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Prediction of the formability of materials for crumple zones of automobiles using numerical simulation

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Abstract This paper describes the method of determining the limit deformation of materials used for crumple zones of the car body using experimental measurements as compared with numerical simulation. Due to application of high strength steels for components of car body, weight is reduced by 25%. Using those increases the strength characteristics even at lower sheet thicknesses. But on the other hand, the use of these materials reduces the formability. It is therefore necessary to define values of the limit deformations, so as to avoid fracture, narrowing, wrinkles etc., when the material is formed.

Key words FLC, FEM simulation, deformation grid, local limit deformation, crumple zones

1. INTRODUCTION TO THE PROBLEM

In the automotive industry reduce emissions and energy consumption can be achieved by reducing the weight of cars (ULSAB) and the application of high-strength steel sheets with special properties. For the prediction of the formability of these steel sheets used for car body components is growing importance in FEM analysis development, and growing pressure on the specification of the input data. Numerical simulation is an important method for imitation of a verification process of drawing. The results from the simulation process helps us get closer to the actual process and possibly prevent unwanted situations in the real process of the real drawn part. In order to simulate possible to the real conditions, it is necessary to define of the input material data. The input data for FEM simulation are related to the description of the material model, which is essential to define forming limit curve (FLC), which describes us safe area from the pressing area inadmissible deformations. This curve defines the limits deformation (in the plane of the sheet) depending on the state of stress and the shows forming limit diagram. [1-5, 7].

FLC is defined as the maximum (limit) stress which a given sample of the steel material can undergo a series of forming operations such as deep drawing, stretching, bending without developing localized thinning area (localized necking), which indicates a fracture beginning.

FLCs are frequently used indicator for the evaluation formability. FLC is a graph that shows the limit stress for the entire range of deformation paths.

For the prediction formability it is necessary to verify values of the real logarithmic strain φ_1 and φ_2 obtained using numerical simulation (in simulation software Pam-Stamp 2G, Autoform..) at critical areas in the plane of the sheet steel with the limit values strain determined using experimental research. When we know the forming limit diagram of sheet steel, we can assess its suitability to formability. It follows that the determination of the forming limit curve (FLC) for advanced high-strength steel sheet is very important [4-6].

PAM-STAMP 2G allows comprehensive analysis of deformation of the drawn part (prediction of the localized fracture of drawn part, wrinkling, stress-strain state and making relocations) based on knowledge of the deformation history of sheet - forming limit curve. This approach can be optimized by using forming technology, before finalizing of the forming tools, the production of which is time consuming and costly [2,4].

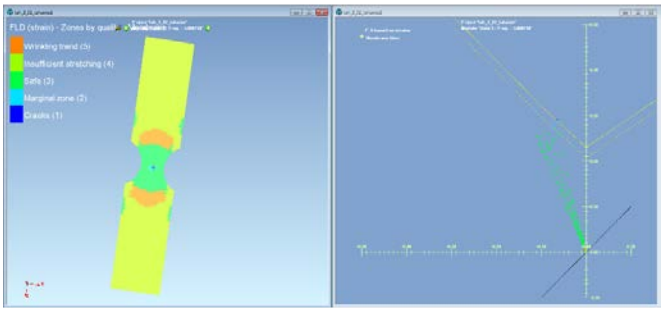

Fig. 1 Forming limit curve of a sample with notch

2. METHODS OF EXPERIMENTAL RESEARCH

In this paper are the results of the study limit deformations detected based on numerical simulations and microscopic measurement. For the experimental research were used two kinds of sheets: advanced high strength steel sheet RAK 40/70 and austenitic stainless steel DIN 1.4301. The mechanical properties of these sheets are in tab. 1 and a chemical composition in the tab. 2.

Tab. 1 Mechanical properties of materials in 90° rolling direction

Mat.	$Rp_{0,2}$ [MPa]	Rm [MPa]	K	n	r
RAK 40/70	434	751	1408	0,285	0,76
DIN 1.4301	305	750	1614	0,491	1,01

Tab. 2 Chemical composition of materials [%]

Mat.	C	Mn	Si	P	S	Cr	Ni	Ti
RAK 40/70	0,141	1,627	0,185	0,046	<0,002	0,056	0,016	0,007
DIN 1.4301	0,07	2,0	1,00	0,045	0,030	20,00	11,5	-

2.1 Experimental measurement

For a determination of the limit deformation of the mentioned materials was selected tensile test on specimens with different notches. To determine the real logarithmic deformations φ1 a φ2 and for obtain forming limit curve of materials were used method of deformation grid. The real logarithmic deformation were determined on a 10 samples of each radiuses notch in the rolling direction of 0 °.

On the used samples were milled notches (r = 5 mm, r = 10mm, r = 17.5 mm, r = 25 mm). To the measured object (samples with different notches) were applied grid points as the circle of diameter 2 mm in depth microscopic electrochemical etching on the device Ostling EU, which is located in the laboratory of department of automobile production (DAP). Change in the radius of notches were modeled various strain conditions, which are necessary for constructing of the left side of the forming limit diagram.

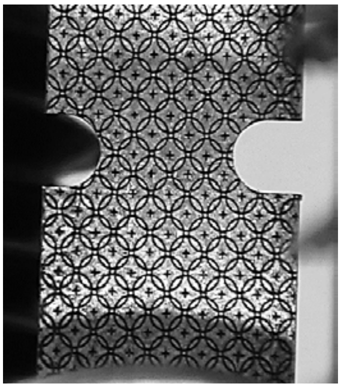

Fig.2a Sample with deformation grid

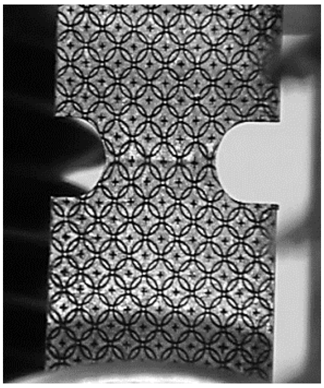

Fig. 2b Sample before fracture

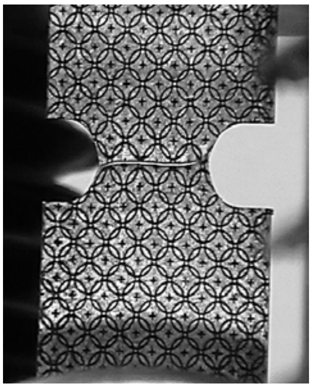

Fig. 2c Sample after fracture

Measurement of the initial state of circular elements size was performed on a universal measuring CarlZeiss microscope in a laboratory of DAP. The measurements were performed on the samples with the notch in the direction of 0°. Surroundings of the expected fracture were selected several circular elements and then averaged. These dimensions are measured as baseline circular elements to determine the real logarithmic deformations of φ_1 and φ_2.

Measurement of the circular elements after deformation on device TIRA-test 2300 was performed, that from the nearest local area of fracture was measured narrowed ellipses, then calculated (1) and (2) the relative deformations (ε_1 a ε_2). The similar way used the calculation of the real logarithmic deformations and the curve was determined.

Fig. 3 Plastic deformation of sample

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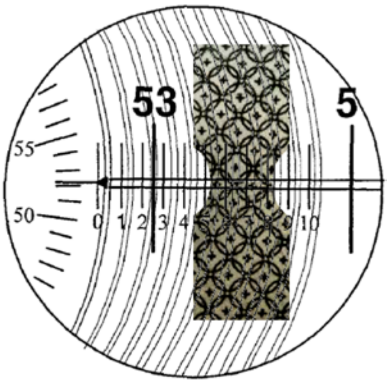


Fig. 4 Measuring of elements of deformation grid using optical microscope

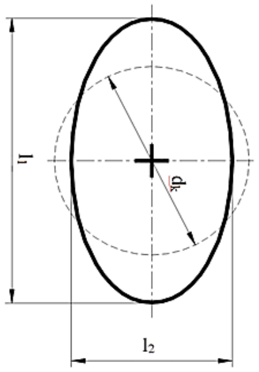


Fig. 5 Statement of grid deformation

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

$$\varepsilon_1 = \frac{d_k - l_1}{l_1} \tag{1}$$

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

$$\varepsilon_2 = \frac{d_k - l_2}{l_2} \tag{2}$$

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

$$\varphi_1 = \ln(1 + \varepsilon_1) \tag{3}$$

$$\varphi_2 = \ln(1 + \varepsilon_2) \tag{4}$$

2.2 Numerical simulation

Numerical simulation of samples with different radius notch was realized using PAM-STAMP 2G. It is simulation software for the simulation of sheet metal forming (deep drawing, bending, etc.). Samples were modeled in 3D CAD software CREO 2.0 and then exported into the simulation software in *igs format – fig. 6a.

Boundary conditions were correctly applied to the model to exactly match the model samples. To achieve the required accuracy the final simulation was needed as accurate and comprehensive as possible define the input material data.

To define a mathematical model in Pam-Stamp 2G were determined input data such as: basic information about materials: elasticity modulus (E), Poisson ratio, density, thickness of blank, stress-strain curve defined of the Krupkowsky law, and not least the rolling direction at 0 ° longitudinal axis sample defined by the model Hill48. With the ability to model a wide range of boundary conditions, and other operating parameters we get credible results that are in substantial agreement on the fact.

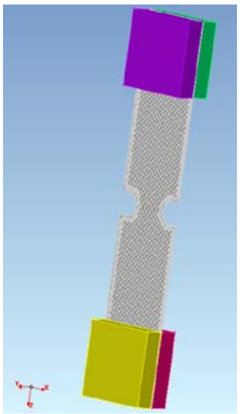
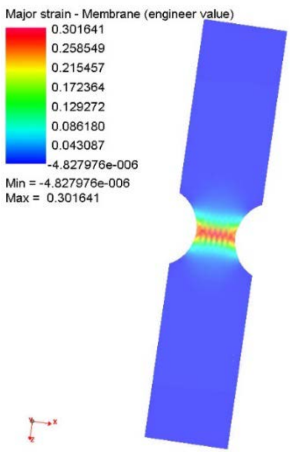


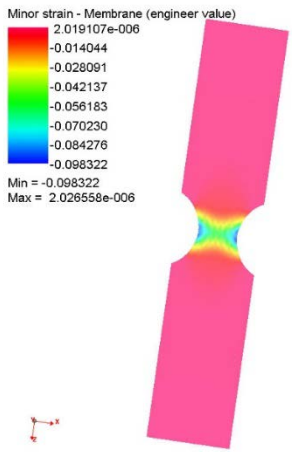
Fig. 6a Model of simulation


Fig. 6b Experiment

Display modes of the simulation analysis can be a combination of display options in the project window and the analysis window. Appropriate selection it is possible to analyze samples at any moment during simulation. The post-processor options can be displayed and analyze the monitored parameters using color map, where is possible the menu choice parameter for analysis. View the major and minor strain fig. 7a and fig. 7b, and also a change of thickness fig. 8b due to deformation of the sample.



7a. Major strain of sample



7b. Minor strain of sample

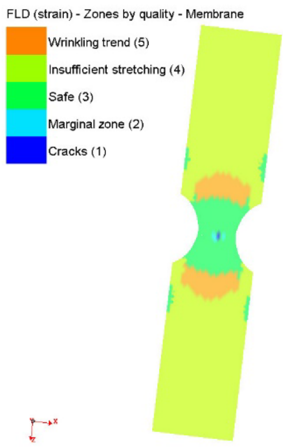


Fig. 8a Qualitative evaluation of sample

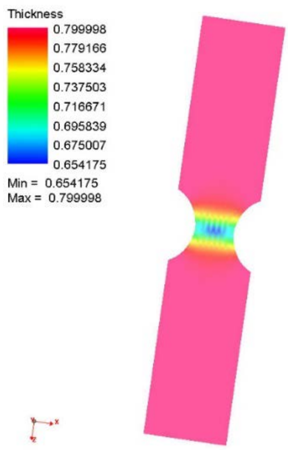


Fig. 8b Thickness of sample after deformation

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3. RESULTS AND DISCUSION

The task of this research was to determine the forming limit curves representing the left side of the forming limit diagram using experimental measurements as compared with the numerical simulation in the Pam STAMP 2G in the field of local thinning in the sheet metal forming. The results of measurements provided by these methods were compared with each other and graphically displayed.

Average values of real logarithmic deformation φ_1 and φ_2 for samples with different notches were experimentally determined tab. 3 and calculated using numerical simulation tab. 4.

Tab. 3 Average values of real logarithmic deformation φ_1 and φ_2 for material RAK 40/70

notches	Experiment		PAM-STAMP 2G	
	φ_1	φ_2	φ_1	φ_2
R5	0,171	-0,017	0,235	-0,031
R10	0,200	-0,030	0,261	-0,043
R17,5	0,243	-0,068	0,314	-0,075
R25	0,247	-0,075	0,318	-0,092
FLD0	0,155	-	0,196	-

Tab. 4 Average values of real logarithmic deformation φ_1 and φ_2 for material DIN 1.4301

notches	Experiment		PAM-STAMP 2G	
	φ_1	φ_2	φ_1	φ_2
R5	0,413	-0,084	0,496	-0,077
R10	0,472	-0,156	0,611	-0,159
R17,5	0,491	-0,173	0,685	-0,226
R25	0,511	-0,252	0,728	-0,272
FLD0	0,375	-	0,411	-

Consequently, these values of the real logarithmic deformations for different ways to measure and compare are graphically illustrated as follows - fig. 10 resp. fig. 11. Each point in determining of the FLC curve in the graph describe one sample with notch, r = 5 mm, r = 10 mm, 17.5 mm, 25 mm. Through the points (real logarithmic deformation φ_1 and φ_2) has been translated trend curve using linear regression.

The correlation coefficients R^2 are shown in fig. 10 resp. fig. 11 for the method of measuring using microscope and numerical method of materials. Axis y represents the minimum value of the deformation (FLD0), when the minor strain is zero. The highest values of FLD0 materials were achieved by numerical simulation. The highest values of deformations were evaluation as begin of localized necking. The forming limit curve FLC is situated between the experimentally measured curve and the curve obtained by numerical simulation.

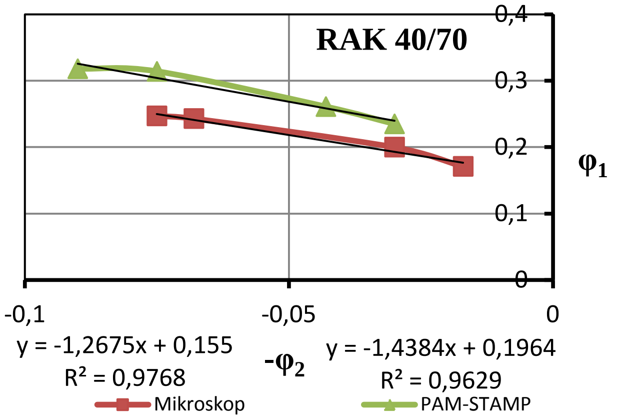

Fig. 10 Left side of FLD - TRIP steel

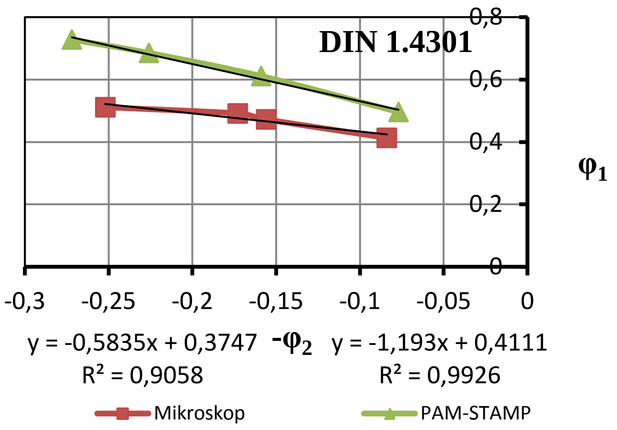

Fig. 11 Left side of FLD - DIN 1.4301

CONCLUSIONS

Knowing the layout and size of plastic deformation using forming limit curves to make better use properties of materials in the manufacture of car body components, and in their operation. Location individual elements measured on a sample with a notch is necessary important for the evaluation limit deformations. Achieved results can be summarized as follows:

- Analyzing and comparing FLC of steel sheets for crumple zones of car body components were used sheets of TRIP steel RAK 40/70 + Z1OOMB0 and austenitic steel DIN 1.4301 / AISI 304 2B,
- Tensile tests on specimens with different notches were modeled deformation states of left side of the forming limit diagram,
- FLC created for austenitic steel is located higher than the FLC for TRIP steel,
- To conclude a good agreement of results obtained by experiment and numerical simulation results obtained for TRIP steel,
- The highest values of FLD0 were achieved using numerical simulation.

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