COMPARISON OF NUMERICAL SIMULATION AND DEEP DRAWING TEST OF DP500 STEEL

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Abstract

Modern approaches and materials must be used to achieve mass reduction of car body parts. Important step is to depict processing of these materials in detail. This article deals with a comparison of deep drawing test of DP500 steel and results of numerical simulation. To achieve this a forming tool with simple shape was designed. The goal of this article is to evaluate prediction of defects (splits, wrinkling, necking and marking lines) in designed stamping.

Keywords: Deep drawing, numerical simulation, DP500 steel, outer car body parts, mass reduction

1. INTRODUCTION

Mass reduction of modern cars is according to stricter emission limits a very important topic. Body in white (BIW) is a section of a car where most of weight reduction is being carried out. Weight reduction achieved through removing of e.g. air-conditioning or electrically positioned seats would cause an attraction decrease of customers. Reducing weight of BIW while maintaining its safety properties does not cause the same problem. Outer car body parts as a part of BIW also have a potential for weight reduction. The disadvantage of exposed parts is their demanding design and great depth. Used materials must have superb ductility and plastic properties. Final parts must also meet minimal stiffness and dent resistance, must be convenient for assembly and have good surface quality [1].

A few different approaches can be used for mass reduction of exposed steel parts. One possibility is to use materials or alloys with lower density than steel (e.g. aluminium, magnesium, titanium, plastics). The problem is that parts made of these materials are mostly more expensive than steel equivalents, require significantly more time to produce or doesn't have the qualitatively same properties at the end. Another approach is to use sandwich plate system (SPS), which benefits from strength of the steel and low density of polymer core. The disadvantage is a problematic joining and lacking possibility of hot-dip zinc coating and phosphating. Third eventuality is to use steel with higher strength properties and good formability and plastic properties. Advantages and disadvantages of this approach are discussed in this article [2,3].

The goal of this article is to evaluate accuracy of numerical simulation of DP500 and 3 different material models of this steel. For this purpose, a set of cup test and deep drawing test of box shaped stamping were carried out.

2. DP500 (CR290Y490T-DP)

DP500 steel is a part of dual-phase steel family. The structure consists of ductile ferritic matrix and hard martensitic phase dispersed in the form of islands. It is a low carbon steel with a 10 - 40 % share of martensite. This combination allows a good combination of hardness, ductility and weldability.

DP500 is thanks to high absorption capacity and fatigue strength commonly used for structural parts of BIW. Another benefit is presence of BH effect. Due to complexity of sheet metal forming stress states, formability of

DP500 can't be stated by a single index and results from mechanical properties. Selected mechanical properties of dual-phase steel CR290Y490T-DP (known as DP500) are mentioned in **Table 1**. Chemical composition of CR290Y490T-DP is shown in **Table 2**.

Table 1 Mechanical properties of Cold Rolled Steels according to VDA 239-100

Steel grade	Proof strength	Tensile Strength	Elongation after fracture	Plastic strain ratio	Strain hardening exponent	Bake hardening	EN 10338 designation	Common designation
	$R_{p0,2}$	R_m	$A_{80\ mm}$	$r_{m/20}$	$n_{10\text{-}20/Ag}$	BH_2	-	-
	MPa	MPa	%	-	-	MPa	-	-
CR290Y490T-DP	290 - 380	490 - 600	≥ 24	*(≈1.0)*	≥ 0.15	≥ 30	HCT500X	DP500

Table 2 Chemical composition of CR290Y490T-DP according to VDA 239-100

C %	Si %	Mn %	P %	S %	Al %	Ti + Nb %	Cr + Mo %	B %	Cu %
≤ 0.14	≤ 0.50	≤ 1.80	≤ 0.050	≤ 0.010	0.015 - 1.0	≤ 0.15	≤ 1.00	≤ 0.005	≤ 0.20

3. CUP TEST

The goal of this test was to verify material model of DP500 through both numerical simulation and cup test. Actual geometry of punch, blank holder and die were scanned into .stl models, which were used in numerical simulation. The punches used in the test varied in radius at its bottom: from 0.5 mm to 2.0 mm. During the whole test a single die and blank holder were used. The dimensions of the tools are shown in **Table 3**.

Table 3 Dimensions of tools used in Cup test

Tool	Diameter		Height	Draw radius
	mm		mm	mm
Punch	Outer	44.7	20.0	0.5 - 2.0
Die	Inner	47.0	14.0	5.5

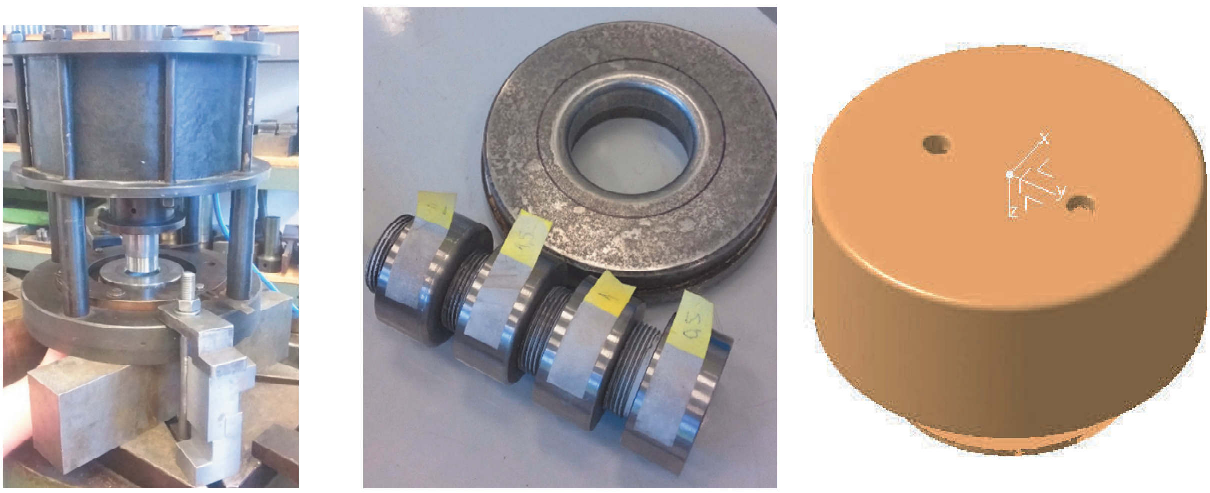

Figure 1 Forming tools used in Cup test in the left, scanned punch in the right

Standard grid pattern (element size 1 mm, relative distance of elements 2 mm) was applied on the surface of blanks. The thickness of the blank was 0.6 mm. Both 62 mm and 82 mm round blanks were prepared for the test. Test was done with a universal hydraulic press. Blank holder force was increased between the tests to reach fracture in the cup. Forming tools and scanned model of punch are shown in **Figure 1**.

The result of the test is that blank holder force must proportionally increase in respect to yield strength of tested material. Drawn cups were photographed and thickness reduction was evaluated. The result is that chosen grid pattern is not suitable for this test. Selected grid pattern is too coarse. The results worsen with lowering value of punch radius. Verification of numerical simulation and Cup test must be amended with metallography cut and thickness measurement or done with finer grid pattern. Picture of photogrammetric analysis and result of numerical simulation are shown in **Figure 2**.

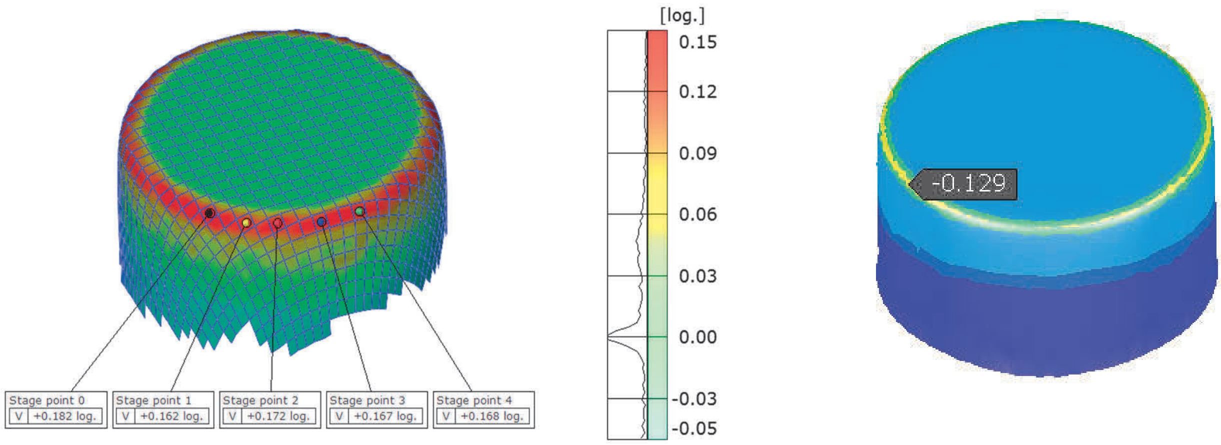

Figure 2 Result of photogrammetric analysis in the left (positive logarithmic thinning), result of numerical simulation in the right (negative percentual thinning)

4. DEEP DRAWING TEST OF BOX SHAPED STAMPING

To verify material models of selected materials a deep drawing tool was designed. The product of these tools is a simple shaped box stamping. Blank holder and die are slant so that the edge in the bottom of a box could cause a marking line, which will be evaluated in other experiments. Forming tools are shown in **Figure 3**.

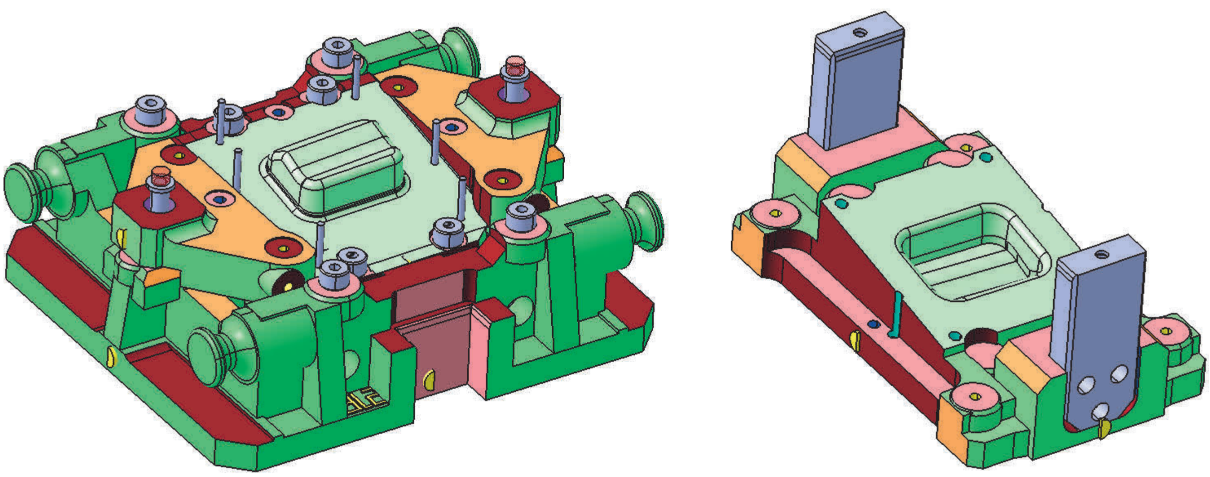

Figure 3 Geometry of tools (punch and blank holder in the left, die in the right) used for drawing the box shaped part (real blank holder and die have drawbeads)

In this experiment 235 mm x 265 mm blanks were used. Group of blanks were degreased, another group remained pre-lubed and the last group was additionally lubed. Blanks with both hot-dip and galvanized zinc layer were used. On selected blanks a deformation grid (same dimensions as in Cup test) was applied. The die (upper tool) was moved in 3 different final positions: lower end, 5.5 mm up from lower end and 10.7 mm from lower end. Numerical simulation was also evaluated in all 3 die positions and all lubrication states. An example of measured stamping and result of photogrammetry analysis is shown in **Figure 4.**

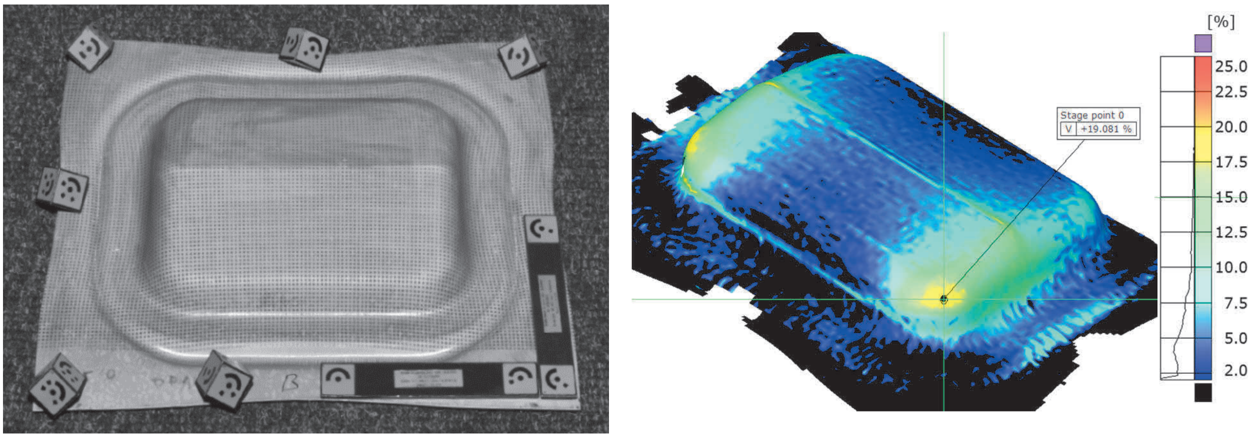

Figure 4 Photogrammetry analysis in the left, result of photogrammetry analysis in the right

For numerical simulation the machining data were used. Surface of forming tools used in numerical simulation is pictured in **Figure 5**. The No-Bearing areas of the blank holder was set according to real tryout. A set of numerical simulations were run and evaluated.

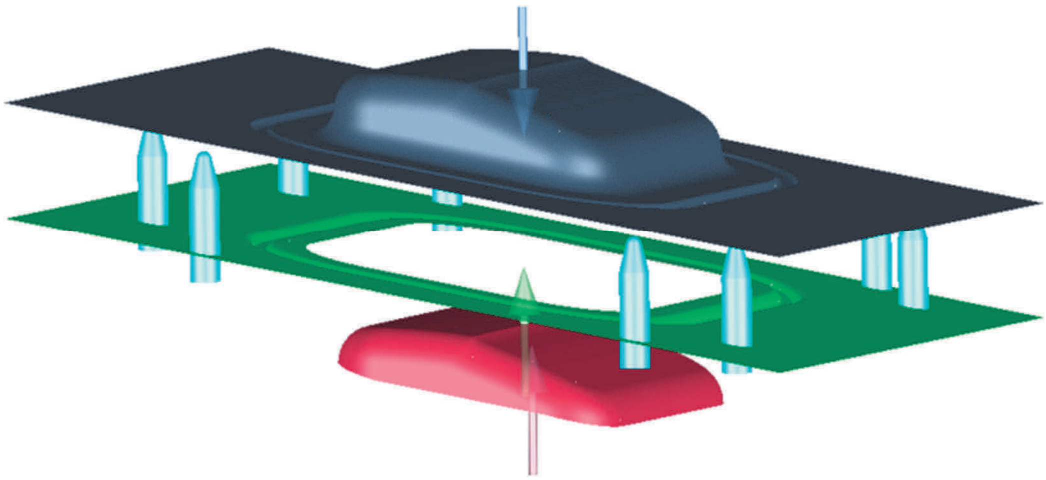

Figure 5 Forming tools in numerical simulation

The result of this test is that correspondence of numerical simulation and deep drawing test greatly varies according to lubrication of blanks. The best match (approximately 5% difference) of numerical simulation was in situation of pre-lubed blanks. The result of physical stamping of pre-lubed blank is shown in **Figure 6** and the result of numerical simulation of pre-lubed blank is shown in **Figure 7.** In both degreased blanks and additionally lubed blanks the match is not that good. The maximum values may be in good correspondence but the overall distribution of thinning is not coincident with physical stamping. The disagreement of overall distribution of thinning is very similar for all tested material models.

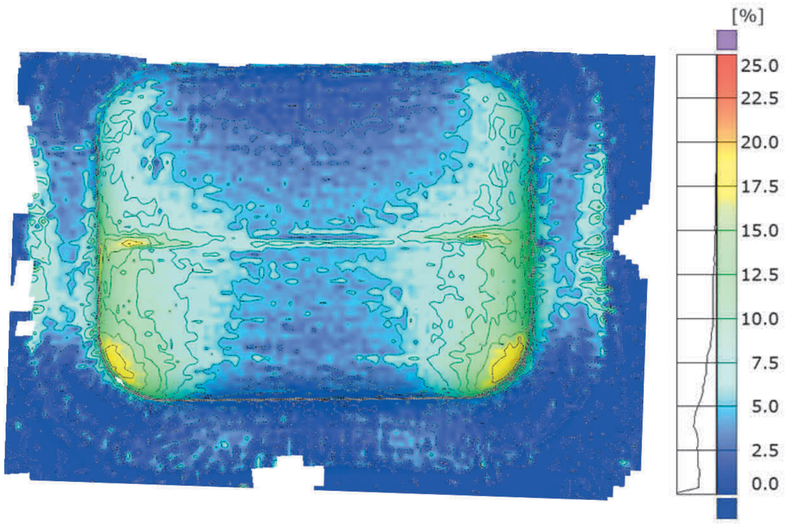

Figure 6 Result of photogrammetry analysis of pre-lubed blank (percentual thinning)

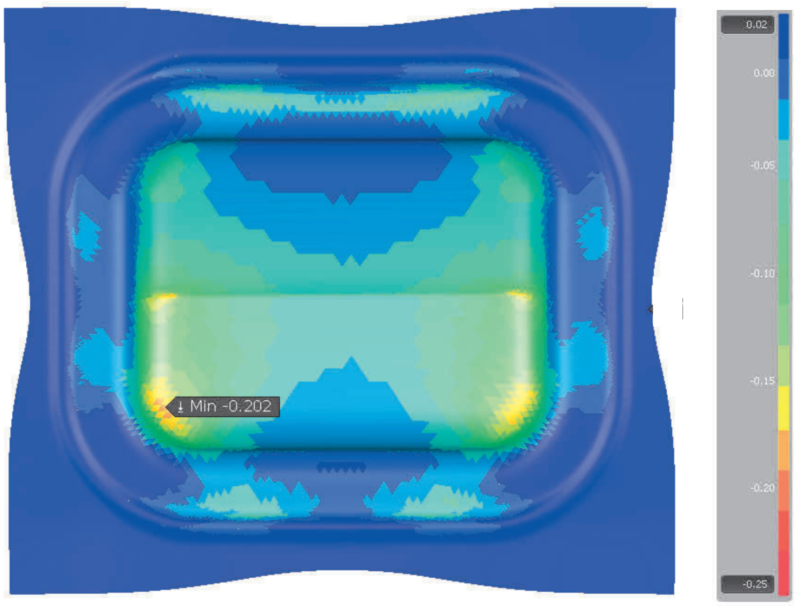

Figure 7 Result of numerical simulation of pre-lubed blank (percentual thinning)

Facts mentioned above express the need for better description of tribology states in numerical simulation. Single coefficient of friction is not sufficient. Amount of lubrication, tool roughness and surface morphology of both blank and tools must be also considered.

5. CONCLUSION

This article follows up problematics of mass reduction of cars, which is a significant topic. Three possible ways of mass reduction are mentioned in the introduction. Discussed possibility of mass reduction of outer car body parts is an application of dual-phase steel DP500. Most innovations are first tried out in numerical simulation. To achieve satisfying results a correct material model and settings must be used. To evaluate the accuracy of material model of DP500 two different experiments were performed: A Cup test and Deep drawing test of a box shaped stamping. The result of a Cup test is that to evaluate physical tests a finer grid pattern must be used because of sharp edges in the bottom of the cup. Another possibility is to amend this experiment with metallography cut and measurement. The result of deep drawing of box shaped stamping is that the accuracy of numerical simulation greatly varies according to lubrication of parts. In case of nonstandard lubrication of blanks, the thickness reduction does not correspond in several sections of the stamping [4].

Facts mentioned above express the need for better description of tribology states in numerical simulation. Single coefficient of friction is not sufficient. Amount of lubricant, tool roughness and surface morphology of both blank and tools must be also considered. The evaluation of material models is not easily feasible in real forming tools because differences in models are minor. Inaccuracies in the input of numerical simulation does greatly influence the result. To evaluate a feasibility of selected outer car body parts is a possible solution to create several material models which represent both upper and lower formability limits of selected materials and to simulate each new part with use of both material model. Solution to mentioned problematics may also improve application of new modern perspective materials. Additional effect of correct setting of tribology state may also reduce the cost of forming tools thanks to reduction of production and design corrections [5,6].

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Sustainable Research and Development in the Field of Manufacturing Technology references

REFERENCES

[1] EVIN, E. The Deformation Properties of High Strength Steel Sheets for Auto-body Components. *Procedia Engineering* [online]. 2014. vol. 69, pp.758-767 [viewed 2018-05-04]. Available from: DOI 10.1016/j.proeng.2014.03.052.

[2] VALEŠ, M., PAČÁK, T. and TATÍČEK, F. Feasibility Study of Manufacturing Outer Car Body Parts with Use of DP500. In *METAL 2017: 26th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 561-566.

[3] YAN, B., LAURIN, K., XU, K., SRIRAM, S., HUANG, M., CHINTAMANI, J., and LALAM, SH. A New Dual Phase Steel for Automotive Body Panels [online]. 2003. vol. 3, iss. 3 [viewed 2018-05-05]. Available from: DOI: 10.4271/2003-01-0518.

[4] RAO, B.V.S., REDDY, G., RAO, G., and REDDY, R. Numerical Analysis On The Effect Of Various Parameters On Fracture Limit For Deep Drawn Cups. *Materials Today: Proceedings* [online]. 2018. vol. 5, iss. 1, pp.1387-1400 [viewed 2018-05-05]. Available from: DOI: 10.1016/j.matpr.2017.11.225.

[5] WANG, B. Analysis on Stamping Forming Simulation and Springback Control of High-Strength Steel Auto-Body Panels. *Applied Mechanics and Materials* [online]. 2014. vol. 608-609, pp.71-76 [viewed 2018-05-04]. Available from: DOI: 10.4028/www.scientific.net/AMM.608-609.71.

[6] NIELSEN, C.V., and BAY, N. Review of friction modeling in metal forming processes. *Journal of Materials Processing Technology* [online]. 2018. vol. 255, pp.234-241 [viewed 2018-05-05]. Available from: DOI: 10.1016/j.jmatprotec.2017.12.023. ISSN 09240136.