TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

**ACTA TECHNICA NAPOCENSIS**

**Series: Applied Mathematics and Mechanics**
**Vol. 54, Issue II, 2011**

# VARIABILITY OF THE MECHANICAL PARAMETERS OF SHEET METALS

**Liana PĂRĂIANU, Sorin COMŞA, Ioana BICHIŞ, Dorel BANABIC**

***Abstract:*** *In this paper the variability of the mechanical parameters of a DC04 [1] steel sheet (0.85 mm thickness) has been studied. In order to analyze the density distribution functions of the mechanical parameters, a total number of 113 uniaxial tensile tests have been performed. Some linear relationships between the parameters have been established. Based on the dispersion of the stress-strain curves, the mechanical coefficients of the Swift hardening law have been determined using a new method. Using this experimental data, the forming limit band has been calculated based on the Monte Carlo technique. In order to determine the forming limit band, a fully implicit Marciniak-Kuczynski model has been used.*
***Key words:*** *Sheet metal forming, Forming Limit Band, Monte Carlo Analysis.*

## 1. INTRODUCTION

The correct description of the material behavior is very important for the sheet metal forming process simulation and represents a challenge for industry. By having control on all the parameters involved in the process, the number of rejected parts is decreased and the production costs will be reduced. The results of the sheet metal forming processes depend on the input parameters which have scattered values and also suffer modifications during these processes. According to Col [1] the following parameters are generally affected by the variability: material parameters, tooling, process and lubrication. A random variability from incorrect tool or sheet positioning can be also present.

The material characteristics are important parameters involved in a mechanical process and have the most significant influence on the quality of the finished parts. These parameters have a probabilistic variance defined by a mean value, a standard deviation, and the coefficient of variation [2].

The process variable effects on the robustness of the sheet metal process were studied by Siekirk [3] and recently by Zhang and Shivpuri [4]. Gerlach et al. [5] proposed a method to increase the robustness of the sheet metal forming process simulation despite of the variability of mechanical parameters of the sheet. Karthik et al. [6] studied the variability of the mechanical parameters of three steel alloys. Two types of tests were performed in two laboratories on 45 coils of materials leaded to the following conclusion: scattered values have been obtained from coil-to-coil but also to test-to-test or lab-to-lab. The relevance of the scatter of mechanical parameters for the assessment of the formability of the sheet parts has been analyzed by Till and Rechberger [7]. Carleer and his coworkers published a series of papers [8], [9], [10] that present a methodology to establish a robust manufacturing process. In order to improve the prediction of the reliability of the production, Carleer incorporated the variability of the mechanical parameters in the simulation of the sheet metal forming process. A summary of his results is presented by Carleer in a subchapter in a recent book [11]. A strategy to deal with material properties variation in sheet metal forming has been developed by Atzema et al. [12], [13]. Rojek et al. [14] shows the possibility of sheet failure prediction by typical deterministic and stochastic analysis. Schleich et al. [15] studied the mechanical parameters of an AA6016 aluminum alloy. Some linear correlation functions between the parameters were found. Părăianu et al. [16] find a more realistic method to determine mechanical parameters from Swift hardening law. The determination is based on the dispersion of the stress-strain curves, and uses the least square method. Marretta and Di Lorenzo [17] and de Souza and Rolfe [18] studied the influence of the material properties variability on springback in the sheet stamping processes.

The mechanical parameters influence the yield locus and the forming limit diagram (FLD) of the sheet metal. The variability of the Forming Limit Curves has been analyzed first time by van Minh, Sowerby and Duncan [19]. Analyzing a large set of experimental results they concluded that the scatter in measured forming limits is due, on the one side, to the errors in the experimental method and, on the other hand, to the scatter of the material properties. Janssens et al. [20] presented an experimental study on the accuracy of the FLD determinations and introduced the concept of Forming Limit Band (FLB). Strano and Colosimo [21] collected a large bibliography with experimental and theoretical FLD's for a specific material. These authors have noticed a large scattering of the data both in the case of experimental and theoretical FLD's. In general, the variability of the mechanical parameters leads to a lower and higher forming limit curve. This is the manner that the concept of FLB is defined. In order to predict the FLB, different approaches have been developed. Banabic and Vos [22] used the Marciniak–Kuczynski model to predict the FLB. They determine the lower and upper forming limit by taking into account the variation of the parameters of the yield locus and the hardening rule. Fyllingen et al. [23], [24] predicted the FLB using Monte Carlo Analyses (MCA) assuming a random thickness distribution. The method has been also proposed at the beginning of 90's by Narasimhan et al. [25] to predict the scatter band in forming limit strains. Kim et al. [26] used the diffuse necking criterion and the Monte Carlo simulation to predict the FLB for hydroforming process. Părăianu [27] predicted the FLB using the Taguchi technique together with ANOVA procedure.

The main purpose of this work is to evaluate the variability of the mechanical parameters of a DC04 steel sheet. Some remarks regarding to the probability density functions (PDF) of the mechanical parameters will be emphasized. Linear correlations between the mechanical parameters used in the FLD determination have been observed. The material parameters of the Swift hardening law have been determined with a new identification method. By introducing these relationships in a Monte Carlo Analysis, an FLB can be drawn.

## 2. EXPERIMENTAL DETERMINATION OF MECHANICAL PARAMETERS

In this study, a DC04 steel sheet (0.85mm thickness) has been used. The chemical composition of this material is (according to EN 10130:2006 [28]): 0.08% Carbon, 0.40% Manganese, max 0.03% Phosphorus, max 0.03% Sulfur and rest up to 100% Iron.

In order to determine the variability of the mechanical parameters, 42 tensile tests have been performed using samples cut at $0^o$ with respect to the rolling direction. Additionally, 33 tensile tests have been made using samples cut at $45^o$ with respect to the rolling direction and 38 tensile tests using samples cut along the transverse direction. The tests have been performed in order to determine the following mechanical parameters: yield stresses and anisotropy coefficients, as well as the n and K coefficients of the Hollomon hardening law.

The literature [20], [22] specifies that a confidence level of 99.5% can be attained by performing at least 30 tests for each direction in the plane of the sheet metal.

As an example, Figures 1-3 show, using Pareto type of plot, the distribution of the following quantities: yield stress, hardening exponent from the Hollomon law and anisotropy coefficient. These analyses are made on the 42 tests performed using samples cut at $0^o$ from the rolling direction. The asymmetric distribution of the yield stress has the asymmetric factor equal to -0.78 and the flattening factor is 0.32. The mean value of the yield stress is localized in the second region of the determined range and is equal with 195.96[MPa]. In the case of the distribution of the hardening coefficient, one may notice that in the range of 0.2125–0.2140 no experimental value has been determined.

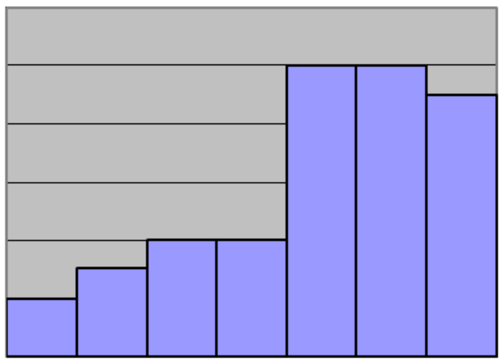

**Fig. 1.** Yield stress $R_{p0.2}$ distribution diagram

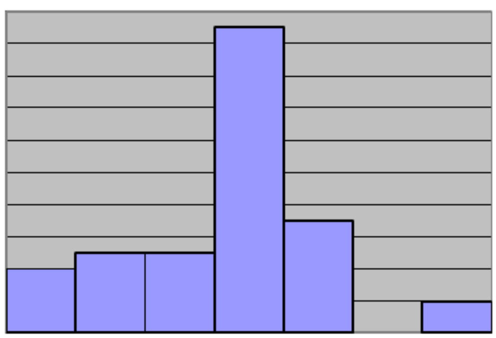

**Fig. 2.** Hardening coefficient distribution diagram

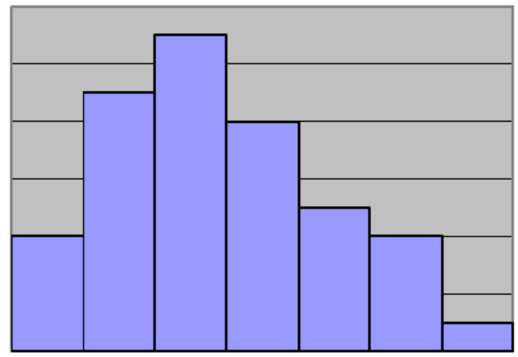

**Fig. 3.** Anisotropy coefficient distribution diagram

The distribution of the anisotropy coefficient is closer to the Gauss distribution that the other two distributions. The asymmetric factor is equal to 0.48. The following statistical parameters have been calculated for all quantities determined during the tests: mean value of the noise variables ($\bar{x}$) that describe the central location of the data; standard deviation shows the variation or "dispersion" of the experimental data from the "average" (mean) value. A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values. The coefficient of variation is defined as the ratio of the standard deviation (σ) to the mean ($\bar{x}$). It is expressed as a percentage, so that the value here should be multiplied by 100.

*Table 1*

**Mechanical parameters of the DC04 steel sheet (0.85 mm thickness).**

| Material parameter | Minimum value | Maximum value | Mean value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| $Y_0$[MPa] | 190.56 | 198.98 | 195.96 | 2.086 | 0.10 |
| $r_0$ | 1.72 | 2.20 | 1.92 | 0.110 | 0.057 |
| $n_0$ | 0.20 | 0.21 | 0.21 | 0.002 | 0.009 |
| $R_{m0}$[MPa] | 303.39 | 312.51 | 308.75 | 2.025 | 0.006 |
| $K_0$[MPa] | 519.40 | 531.88 | 526.97 | 3.800 | 0.011 |
| $Y_{45}$[MPa] | 207.06 | 215.35 | 210.97 | 2.401 | 0.011 |
| $r_{45}$ | 1.17 | 1.44 | 1.31 | 0.062 | 0.047 |
| $Y_{90}$[MPa] | 201.75 | 209.79 | 205.49 | 2.154 | 0.010 |
| $r_{90}$ | 2.00 | 2.65 | 2.22 | 0.145 | 0.065 |

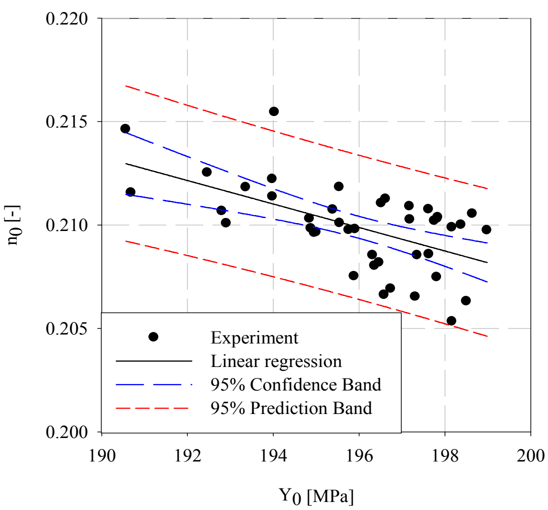


**Fig.4.** Relationships between mechanical parameters determined at $0^o$ from the rolling direction: correlation between the yield stress and the hardening exponent of Hollomon's law

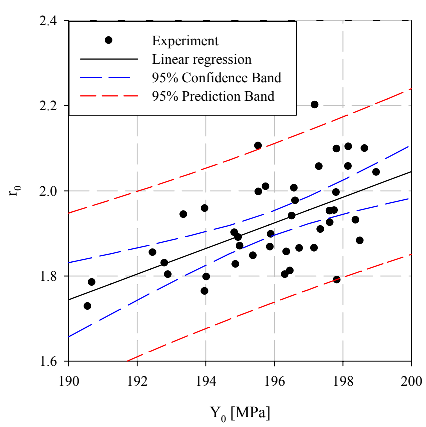


**Fig.5.** Relationships between mechanical parameters determined at $0^0$ from the rolling direction: correlation between yield stress and the anisotropy coefficient

In order to build a reliable and robust FLB a correlation between mechanical parameters must be established. Table 1 shows the characteristic values of the mechanical parameters obtained from experiments, together with their minimum and maximum values. The statistical coefficients mentioned above have been calculated for each parameter. By analyzing the results presented in Table 1, the coefficients of plastic anisotropy have the most important variation, namely 28% at $0^o$, 23% at $45^o$ and 32.5% at $90^o$. The smallest range of variability corresponds to the yield stresses: 4.4%, 4% and 4% for $0^o$, $45^o$ and $90^o$, respectively.

Figures 4 and 5 show the uniaxial yield stresses and the corresponding values of the hardening exponent and plastic anisotropy coefficient. The experimental points in the diagram have been obtained from tensile tests performed along the rolling direction. As one may notice, a linear correlation between the mechanical parameters can be determined. This correlation is shown on the diagram together with the confidence and prediction band corresponding to an accuracy level of 95%. The linear correlation functions of the mechanical parameters have the following expressions:

$$\begin{aligned} n_0 &= 0.3212 - 0.0006 \cdot Y_0 \\ K_0 &= 343.9275 + 0.9341 \cdot Y_0 \\ r_0 &= -3.9824 + 0.0301 \cdot Y_0 \\ r_{45} &= 1.68 - 0.0017 \cdot Y_{45} \\ r_{90} &= 1.1505 + 0.0052 \cdot Y_{90} \end{aligned} \quad (1)$$

This set of equations will be used in the prediction of the upper and lower forming limits curves by using the Marciniak-Kuczynski model.

## 3. EVALUATION OF THE COEFFICIENTS OF THE POWER HARDENING LAW

Based on the dispersion of the stress-strain curves, the mechanical coefficients of the Swift hardening law have been determined using a new method. This method is presented in the following.

The mathematical formulation of Swift hardening law is

$$Y(\varepsilon) = K(a+\varepsilon)^n \quad (2)$$

where $Y$ is the yield parameter, $\varepsilon$ is the accumulated plastic strain, while $K, a$ and $n$ are material parameters obtained from an identification procedure.

Let $\varepsilon_i, i = 1,\ldots,N,$ be a set of discrete values obtained by equal partitioning the range of plastic strains associated to the tensile tests performed along the rolling direction. Each of the discrete values $\varepsilon_i, i = 1,\ldots,N,$ can be put into correspondence with an average yield stress $Y_i$ and a standard deviation $\sigma_i$ representing the spread of the experimental yield stresses around the average value $Y_i$. The standard deviation can be used to define a weighting factor:

$$w_i = \frac{1}{\sigma_i^2} \quad (3)$$

In order to enhance robustness of the identification procedure, the Swift hardening law will be expressed in a logarithmic form:

$$\ln Y = K' + n \ln(a+\varepsilon), \varepsilon \geq 0 \quad (4)$$

where $K' = \ln K$.

The identification procedure is based on the least square method. More precisely, the procedure enforces the minimization of the following error-function:

$$f(K', a, n) = \frac{1}{2}\sum_{i=1}^{N}\left[K' + n\ln(a+\varepsilon_j) - \ln Y_i\right]^2 w_i \quad (5)$$

By taking into account equation (4) and (5), this function can be written as

$$f(K', a, n) = \frac{1}{2}\sum_{i=1}^{N}\left[\frac{K' + n\ln(a+\varepsilon_i) - \ln Y_i}{w_i}\right]^2 \quad (6)$$

The minimum conditions of the function $f$ are

$$\frac{\partial f}{\partial K'} = 0, \frac{\partial f}{\partial a} = 0, \frac{\partial f}{\partial n} = 0 \quad (7)$$

These constraints are equivalent with the following set of equations:

$$K'\sum_{i=1}^{N}\frac{1}{\sigma_i^2} + n\sum_{i=1}^{N}\frac{\ln(a+\varepsilon_i)}{\sigma_i^2} = \sum_{i=1}^{N}\frac{\ln Y_i}{\sigma_i^2} + n$$
$$K'\sum_{i=1}^{N}\frac{1}{(a+\varepsilon_i)\sigma_i^2} + n\sum_{i=1}^{N}\frac{\ln(a+\varepsilon_i)}{(a+\varepsilon_i)\sigma_i^2} = \sum_{i=1}^{N}\frac{\ln Y_i}{(a+\varepsilon_i)\sigma_i^2}$$
$$K'\sum_{i=1}^{N}\frac{\ln(a+\varepsilon_i)}{\sigma_i^2} + n\sum_{i=1}^{N}\left[\frac{\ln(a+\varepsilon_i)}{\sigma_i^2}\right]^2 = \sum_{i=1}^{N}\frac{\ln Y_i \ln(a+\varepsilon_i)}{\sigma_i^2} \quad (8)$$

One may notice that equation (8) are linear with respect to the unknowns $K'$ and $n$. As a consequence, any two of these equations can be easily solved with respect to these quantities. Of course, the solution will contain the coefficient a as a parameter. By replacing $K'$ and $n$ obtained from the solution procedure described above in the third of equation (8), one gets a non-linear equation containing only the parameter a as unknown. This equation can be solved only in a numerical manner (for example, by using the bisection method in combination with a bracketing procedure). As soon as the parameter a is known, $K'$ and $n$ result from Equation (8). In the last stage of the identification procedure, the original parameter $K$ results from equation (4).

Using this procedure, the following values of the coefficients of Swift hardening law have been determined: $a = 0.01016$, $n = 0.238$ and $K = 547.314$[Mpa]. These values correspond to the set of 42 tensile tests performed along the rolling direction.

## 4. PREDICTION OF THE FORMING LIMIT BAND BASED ON THE MONTE CARLO ANALYSIS

As mentioned by Schleich et.al. [15], by taking into account the existing correlations between the mechanical parameters (see Eqs (1)), a FLB can be calculated. The yield stresses associated to the $0^o$, $45^o$ and $90^o$ directions have been chosen as independent parameters. Assuming a statistic distribution of these quantities, their values have been randomly generated in a range around the experimental average. By using equation (1), the following mechanical parameters have been calculated: $r_o$, $r_{45}$, $r_{90}$, n and K. The BBC2005 yield criterion [29] has been used to describe the mechanical behavior of the sheet metal. The coefficients of the yield criterion have been determined using $Y_o$, $Y_{45}$, $Y_{90}$, $r_o$, $r_{45}$, and $r_{90}$ as input data.

In order to determine the FLB, a Marciniak-Kuczynski [30] strain localization model has been applied. The inhomogeneity factor has been also randomly chosen between 0.990 and 0.999. Figure 8 shows the FLB calculated using MCA.

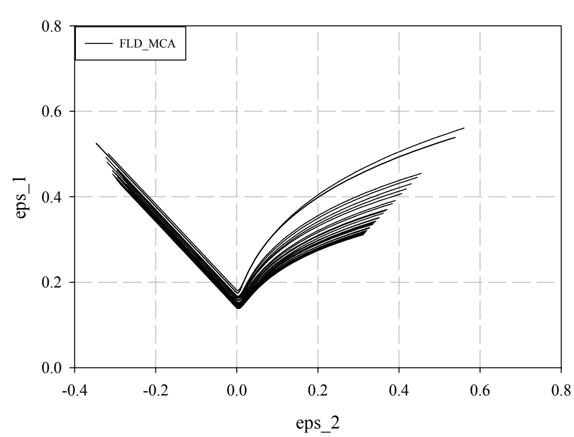


**Fig. 8.** Forming limit band obtained using a Monte Carlo Analysis.

## 5. CONCLUSION

The paper presents a methodology for the calculation of the FLB that takes into account the variability of the mechanical parameters. The input parameters and their variability have been determined by performing 42, 33 and 38 tensile tests at $0^o$, $45^o$ and $90^o$ with respect to the rolling direction. The analysis of the experimental data shows that the coefficients of plastic anisotropy have the most important variation (28%, 23%, and 32.5% respectively). In contrast, the uniaxial yield stresses have a narrower variation range (about 4% in all cases). Using the results of the tensile tests, correlation linear functions of the mechanical parameters have been established. Unfortunately, no conclusion could be drawn in order to establish the distribution function of the mechanical parameters.

In order to determine the coefficients of the Swift hardening law, a new identification procedure has been proposed. The results provided by this procedure seem to be more realistic than the values measured by the tensile testing machine for individual specimens.

In the final section of the paper, an FLB has been calculated. Using the experimental data and the correlation functions, a Monte Carlo scheme has been applied. The paper shows that an FLB can be obtained taking into account the variability of the mechanical parameters and the correlation functions between these quantities.

## 6. ACKNOWLEDGEMENTS

This paper was supported by the project "Development and support of multidisciplinary postdoctoral programmes in major technical areas of national strategy of Research - Development - Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013."
This work was also supported by CNCSIS in the frame of the Projects PN II-RU code no. PD_615 contract 210/2010 and Projects PCCE code no. 100, contract 6/2010.

## 7. REFERENCES

[1] Col, A., *Investigation on press forming scatter origin*, Proceedings of the Sixth International ESAFORM Conference on Material Forming, Salerno, Italy, pp. 183-186, 2003

[2] Jansson, T., Nilsson, L., Moshfegh, R., *Reliability analysis of a sheet metal forming process using Monte Carlo analysis and metamodels*, Journal of Materials Processing Technology 202, pp. 255-268, 2008

[3] Siekirk, J.F., *Process variable effects on sheet metal quality*, Jornal of Applied Metalworking 4, pp.262-269, 1986

[4] Zhang, W., Shivpuri, R., *Investigating reliability of variable blank holder force control in sheet drawing under process uncertainties*, Journal of Manufacturing Science and Engineering 130, pp.1-8, 2008

[5] Gerlach, J., Blummel, K., Paul, U., *Method to ensure appropriate use of material parameter variations for simulation*, Proc. of the ICTP Conf., Yokohama, pp. 841-846, 2002

[6] Karthik, V., Comstock, R. J., Hershberger, D. L., Wagoner, R. H., *Variability of sheet formability and formability testing* Journal of Materials Processing Technology 121, pp. 350-362, 2002

[7] Till, E.T., Rechberger, F., *Influence of scatter of material properties on formability of parts*, Proceedings of the IDDRG International Conference, Sindelfingen, pp.236-245, 2004

[8] Carleer, B., Zwickl, T., *Robust forming process under the "reality" of process and material scatter*, In: New developments in sheet metal forming (ed. K. Siegert), Frankfurt: MATINFO, pp.175-192, 2004

[9] Carleer, B., Sigvant, M., *Process scatter with respect to material scatter*, In: New developments in sheet metal forming (ed. M. Liewald), Frankfurt: MATINFO, pp.225-239, 2006

[10] Carleer, B., *Applicability of stochastical methods in the control of the scatter influence of constitutive parameters* Proc. of the FLC Conf., Zürich, pp. 116-122, 2006

[11] Carleer, B., *Robust design of sheet metal forming process*, In: Sheet metal forming

processes. Constitutive modelling and numerical simulation (ed. D. Banabic), Berlin Heidelberg: Springer, pp. 255-267, 2010

[12] Atzema, E., Brouwer, H., Kommelt, P., *Long and short term strategy to deal with material property variation in sheet metal forming*, Proc. of the IDDRG International Conf., Porto, pp. 121-128, 2006

[13] Atzema, E., Abspoel, M., Kömmelt, P., Lambriks, M., *Towards robust simulations in sheet metal forming*, International Journal of Material Forming 2, pp.351-354, 2009

[14] Rojek, J., Kleiber, M., Piela, A.,Stocki, R., Knabel, J., "Deterministic and stochastic analysis of failure in sheet metal forming operations", Steel Grips 2, pp.29-34, 2004

[15] Schleich, R., Sindel, M., Liewald, M., *Reverse engineered quality limitations of material batches for sheet metal forming processes*, Proc. of the IDDRG International Conference, Olofström, Sweden, pp. 303-311, 2008

[16] Părăianu L., Bichis, I., Banabic D., *Variability Analysis of the Mechanical Parameters in order to Determine the Forming Limit Band*, Proc. of the ESAFORM AIP Conf, Keynote paper, April 2011, accepted to be published

[17] Marretta, L., Di Lorenzo, R., *Influence of material properties variability on springbank and thinning in sheet stamping processes: a stochastic analysis*, International Journal Advanced Manufacturing Technology 51, pp. 117-134, 2010

[18] de Souza, T., Rolfe, B., *Characterising material and process variation effects on springback robustness for a semi-cylindrical sheet metal forming process*, International Journal of Mechanical Sciences 52, pp.1756–1766, 2010

[19] van Minh, H., Sowerby, R., Duncan, J.L., *Variability of forming limit curves*, International Journal of Mechanical Sciences 16, pp.34-44, 1974

[20] Janssens, K., Lambert, F., Vanrostenberghe, S., Vermeulen, M., *Statistical evaluation of the uncertainty of experimentally characterized forming limits of sheet steel*, Journal of Materials Processing Technology 112, pp. 174-184, 2001

[21] Strano, M., Colosimo, B.M., *Logistic regression analysis for experimental determination of forming limit diagrams*, International Journal of Machine Tools & Manufacture 46, pp. 673–682, 2006

[22] Banabic, D., Vos, M, *Modelling of the Forming Limit Band –A new Method to Increase the Robustness in the Simulation of Sheet Metal Forming Processes*, CIRP Annals - Manufacturing Technology 56, pp. 249-252, 2007

[23] Fyllingen, Ø., Hopperstad, O.S, Langseth, M., *Stochastic simulations of forming limit diagrams*, Proceedings of the ESAFORM Conference, Zaragoza, pp. 293-296, 2007

[24] Fyllingen, Ø, et al., *Estimation of forming limit diagrams by the use of the finite element method and Monte Carlo simulation*, Computers and Structures 87, pp. 128–139, 2009

[25] Narisimhan, K., Zhou, D., Wagoner, R.H., *Application of the Monte Carlo and finite element methods to predict the scatter band in forming limit strains*, Scripta Metallurgica Materialia 26, pp.41–46, 1992

[26] Kim, J., Kang, B-S., Lee, J.K., *Statistical evaluation of forming limit in hydroforming process using plastic instability combined with FORM*, International Journal Advanced Manufacturing and Technology 42, pp. 53–59, 2009

[27] Părăianu, L., Comşa, S., Bichiş I., Banabic, D., *Influence of the Mechanical Parameters on the Forming Limit Curve,* ICTP Conf., submitted paper, September 2011

[28] EN 10130:2006. *Cold rolled low carbon steel flat products for cold forming - Technical delivery conditions*

[29] Banabic, D., et al.,. *Sheet Metal Forming Processes. Constitutive modelling and numerical simulation,* Springer, Heidelberg, Berlin, 2010

[30] Marciniak, Z., Kuczynski, K., *Limit strains in the processes of stretch forming sheet metal*, International Journal of Mechanical Sciences 9, pp. 609–612, 1967

VARIABILITATEA PARAMETRILOR DE MATERIAL AI TABLELOR METALICE

În această lucrare este analizată variabilitatea parametrilor mecanici pentru un aliaj de oțel folosit în industria constructoare de autovehicule (DC04, cu o grosime de 0.85mm). În scopul determinării parametrilor de material au fost realizate 113 teste de tracțiune uniaxială. Astfel, s-au stabilit relații liniare între aceşti parametri. Pe baza dispersiei curbelor tensiune-deformație, parametrii de material ai legii de ecruisare Swift au fost determinați folosind o metodă nouă. Pe baza relațiilor dintre parametrii mecanici, a fost posibilă calcularea benzii limită de deformare folosind metoda Monte Carlo. Calculul benzii limită de deformare are la bază modelul Marciniak-Kuczynski scris sub o formă complet implicită.

**Părăianu Liana,** Dr. Eng., Technical University of Cluj-Napoca, Manufacturing Engineering Departement, Bd. Muncii 103-105, 400641 Cluj-Napoca, Email: paraianu@tcm.utcluj.ro, Phone +40264401747.

**Comşa Sorin,** Dr. Eng., Technical University of Cluj-Napoca, Manufacturing Engineering Departement, Bd. Muncii 103-105, 400641 Cluj-Napoca, Email: dscomsa@tcm.utcluj.ro, Phone +40264401731.

**Bichiş Ioana,** Ph.D. Student, Technical University of Cluj-Napoca, Manufacturing Engineering Departement, Bd. Muncii 103-105, 400641 Cluj-Napoca, Email: ioana.bichis@tcm.utcluj.ro, Phone +40264401747.

**Banabic Dorel,** Dr. Eng., Technical University of Cluj-Napoca, Manufacturing Engineering Departement, Bd. Muncii 103-105, 400641 Cluj-Napoca, Email: banabic@tcm.utcluj.ro, Phone +40264401733.