USING OF 3D OPTICAL MEASUREMENT SYSTEM FOR DETERMINATION OF DEFORMATION CHARACTERISTICS

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Abstract

This article discusses the experimental techniques for determination of limit deformations based on 3D optical measurement system compared to the classical method of microscopic deformation and destination measurement. Experimental research was performed on materials such as: steel sheet RAK 40/70 and austenitic stainless steel DIN 1.4301 sheet with a thickness of 0.75 mm. Limit deformations were determined by experimental tests using a microscope and 3D optical system Argus. Limit deformation curves obtained from the system Argus and microscopic measurement were compared and verified using relations recommended for their prediction.

Key words: Argus, limit deformation, tensile test, deformation grid, FLC

INTRODUCTION

In the automotive industry, the most frequently discussed are requirements for the properties of sheets, which are shown by functional properties of the final drawn part such as impact resistance, deformation resistance, stiffness, etc. But on the other hand, there are strict requirements for manufacturability of different kinds of drawn parts in required quality. In terms of manufacturability prediction of high strength materials of HSS (such as BH, HSLA, IF-HS steels), progressive types of AHSS materials (e.g. DC, DP, MS, TRIP and TWIP steels) and identification of critical points on drawn parts, which can designers and technologists rely on their own experience as well as the experimental methods (especially FLD) and methods of numerical simulation (FEM) of drawing process [1]. Conditions for stability loss of blank of sheet due to local reductions and fracture could be predicted based on s comparison of local deformations φ_1 in sheet plane on real drawn part with values of limit deformations φ_{1C} in sheet plane (Forming Limit Diagram - FLD), which are detected by laboratory tests at different stress-strain states .

The left side of the diagram shows a conditions that occurs when the blank of sheet is in one axial tensile stress (tensile test apply to: $\varphi_1 = -2\varphi_2$) and the right side shows the statuses that can occur when the blank of sheet is stressed by biaxial tension (for uniform biaxial tension applies: $\varphi_1 = \varphi_2$). In case if there is no transverse contraction $\varphi_2 = 0$ (for example, when bending wide blanks) the blank is subjected to pure shear resp. it is a state of plane strain deformation. Curling (wrinkling) of the drawn part or component occurs after exceeding the limit value φ_{1C} of deformation under pressure stress (crash test of body components) or a combination of pressure - pull in the production of components of deep drawn body flange.

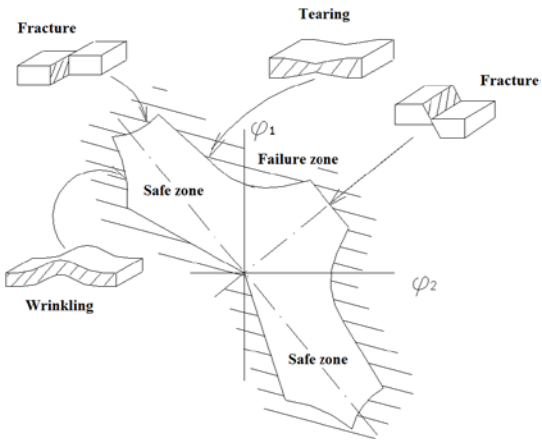


Fig. 1 Illustration of a forming limit diagram [1, 2]

Position of the curve in the forming limit diagram depends not only on the material properties, the stress-strain state, but also on the initial thickness of the blank of sheet, the strain rate, and on method of the blank of sheet preparation, the friction between contact surfaces of the tool and the blank of sheet. Forming limit curve of specific blank of sheet forms the boundary between production of good drawn parts of sheet (equivalent to the technical requirements) without local necking of the cross section in the critical area (Safe Zone - good drawn parts) and the production of drawn parts with greater incidence of local cross section necking or breach of drawn parts (zone failure - failure drawn parts) fig. 1 [3, 4].

1. EXPERIMENTAL RESEARCH

The laboratory tests which are built by limit diagrams use different techniques. Within the experimental research on the assessment and comparison FLC was elected to the tensile test specimens with different notch radius. This test, we get the left part of the diagram limit distortions (FLD) material: RAK 40/70, which is the material used for car bodies in the security structure of the nominal thickness of 0.75 mm. And also sheet of austenitic steel DIN 1.4301. Their mechanical properties are listed in table. 1.

Tab. 1 Materials mechanical properties

Material	$Rp_{0,2}$ [MPa]	Rm [MPa]	A80 [%]	K	n	r
RAK 40/70	435	756	30	1469	0,295	0,74
DIN 1.4301	298	737	64	1603	0,492	1,01

To determine the actual plastic deformation and their directional course and to obtaining the FLC of given materials was used the deformation grid method. The real deformations were determined on five specimens of each notch in the rolling direction of 0°.

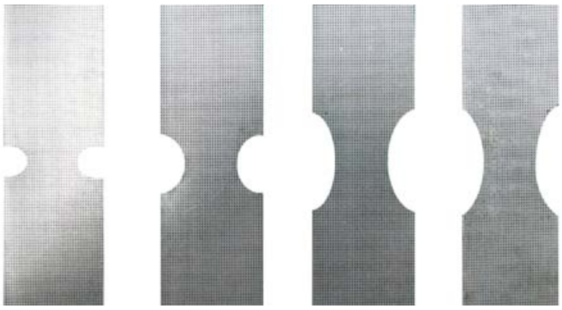
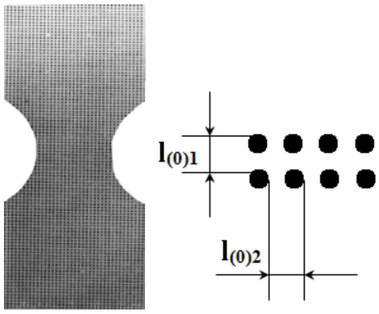


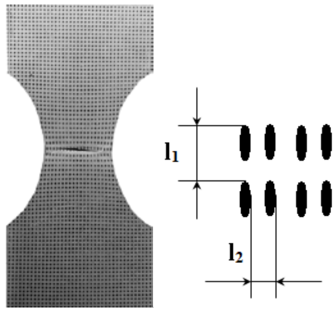
Fig. 2 Deformation grids on specimens with different notches radius

Mentioned specimens were sheared of the board sheet size 200 x 40 mm and were made different radiuses of notches by milling of r = 5 mm, r = 10 mm, r = 17.5 mm, r = 25 mm - Fig. 2. After mechanical cleaning and degreasing, deformation grid (raster) in microscopic electrochemical etching depth on the device Ostling EU and templates with deformation network in the form of points with a diameter ϕ 1, 5 mm was applied on the measured (evaluated) object in our case specimens with the notch of the examined steel.

Measurement of the initial state of the circular elements size (before deformation) was performed on a universal measuring microscope CarlZeiss in a laboratory KTaM. The measurements were carried out on the specimens with the notches. From area of the expected fracture were selected 10 distances of circular elements and then were made an average. These dimensions serve as source values of circular elements to determine the real deformation φ_1 and φ_2.



a) before deformation



b) after deformation

Fig. 3 Microscopy measurement of deformation grid

Measuring of elements after plastic deformation (blasting machine TIRAtest 2300) was carried out that the area around the fracture length measured local thinning of distance length of elements (generally, at the method of grid deformation is based on the measurement of the individual elements of the deformation grid). In our case, elements in the form of points (after ellipse deformation) for measuring by optical microscope - Fig. 3. Subsequently, there were calculated real deformations (φ_1 and φ_2).

By resizing the main axis of the deformed element distance in the radial direction, we determine a radial deformation ε_1:

$$\varepsilon_1 = \frac{l_1 - l_{(0)1}}{l_{(0)1}} \quad (1)$$

By resizing the secondary axis of the deformed element distance in the tangential direction, we determine a tangential deformation ε_2:

$$\varepsilon_2 = \frac{l_2 - l_{(0)2}}{l_{(0)2}} \quad (2)$$

Following the determination of strain deformations were calculated real radial and tangential deformation based on relation (3) and (4).

$$\varphi_1 = \ln(1 + \varepsilon_1) \quad (3)$$

$$\varphi_2 = \ln(1 + \varepsilon_2) \quad (4)$$

Another of auxiliary tools for determining the FLC is an optical 3D scanning and computer evaluation. Equipment for such scanning and computer evaluation of deformation is called a contactless optical measurement system ARGUS from GOM. This device is used for contactless measurement of the real 3D deformation of different types of drawn parts as well as test specimens of sheet. ARGUS system is suitable for optimization of the forming process, the detection of areas with critical deformation, optimization of tools for drawing and for further optimization and validation of numerical simulation of sheets drawing (FEM) [2, 3].

Fig. 4 Specimens plastic deformation

Using this method of the evaluation, specimens after deformation were deployed on a circular turntable. Deformation grid, following the static tensile test - Fig. 4 for each specimen was recorded with a CCD camera. After that, from the captured photos there were calculated coordinates of the grid points using a program item called "image processing".

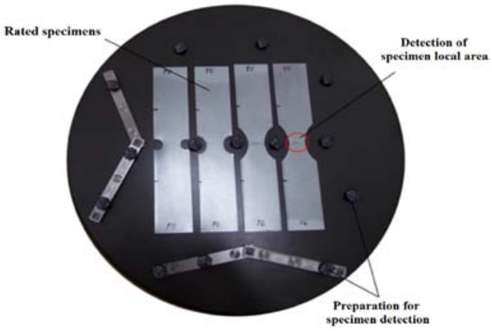


Fig. 5 Preparation of specimen's measurement using Argus system

After shooting by camera the output from the ARGUS system is the specimen on which are individual circular elements recognized by program - Fig. 7, its data is displayed in a separate window by clicking on the element. Separate window is selected from Project menu→ show point data titled "Stage Point Data" - Fig. 8. In this window can be seen the change of thickness (Thickness Reduction) due to deformation by drawing. To determine the forming limit curve it is needed the selection of the largest main deformation (major strain) and the smallest main deformation (minor strain).

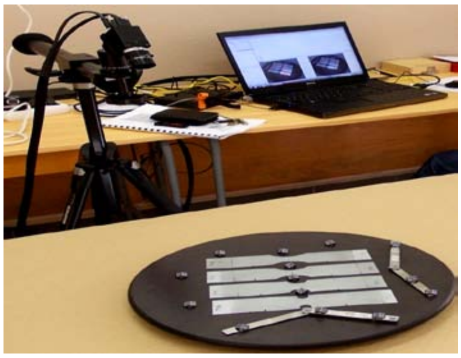


Fig. 6 Specimen sampling

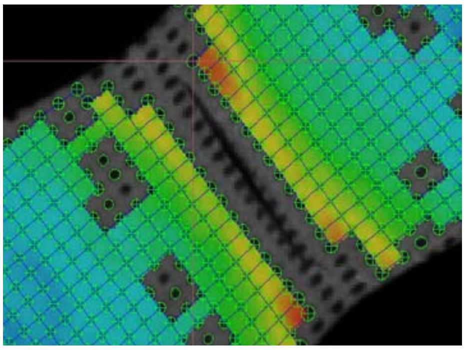
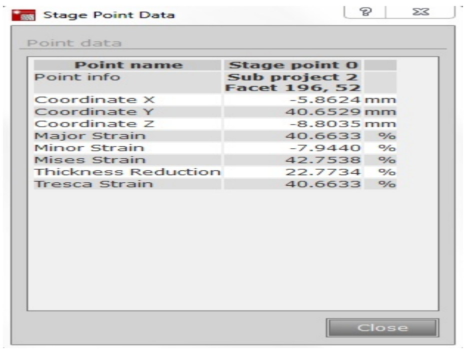


Fig. 7 Recognized elements



Point name	Stage point 0	
Point info	Sub project 2 Facet 196, 52	
Coordinate X	-5.8624	mm
Coordinate Y	40.6529	mm
Coordinate Z	-8.8035	mm
Major Strain	40.6633	%
Minor Strain	-7.9440	%
Mises Strain	42.7538	%
Thickness Reduction	22.7734	%
Tresca Strain	40.6633	%

Fig. 8 Element coordinates

These generated data as a percentage, were reduced to a level of deformation (ε_1, ε_2) and then were calculated pursuant to relations (3) and (4), the real deformation φ_1 and φ_2 Based on results φ_1 and φ_2 to identify points in the critical areas of the specimen (local thinning, area fracture) were constructed FLC for tested direction (rolling direction 0°). This program also allows display of 3D colour maps of sample deformation due to the applied voltage - Fig. 9. Also, this program generates FLC curve, which it provides based on deformation of the test specimen - Fig. 10.

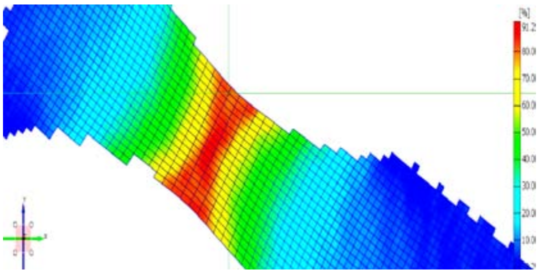


Fig. 9 Argus – color map of deformation

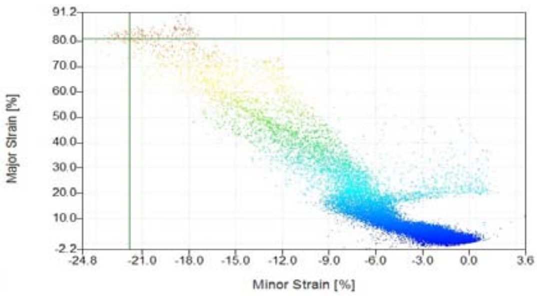


Fig. 10 FLC Argus

For validation of FLC obtained by microscopic measurement, the ARGUS system with the calculation set curve, there were used two models. And this model pursuant to Keeler-Brazier (K - B) relations (5) and (6) [1, 2]:

$$FLD^{true}_{0(A_{80})} = \ln\left[1 + \frac{2{,}78 + 3{,}244a_0 + 0{,}892A_{80}}{100}\right] \quad (5)$$

$$FLD^{true}_{0(n)} = \ln\left[1 + (23{,}3 + 14{,}13a_0).\frac{n}{100.0{,}21}\right] \quad (6)$$

where n – strain hardening exponent,
a0 – sheet thickness,
A80 – elongation.

for $\varepsilon_2 < 0; \varepsilon_1 = FLD^{true}_0 - \varepsilon_2$

for $\varepsilon_2 > 0; \varepsilon_1 = FLD^{true}_0 + 0{,}6(\exp(\varepsilon_2) - 1)$

and model pursuant to Swift-Hill relations (7) till (10) [4,7]:

for $\varepsilon_2 < 0$ – left side of FLD

$$\varepsilon_1 = \frac{1 + (1-\alpha)r_m}{1+\alpha} n \quad (7)$$

$$\varepsilon_2 = \frac{\alpha - (1-\alpha)r_m}{1+\alpha} n \quad (8)$$

and for $\varepsilon_2 > 0$ – right side of FLD

$$\varepsilon_1 = \frac{[1 + r_m(1-\alpha)].\left[1 - \frac{2r_m}{1+r}\alpha + \alpha^2\right]}{(1+\alpha)(1+r_m)\left[1 - \frac{1+4r_m+2r_m^2}{(1+r)^2}\alpha + \alpha^2\right]} n \quad (9)$$

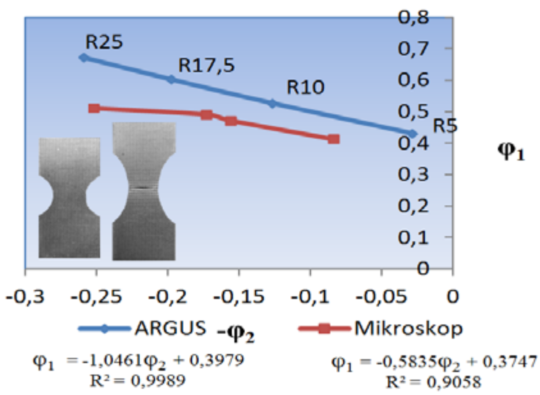
$$\varepsilon_1 = \frac{[(1+r_m)\alpha - r_m].\left[1 - \frac{2r_m}{1+r}\alpha + \alpha^2\right]}{(1+\alpha)(1+r_m)\left[1 - \frac{1+4r_m+2r_m^2}{(1+r)^2}\alpha + \alpha^2\right]} n \quad (10)$$

2 ACHIEVEMNTS AND DISCUSION

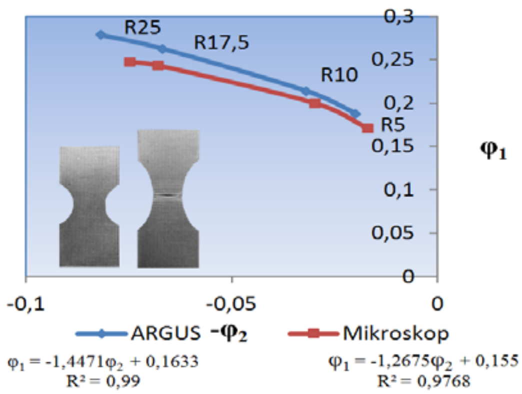
The role of experimental research was to determine the FLCs using an optical Argus system and microscopic measurements in the area of local necking by one-axial tension. The measurement results obtained using these two methods were compared with each other and validated with formulas according to [1, 2] recommended to prediction of FLCs.

Values of deformations ε_1 and ε_2 for specimens with different radius notches were experimentally determined by tensile test on specimens with notched by deformation grid method for materials RAK 40/70 and DIN 1.4301. Furthermore, these values are converted to values of real deformations φ_1 and φ_2.

Follows, these values of real deformations for individual ways of measuring, were graphically illustrated in fig. 11. Through the points has been translated a trend line equation determined by linear regression. These methods of determining FLCs were examined together and were graphically compared.



a) DIN 1.4301



b) RAK 40/70

Fig. 11 Forming limit curves of materials

Based on the achieved results of experimental materials (values FLD0 → $\varphi_2 = 0$) can be observed good agreement between the experimentally obtained FLCs and FLCs obtained by ARGUS system. Based on the results it is evident that the ARGUS system is a very flexible tool for steel specimen deformations analyse. According to the relation (5) till (10) there were calculated coordinates of the FLCs real deformation of the model by Keeler-Brazier and Swift-Hill which graphically determined FLDs and then were compared with experimental (microscopic measurement and the ARGUS system) determined values of the actual deformations fig. 12.

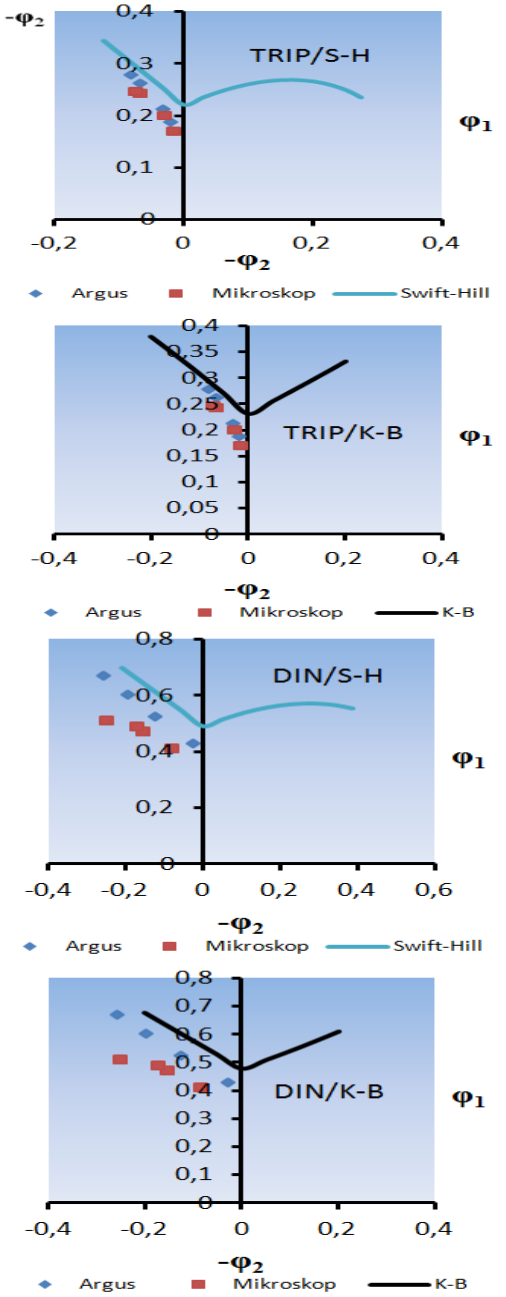


Fig. 12 Comparison of experiment determined FLC´s with calculated models

Fig. 12 shows that the area between the experimentally determined FLCs and calculated FLCs can be considered as the limit, because experimentally determined real deformation exhibit a relatively good correlation with FLC as measured by formulas recommended for prediction of the ultimate deformation curves

CONCLUSION

Achieved results of this study can be summarized as follows:

1. For comparison of forming limit curves for steels with higher strength properties were used TRIP steel sheets RAK 40/70 and austenitic steel DIN 1.4301.
2. Tensile tests on specimens with different notches radius were modelled deformation states on the left sides of the forming limit diagram and evaluated by microscopy and ARGUS system.
3. Based on achieved results of experimental materials can be observed good correlation between the experimentally obtained FLCs and FLCs obtained by ARGUS system. FLC for austenitic steel is situated above as the FLC for TRIP steel. That means that the position of the FLCs depends more on the plastic properties (strain hardening exponent, extension) and at yield and normal anisotropy.

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