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PUNCH DISPLACEMENT PREDICTION IN AIR BENDING PROCESS USING FINITE ELEMENT SIMULATION

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ABSTRACT
The success of air bending process depends on ability to accurately determine the punch displacement for desired bend angle after unloading. Punch displacement in the air bending is a complex function of tool and part geometry, mechanical properties of sheet and their changes during bending. The aim of this research was to develop the FE models for punch displacement and springback prediction using LS-Dyna. In order to validate results of the FE simulation, five bending experimets for materials S355MC and DD13 were conducted. It was found that FE springback predictions for microalloyed S355 MC steel are significantly lower compared to experimental data, while predictions for mild DD13 steel can be reliably used.
Key words: air bending, FE analysis, punch displacement, springback

1. INTRODUCTION
The main advantage of air bending process is ability to produce different part angles for different materials and sheet thicknesses, without changing tool set. Determination of the required punch displacement for known tool and part geometry is a very difficult task, since it depends on kind of used sheet material and is very sensitive to variations in mechanical properties and sheet thickness. An additional problem is dimensional change of the part caused by elastic recovery after unloading, also called springback. As a consequence of the significant presence of process variation, the bend angles in air bending are often not satisfy todays increasing tolerance requirements. In practice the punch displacements are often determined through „trial and error" iterations, while variation of the bend angles can be reduced using on-line measurement of part and tool geometry during loading and unloading without release a part from tool, (5).
In this research a FE model of the air bending process was developed in order to predict punch displacement as a function of bend angle on loading and springback intensity after unloading. The simulation results were compared to experimental data for two materials: mild DD13 and microalloyed S355 steel.

2. FINITE ELEMENT ANALYSIS
FE Simulations were conducted in LS-Dyna using two solvers: explicit for forming and implicit for springback. The process was modeled using shell elements for all parts (tool and sheet) and, because of symmetry, only a half of model was considered. The FE model for forming analysis contains: the rigid punch and die parts, a deformable sheet part and a fixed one-cell part positioned at desired angle according to x-y plane, Figure 1 a). Using this model the punch displacements for desired angles of V-shape products were determined using the code ability to stop calculation when contact between two model parts appears. The FE model for springback contains only deformed sheet part with stress-strain state from the previous explicit analysis at the moment when calculation was stopped. This model calculates the springback using above-mentioned stress-strain state as initial and nodal displacement restriction as limiting conditions, Figure 1 b).

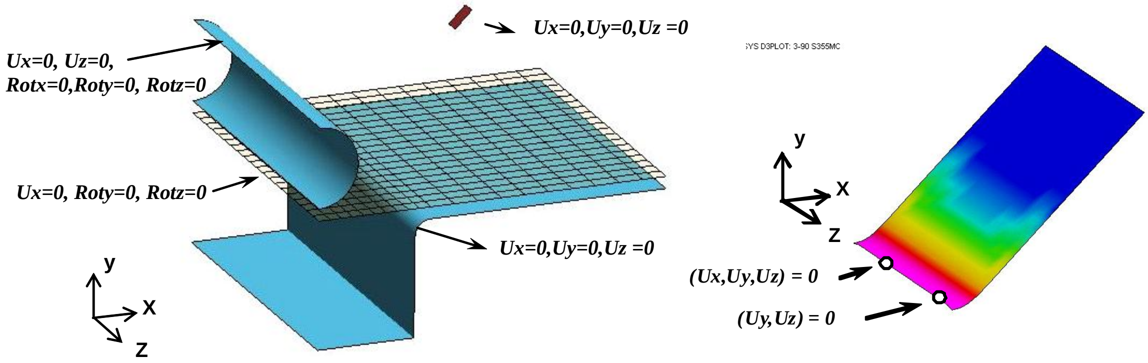


Figure 1: FE models with boundary conditions for forming a) and springback b)

3. EXPERIMENTAL WORK

In order to compare predicted and experimental data an experimental tool with adjustable die width and exchangeable punch radius has been built and placed in the laboratory tensile test machine, Figure 2. The V-shape products were made of sheets 80x40x4 mm, where part angles before unloading were measured by fitting straight lines to the selected points on part legs from the digital photos. The angles after unloading were measured by "MarSurf XC 20" pertometer and calculated using MarSurf CAD software. Springback angle was determined by calculating the difference between part angles before and after unloading.

Values of the tool parameters were chosen according to industry trend to reduce die opening where the ratio die-opening/sheet-thickness generally varies between 5 and 10, (3). Bending experiments was conducted using five combinations of the punch radii and the bend angles, while the die opening and the die radius were constant with values 25 mm and 2 mm, respectively.

Two materials was used in this research, first one was microalloyed hot rolled high strength steel S355MC and second one was non-alloyed hot rolled steel for cold plastic deformation DD13.

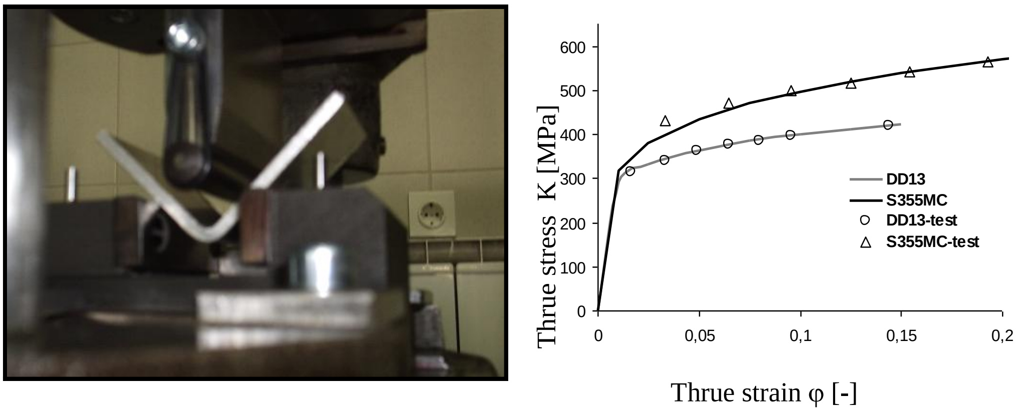
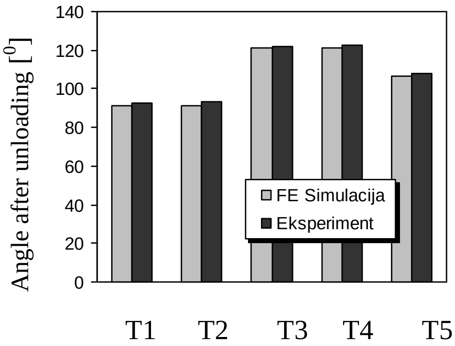


Figure 2: Experimental tool (left) and flow curves for S355MC and DD13 steels (right)

The flow-stress data for chosen materials were obtained experimentally by uni-axial tensile test, where more pronounced strain hardening effect for microalloyed S355MC steel compared to non-alloyed DD13 steel can be seen, Figure 1 - right.

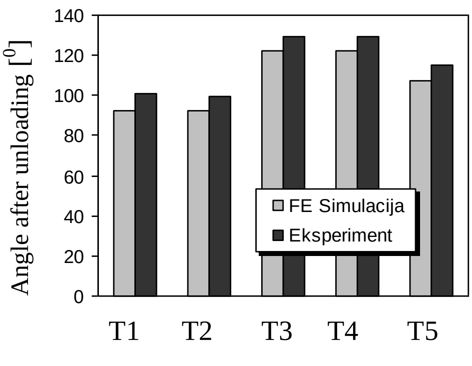
4. RESULTS AND DISCUSSION

Realization of the punch displacements on the experimental tool was done by using block gauges as limiters, where values for different punch radii and part angles (design points) were previously obtained by the FE simulation.
Measured bend angles during and after loading and values obtained by FE prediction for DD13 and S355MC steels were compared in Figures 3 and 4, respectively.
As for the bend angles under loading a systematic deviation of experimental results from FE values set as 90,120 and 105 degrees was observed. The average experimental values were greater for 0.66 [^{0}] and 1.52 [^{0}] then the predicted ones for DD13 and S355MC steel, respectively.
As for the bend angles after unloading it can be seen that the average predicted values are lower for about 1.22 [^{0}] and 7.85 [^{0}] for DD13 and S355MC steel, respectively.
Bending experiments shows that material S355MC has about 3 to 4 times larger springback for then material DD13. This could be explained by the fact that S355MC steel with C=784,6 and n=0,195 has higher work-hardening and consequently higher springback, compared to material DD13 with C=525,1 and n=0,130, (1). Namely, since the springback is a result of elastic strains in sheet at the end of deformation, it increases proportionally as the flow stress of material rises.



Design point (R_p-BA) BA-bend angle	Angle after unloading [^{0}] FE	Angle after unloading [^{0}] Exp.	Bend angle θ_s [^{0}] Exp
T1 (3-90)	91,11	92,86	90,96
T2 (5-90)	91,29	93,30	90,32
T3 (3-120)	121,20	121,46	119,58
T4 (5-120)	121,11	122,38	120,84
T5 (4-105)	106,36	106,90	105,04

Figure 3 :Comparison of the experimental and predicted part angles after unloading, left) and angles at the end forming, right), for five design points and DD13 steel



Design point (R_p-BA) BA-bend angle	Angle after unloading θ_k [^{0}] FE	Angle after unloading θ_k [^{0}] Exp.	Bend angle θ_s [^{0}] Exp
T1 (3-90)	92,43	101,26	92,22
T2 (5-90)	92,46	99,54	92,32
T3 (3-120)	121,93	129,42	120,78
T4 (5-120)	121,99	129,12	120,80
T5 (4-105)	107,25	115,42	106,48

Figure 4 :Comparison of the experimental and predicted part angles after unloading, left) and angles at the end forming, right), for five design points

The predicted average value of springback is lower for about 1.22 [^{0}] for DD13 steel and 7.85 [^{0}] for S355MC steel, compared to the measured average value. Such considerably underestimation of the springback for microalloyed S355MC steel could be explained by the fact that elastic modulus of steel during unloading in reality decreases as value of plastic strain under loading increases, (2). In FE simulation the elastic modulus of both steels is assumed constant (210 GPa) during unloading.

5. CONCLUSIONS

- Presented FE models of the air bending process can deliver sufficiently accurate data for DD13 steel as for the punch displacement-bend angle and punch displacement-springback angle relations. The average value of the part angles after unloading was lower for about 1.22 [^{0}] compared to experimental value, for observed design points.

- FE predictions of springback are not accurate enough for S355MC steel, where the average predicted value for observed design points was lower for about 6.24 [^{0}] compared to experimental one. The main reason for result deviation is that the elastic modulus in the FE simulation is assumed to be constant, however in reality it decreases as plastic strain increases.

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