. Instead of a costly grid pattern, a stochastic spray structure of dark and bright spots is used, that is applied to sample surface by spraying. Based on the assignment of every pixel in two images under different strain levels, this method uses correlation technique to determine the displacement fields of a sheet surface [Stoilov et al, 2008]. After derivation of the optical strain measurements, experimental data for determination of FLD-s are obtained. The methods utilizing two numerical cameras are convenient for applying in routine design of deep drawing processes. But relatively high price of the equipment needed for their implementation (including respective hardware and software), embarrasses for the present the application of this systems on a mass scale.

The software system for measurement the geometrical parameters of ellipses of a deformed grid, presented in this work, processes data acquired in the computer memory through a digital (CCD) camera. The optical sensor consists of this camera and a mechanical piece (fig.5-a). This allows maintaining both the camera optical axis orthogonal upon each local area of specimen surface and focus of the camera lens. The used sensor posses resolution 1280×900 pixels, although a resolution 800×600 pixels is quite enough for obtaining good enough uncertainty of this type of measurements. An operator scans the surface of interest by the optical sensor. By such a way the optical sensor can be positioned precisely enough upon the sample surface (fig. 5-b) and a satisfied accuracy in measurement of ellipses axis length is achieved. The operator measures if the quality of the memorized ellipse image is high enough to be processed by the system with a maximum accuracy. The procedure of image capturing at the concrete location of the sensor on the specimen surface can be repeated in case it is necessary and the next step of the measurement algorithm is executed after that.



a b

Fig. 5. a – A view of the CCD camera, equipped by mechanical piece; b – The optical sensor in a process of manual scanning.

Each ellipse image is approximated by a numerical curve. For fulfilling of this approximation the operator selects an arbitrary, but big enough number of points laying on the respective ellipse image (fig.6). It is desirable the points to be chosen in an equidistant way over the whole ellipse image. That will contribute to minimization of measurement uncertainty. The numerical solution of this approximation problem is not difficult and usage of a standard software package leads to excellent results.

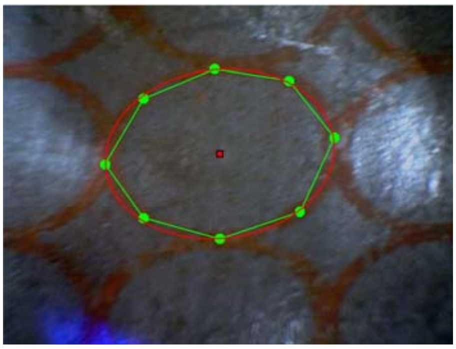


Fig.6. Approximation of an ellipse image

Simplicity of input data is needed for correct work by the used software package. When a Cartesian coordinate system is used, two values of *y*, defining two different points of the approximated ellipse, localized symmetrically upon the coordinate axis *X* correspond to each *x* value. Due to that a transformation of ellipse presentation from Cartesian (eq. 3) to polar (eq. 4) coordinates is required.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \tag{3}$$

where: *a* and *в are* the major and minor ellipse axes (fig. 6).

$$r=\frac{a\left(1-e^2\right)}{1+e\cos(\theta)} \tag{4}$$

where: *r* and *θ* are polar coordinates, and *e* is the eccentricity of the ellipse.

Equations (3) and (4) describe an ellipse, which coordinate system is centered at its own center.

The origin of a coordinate system, related to the camera frame, is chosen to be at one of frame's corners. That is why a translation which will ensure coincidence of ellipse centre to the frame's coordinate system is required for correct performance of the approximation algorithm. In general the main strain direction does not coincide to any coordinate axes. This is taken in to consideration in equation 6 by a parameter φ.

The ellipse center coordinates x_0 and y_0 are defined through the coordinates of a middle point, determined respectively by the most left and most right ellipse points located horizontally, as well as the lower and higher points, located at vertical direction. Those points are chosen by the operator and are fixed over the ellipse image, shown on the computer screen (fig. 6). After the obtaining center coordinates x_0 and y_0 they are eliminated in equation (5), presenting ellipse, in a coordinate system, which is not located at its centre.

$$\frac{\left(x-x_0\right)}{a^2}+\frac{\left(y-y_0\right)}{b^2}=1 \tag{5}$$

Equation (6) is used for performing the approximation.

$$r=\frac{a(1-e^2)}{1+e\cos\left(\theta-\varphi\right)} \tag{6}$$

where *φ* is the rotation angle of the ellipse.

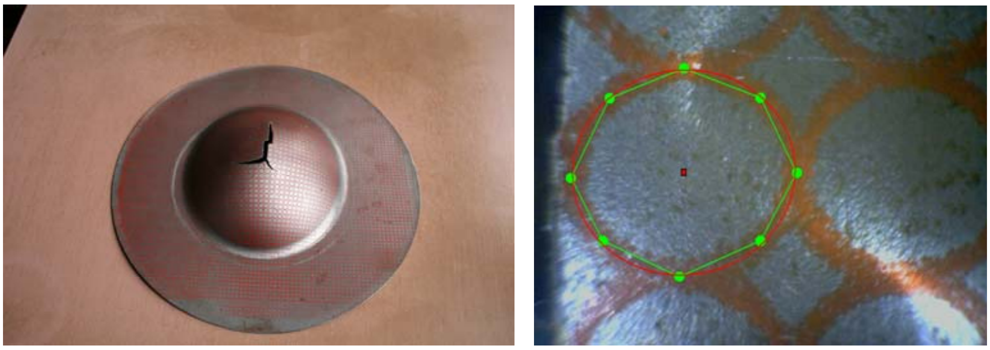
Values of parameters *a, e* and φ are derived after the approximation procedure completing and parameter *в* is quantitatively defined by equation 7.

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} \qquad 0 < b \le a \tag{7}$$

The major (a) and minor (b) ellipses axes lengths are retransformed again in Cartesian coordinates. After that relative strains at the local specimen areas, revealed by ellipses are calculated using equation 2 and limit forming curve of the respective Nakazima's sample is plotted. Elaborating experiments and measurements with all Nakazima's samples the complete forming limit diagram of studied metal sheet material can be obtained.

Experimental results

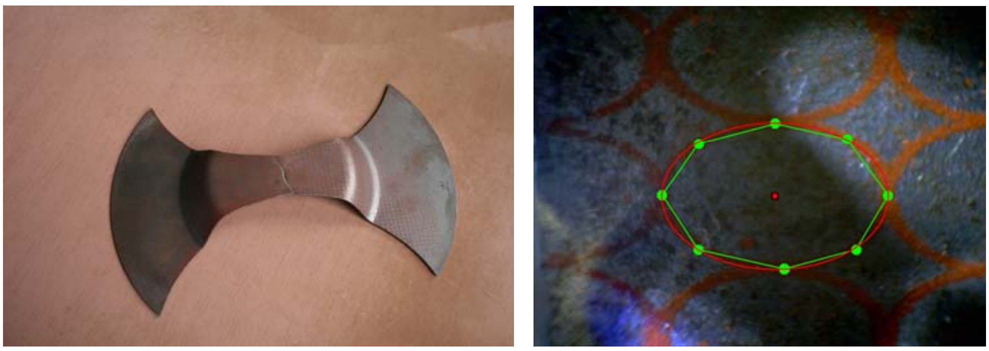
A Nakazima's specimen is presented in fig.7-a, at which two-dimensional tensile strain is realized through forming process by a semispherical die. The load action has been stopped when a crack has appeared. Figure 7- b reveals magnified image of a sample surface local area together with coordinate grid printed on the surface. The chosen points over an ellipse as well as the approximated ellipse are also shown in this figure.



a b

Fig. 7. a – A Nakazima's specimen, deformed at forming process by a semispherical die;
b - magnified image of the sample surface local area

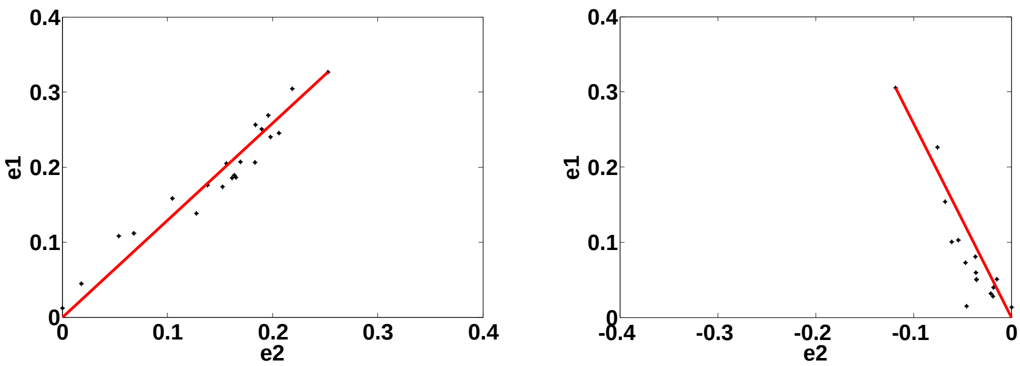
One–dimension tensile strain of a Nakazima's sample with appropriate dimensions (fig. 8a) is obtained through forming process by a flat die. The approximated image of an ellipse over the sample surface is presented in fig. 8b.



a b

Фиг. 8. a - A Nakazima's specimen, deformed at forming process by a flat die;
b - magnified image of the sample surface local area.

Relation $\beta = e_2/e_1$, defining the limit forming determined experimentally by usage of the software system described in this work and samples shown in figures 7 and 8, are revealed in fig. 9



a b

Fig. 9. Relations $\beta = e_2/e_1$, obtained experimentally for Nakazima's samples deformed by spherical (a) and flat (b) die.

Conclusion

A software system assisting the measurements of different major and minor axes lengths of the ellipses, caused by different strain degrees of Nakazima's samples is presented in this work. In contrast to the performance of such measurements through measurement strip, measuring magnifying glass or microscope the system uses an optical sensor for capturing the ellipses images in the computer memory. An operator realizes manual scanning of ellipses grid on the deformed sample surface. The information about ellipse geometry at each position of scanning is processed by computer using the developed software algorithm. The created equipment and software present a convenient tool for carrying out experiments in laboratory conditions, by which forming limit diagrams to be obtained. They are suitable for training students on derivation of forming limit diagrams of sheet metal materials, required for investigation and optimal design of deep drawing technological processes.

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Authors' Information

Georgi Stoilov – Institute of Mechanics, BAS, Acad. G. Bonchev St., bl. 4, Sofia 1113, Bulgaria; e-mail: gstoilov@imbm.bas.bg

Jordan Genov – Department of Material Science and Technology of Metals, Technical University of Sofia, Kliment Ochridski Bul., No4, Sofia; e-mail: jgenov@tu-sofia.bg

Vasil Kavardjikov – Institute of Mechanics, BAS, Acad. G. Bonchev St., bl. 4, Sofia 1113, Bulgaria; e-mail: kavarj@imbm.bas.bg

Jordan Kovachev – Department of material science and technology of metals, TU-Sofia, Kliment Ochridski Bul., No4, Sofia, graduate student; e-mail: danchoni85@abv.bg