INFLUENCE OF THE COMPUTATIONAL MODELS FOR THE SPRING-BACK PREDICTION AT STAMPING

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Abstract

The metal forming technology is (mainly due to the automotive industry) one of the most dynamically developing branch of the engineering industry. Continuous effort to achieve the top technological level and car´s safety factor at keeping the low price level means necessity to still implement into own production process also the newest mathematical models of these technological processes. Thus these days represents utilization of numerical simulations an essential part of the car shape lay-out design, determination of the basic technological operations and also e.g. stamping tools shape optimization. Alongside it implementation of the new materials into production reveals necessity to develop new and more precise computational models of materials deformation behavior as well as models determined for the spring-back prediction. Nowadays in the branch of the metal forming technologies there are several truly top software among which also belongs software PAM-STAMP 2G. In this article is evaluated influence of the computational model on the numerical simulation accuracy by PAM-STAMP 2G at the spring-back prediction. For the deformation analysis was chosen corrosion-proof material DIN 1.4301 and for the spring-back prediction were used two anisotropic computational models termed as Hill 48 and Vegter in combination with the hardening kinematic model termed as YOSHIDA UEMORI. Accuracy of the measured results from the individual computational models is evaluated by the compliance of the carried out experiment and results from the numerical simulations. For the own experiment was chosen test where the material is drawn over the drawbead and drawing edge.

Keywords: Spring-back, numerical simulation, Yoshida hardening model, stainless sheet

1. INTRODUCTION

Nowadays are on the sheet stampings posing quite strict claims mainly in light of their strength, surface quality and dimensional accuracy. Stiffness and strength of produced part are essentially influenced by its shape and selection of the material. Design changes at the new types of the car-bodies quite markedly increase the requirements for shape and dimensional accuracy of sheet stampings and it also forces the processors of sheet to implement the newest methods which can fulfill these targets. Achieving the shape and dimensional accuracy of the formed part in bending is closely connected mainly with the material spring-back. Spring-back of the drawn stampings differs by its technological principle from products produced only by bending. Difference rests mainly in the deformation evolution and stress state on the drawing and bending edge of tool. At the conventional types of bending is major stress direction in the cross-section area tensile (on the outer side) and compressive one (on the inner side). Important is fact that during the bending process is changed magnitude but not sense of these stresses. Thus there is not influence of the Bauschinger effect. However, at the drawing process is material on the drawing edge bended in the first phase and then it is straightened in the second phase. Thus here takes place Bauschinger effect during the material hardening. This paper is focused into the area of utilization mathematical modelling for spring-back prediction at sheet stampings. To evaluate the exercise of the Bauschinger effect influence at spring-back prediction by the mathematical modelling there were selected two anisotropic yield criterions termed as the Hill-48 and Vegter in combination with isotropic and kinematic hardening of formed material. Due to the high magnitude of spring-back, there was for this test chosen stainless material DIN 1.4301 because there was strong presumption to prove the influence of individual computational models on the test results.

2. METHODOLOGICAL BASES AND EXPERIMENTAL PART

In this chapter are described all important tests which are necessary to carry out the spring-back prediction by numerical simulation. Among them it can be found static tensile test, hydraulic bulge test and cyclic test.

2.1. Static tensile test

To define the material model Hill-48 it was necessary to carry out the static tensile test and determined the normal anisotropy coefficients in the directions 0°, 45° and 90° regarding the rolling direction. Conditions of tests were chosen to be comfortable with the standards EN ISO 6892-1 and EN ISO 10113. From the measured values of static tensile test in the individual directions were subsequently computed the hardening curves of true stress σ (MPa) in dependence on true strain ε (-). With respect to mathematical definition of hardening curves in model Hill-48 was made their approximation by the power-law function. Mechanical values of the tested material, fitting constants (K, n, ε_0) from that power-law function and also the values of the normal anisotropy coefficients (r_α) in dependence on the rolling direction are summarized in **Table 1**.

Table 1 Values of the fitting constants and normal anisotropy coefficients in dependence on rolling direction

Rolling direction	Yield strength (MPa)	Ultimate strength (MPa)	Uniform elongation (%)	Total elongation (%)	K (MPa)	n (-)	ε_0 (-)	r_α (-)
0°	294	655	47.6	53.2	1469.5	0.498	0.0403	0.871
45°	278	610	54.1	60.4	1372.8	0.512	0.0473	1.139
90°	284	624	54.5	60.1	1415.7	0.532	0.0522	0.787

2.2. Hydraulic bulge test (HBT)

For proper definition of the Vegter yield criterion is especially necessary to carry out the so-called hydraulic bulge test (HBT). The hydraulic bulge test represented the second major part of the experiment. For this test is very important fact that there is a bi-axial stress state cause it is very important "point" for the future utilization in the different yield criterions [1]. Due to the different stress state in comparison to the static tensile test, for its stress-strain curve it is necessary to compute so-called effective stress σ_{EF} (MPa) and effective strain ε_{EF} (-).Values of these constants for the hydraulic bulge test were as following: K = 1676 MPa, n = 0.6617 and ε_0 = 0.06219. Such values are truly very important to compute the very significant bi-axial point in the advanced computational models in numerical simulations (e.g. for Vegter yield criterion). Beside values of uni-axial tensile (eventually compression) point and normal anisotropy coefficients are these values the crucial for proper computation of required yield criterion.

2.3. Cyclic test

To define the material model termed as Yoshida-Uemori there was needed to carry out such cyclic test under that can take effect the change in loading sense (+, -) of the tested sample [2, 5]. Due to the compressive stress states is carrying out of this test for sheet samples very demanding and there is loss of stability resulting as sample buckling. Because of these reasons was at Department of Engineering Technology designed the testing jig which enables to carry out cyclic test for sheet sample on the device for the static tensile test. Such testing jig was designed as additional device for the clamping grips. Testing jig consists of four subdivided supporting grips that are hydraulically controlled and prevent the sheet sample from buckling during the compression. Strain magnitude is recorded by the contact length-gauge with high accuracy. As a result from test there is cyclically repeating course of tensile and compressive stress in dependence on deformation. The offset of individual measured curves from monitored cycles rests in the magnitude of Bauschinger effect for tested material [3]. The whole lay-out arrangement of the cyclic test is clearly shown in **Figure 1** (left). Results of the measured magnitudes are evident from the graph which is shown in **Figure 1** (right).

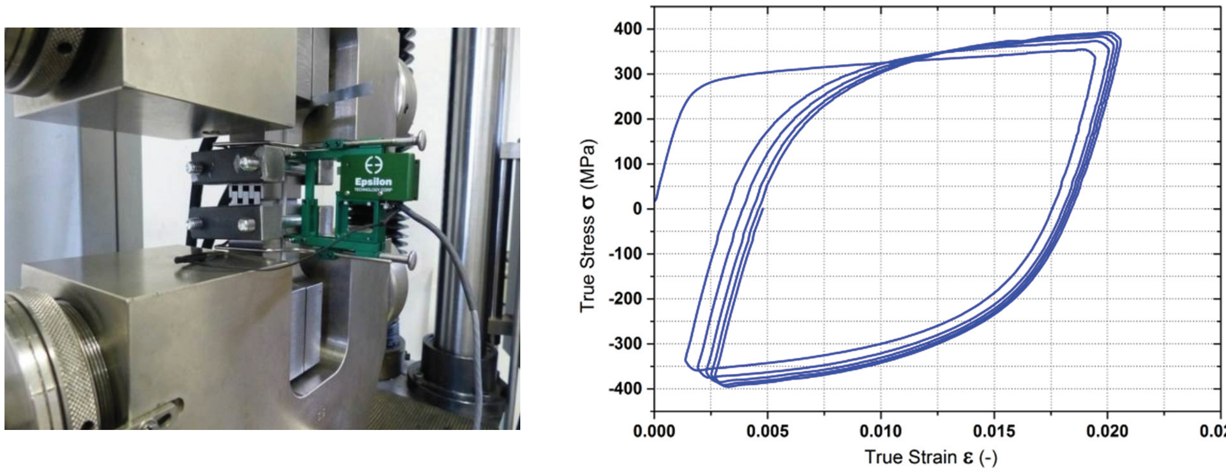

Figure 1 Arrangement of the cyclic test on the device TIRA Test 2300 (left) and results from the cyclic test for the stainless material DIN 1.4301 (right)

2.4. Experimental measurement of the spring-back

For experimental determination of the spring-back it is suitable to choose such test when change of the stress state occurs in the bending area because in this case can be fully developed so-called Bauschinger effect [4]. Regarding the labs equipment of the Department of Engineering Technology was for spring-back analysis chosen test when sheet sample is drawn over the drawbead and drawing edge of the testing jig. Thus such procedure simulates the process which occurs in the drawing tools. During test is sheet sample bended 4-times and always with the opposite loading sense (+, -) then in the previous case. Principle of test is obvious from **Figure 2**.The magnitude of the blank-holder force was necessary to be set in such manner that testing clamps were closed fully and there were created bends in drawbead. Conditions of test were as following: magnitude of normal holding force 12 kN, feed rate 10 mm·s^{-1} and the sample displacement was 200 mm. After termination of test was sheet sample subjected to the dimensional and shape analysis on the 3D coordinate measuring device SOMET XYZ 464 with relevant software TANGO !3D for their evaluation. As a result of the experimental measurement there is array of points in the step format that copies the real shape of sample. Sheet contour is defined by 70 measured points among which is finally fit the SP_line curve. Measuring and result from experiment is evident from **Figure 3**. The obtained contour of sheet is subsequently used as comparative criterion to verify matching between results from the real experiment and from numerical simulation (in this case was used software PAM-STAMP 2G).

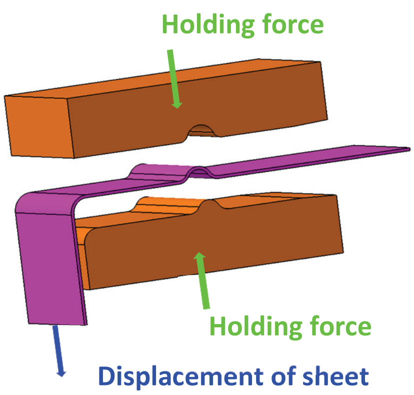

Figure 2 Strip drawing test over the drawbead and drawing edge

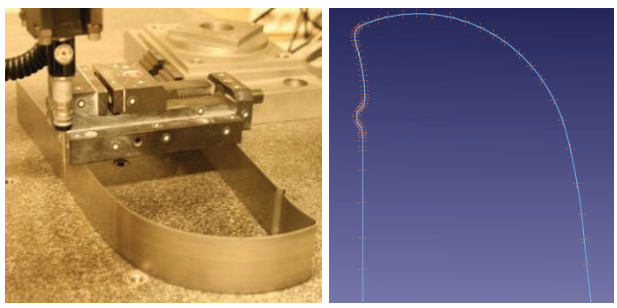

Figure 3 Measurement of the curved shape after the spring-back of material

3. NUMERICAL SIMULATION OF THE SPRING-BACK

For numerical simulation of the spring-back it was used software PAM-STAMP 2G. For its mathematical computation was applied yields criterions termed as Hill-48 and Vegter and these yield criterions were combined always both with the isotropic and kinematic hardening model (so-called Yoshida model). That it´s why there were used four computational models and were compared with results from the real experiments.

3.1. Definition of the material models

To define the Hill-48 yield criterion in software PAM-STAMP 2G is firstly needed to enter into the material card the following values: Young´s modulus, Poisson´s ration, density of material, normal anisotropic coefficients in directions 0°, 45° and 90° and average yield strength magnitude. Thus for its definition it is enough to make static tensile test in three directions. Yield criterion Hill 48 doesn´t make possible to take into account the different yield strengths at another stress state than at uni-axial tensile stress-state. On the other hand, the advance yield criterion termed as Vegter yield criterion enables for the static tensile test to define material properties in the arbitrary number of tested directions and also takes into account change of yield strength at the multi-axial stress state (e.g. shear test, hydraulic bulge test or compression test). So Vegter yield criterion better describes the material transition into the plastic state. Material cards of the tested material DIN 1.4301 for both used yield criterions in software PAM-STAMP 2G are shown in **Figure 4**.

Both yield criterions mentioned before are further in the area of plastic deformation combined with the isotropic and kinematic hardening model of material. Isotropic hardening of material is characterized by the average stress-strain curve (hardening curve) from the static tensile test. This curve is mostly approximated by the mathematical equation termed as Swift-Krupkovsky (a little modification of the power-law function) and that is why this model can't take into account influence from the Bauschinger effect.

Kinematic hardening model that is in the PAM-STAMP 2G termed as the Yoshida model, uses for definition the stress-strain curve results from the cyclic test (so tensile and compressive stresses). Thus in the second case there is a kinematic hardening model which is able to measure the influence of the Bauschinger effect that takes place in the area of the drawbeads and drawing edge in testing jig. Deformation hardening models used for the finite element analysis (FEM) are illustrated in **Figure 5**.

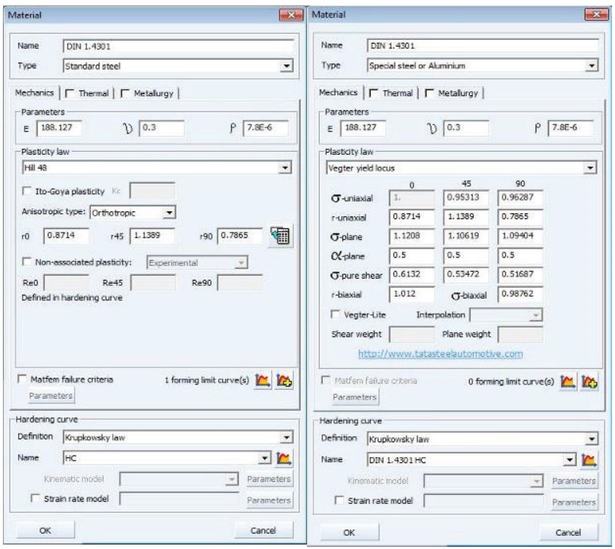

Figure 4 Definition of the yield criterions: Hill-48 (left) and Vegter yield criterion (right)

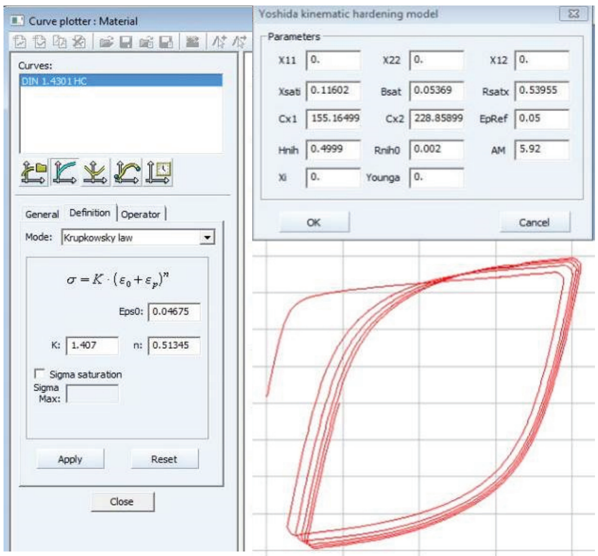

Figure 5 Definition of the hardening models: Isotropic (left) and kinematic hardening model (right)

3.2. Problem setting in the environment PAM-STAMP 2G

Boundary conditions for the numerical simulation were set in such manner so that they corresponded to the performed test. Tools with the drawing material in the PC environment are shown in **Figure 2**. Before the own sheet displacement in tool, there was necessary to close the virtual clamps by defined force 12 kN and to bend sample by 90° over the drawing edge. For this purpose was needed to create the auxiliary bending tool. Subsequently there was only sheet displacement by the distance 200 mm. After drawing of the sample there was own computation of the spring-back and its results were compared with the experiment. These results aren't in this paper illustrated graphically because of space. However, from such comparison of result from the numerical simulation without spring-back (when the sample was just drawn over the drawbead and drawing edge) and result for the same sample after spring-back that was computed by the PAM-STAMP 2G, it was evident big influence of the spring-back on the sample shape as it was presumed.

3.3. Comparison of results from the real experiment and the numerical simulation (PAM-STAMP 2G)

As a criterion for comparison suitability of the computational model for the monitored problem there was used the shape matching between the real sample shape and shape of the sample from the numerical simulation. There were evaluated all four used mathematical models regarding the real sample shape. With respect to fact that selection of Hill-48 or Vegter yield criterion didn´t strongly influence results and regarding the length of this paper is in **Figure 6** shown only fundamental difference between tested deformation hardening model (isotropic and kinematic hardening model termed as Yoshida). In **Figure 6** is illustrated the comparison of results from the experiment and computational Vegter model in combination with the isotropic hardening model (**Figure 6** left) and in combination with the kinematic hardening model (**Figure 6** - right). Almost the same result was observed for the computational model Hill-48 in combination with the isotropic hardening.

From **Figure 6** it´s obvious that selected computational model with the isotropic hardening model isn´t able, with sufficient accuracy, to simulate processes which occur just beyond the drawbead. Compared to reality when spring-back occurs also beyond the drawbead, numerical simulation reveals spring-back as far as beyond the drawing edge of the testing jig.

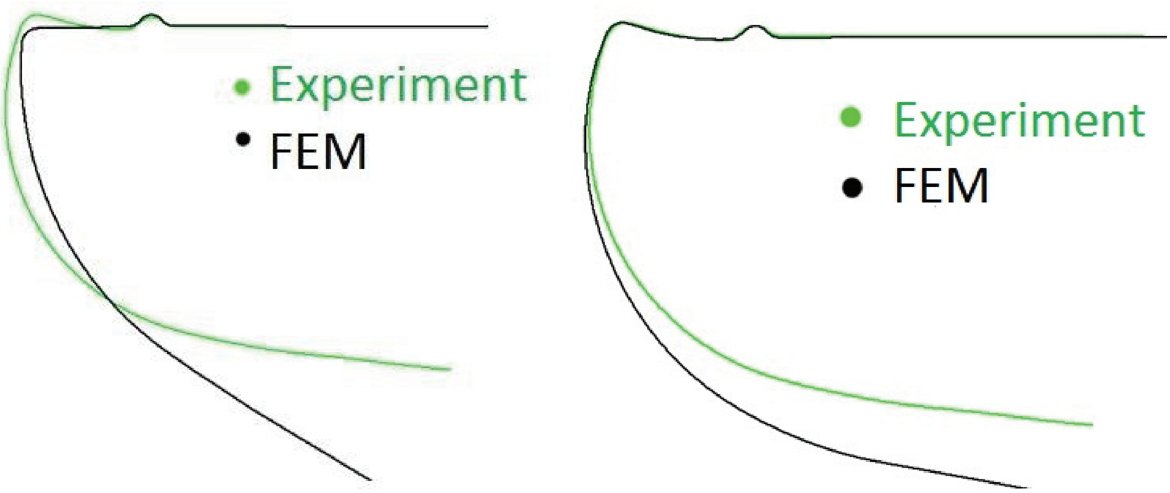

Figure 6 Comparison of results (in light of shape) for the real experiment and for the numerical simulation: Vegter model with the isotropic hardening (left) and Vegter model with the kinematic hardening (right)

4. CONCLUSION

Selection of the proper mathematical model for solving all types of technological problems is a basic factor that influences the quality of achieved data outputs. Thus creation of mathematical model and obtaining all necessary data inputs mostly means the very time-consuming phase in mathematical modelling. However at selection mathematical model it is important to take into account that individual factors which enter into FEA don´t influence results in the same manner. It is very suitable to qualify their influence ratio already at the beginning of FEA. In this paper was tested mathematical model influence on the accuracy of prediction spring-back at stamping. There were tested and evaluated 2 yield conditions termed as Hill-48 and Vegter in combination with isotropic and kinematic hardening model. For FEA it was used software PAM-STAMP 2G. Suitability of the individual tested mathematical models for given problem was made by the comparison of results from the experiment and numerical simulation - so as criterion for evaluation the mathematical model suitability, there served the shape matching of samples. From the measured and computed results arises that tested Hill-48 and Vegter yield criterions do not strongly influence the result of mathematical problem. This is probably due to the character of this problem when there aren´t big deformation in the strain area. Quality of the selected yield criterion would take bigger effect at the most complicated problems. On the other hand, truly very important influence on the spring-back magnitude has selection of the deformation behavior model. The kinematic hardening model reveals much better matching with experiment than isotropic deformation behavior model. The highest matching between FEA and experiment was achieved by the Vegter yield criterion and kinematic hardening model termed as Yoshida. Nevertheless, also results of mathematical model Hill-48 in combination with the kinematic hardening model revealed quite good matching with the experiment. Regarding much shorter time that is necessary to gain input data for model Hill-48, there should be carefully considered whether to use Vegter yield criterion for the simpler problems. For complicated stampings with presumed big deformation is recommended to use the advanced yield criterions. Presented results proved that the crucial influence on the spring-back prediction rests in selection of the deformation hardening model and that the yield criterion doesn´t influence result so much.

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