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Numerical simulation of car body elements pressing applying tailor welded blanks – practical verification of results

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The cycle of investigations on applying tailor welded blanks (TWB) for sheet forming processes was conducted at Department of Materials Technology of the Silesian University of Technology and as The European Research Project Acronym SIM-TWB. The model of tailor welded blank (TWB model) have been worked out and great number of FEM simulations of stamping process of different geometry drawpieces using TWB were conducted. The paper presents the practical verification of simulation results of stamping process of car body drawpieces: B-pillar and reinforcement of floor of boot, applying TWB for stamping. Stampack – a commercial program for FEM simulation was applied, as well as worked out 5-zones TWB model have been used. The practical verification showed the good agreement of results of simulation and practical experiments of stamping processes of both chosen drawpieces. Hence worked out TWB model is proper and recommend to simulation of TWB forming processes.

Keywords: *tailor blank model, FEM simulation, STAMPACK software, forming of tailored blanks, B-pillar forming*

1. Introduction

The full exploitation of the advantages offered by tailor-blanks is presently limited due to the design and production complications that currently exist. Without adequate simulation to reduce the project time, costly trial-and-error methods are required to enhance the process and make the changes necessary. Because of this the cycle of investigations on applying tailor welded blanks (TWB) for sheet forming processes was providing at Department of Materials Technology of the Silesian University of Technology and as The European Research Project Acronym SIM-TWB. The need for the SIM-TWB project was therefore clear: advances in simulation technology must be made soon in order to take full advantage of concurrent engineering approaches to reduce time and cost, improve quality and safety and enable advances in tailor-welded-blank technology and usage. In this context the use of Finite Element Method (FEM) with specifics developments for tailor-welded blank technology is a way to achieve the objectives exposed above. The first laboratory and industrial experience with stamping of laser welded blanks, which was elaborate in Department of Materials Technology of the Silesian University of Technology (SUT), allowed to start research on tubes hydroforming processes. The recognition of joined sheet and weld joint mechanical properties and proper their drawability evaluation gave the parameters for lead up finite element method (FEM) simulation of forming and hydroforming of tailor blanks. In papers [1–2] were presented methods of drawability evaluation for both processes using welded blanks and tubes. Part of description of technical developments of FEM simulation using STAMPACK with added software modules for tailor blank is presented in this paper. Different models of tailor blank were tested and simulations were provided by CIMNE (Spain), IPPT-PAN (Poland), QUANTECH A.Z. (Spain), IST (Portugal), SUT (Poland) and industrial partners as a part of SIM-TWB project cooperation work. The most proper model of tailor blank was applied into STAMPACK software and used for FEM simulation of B-pillar pressing.

2. Using STAMPACK and extend model of tailor blank

The mathematical definition of the model to be used for the weld seam included the sheet alignment, welding process and the heat affected zone aspects. The definition of the program structure, input parameters, user interface, weld seam database requirements and user definition of the tailor-blanks has been performed based on the current commercial version of the STAMPACK software and earlier investigation of SIM-TWB European Consortium Partners. This specification assisted the definition of the experimental work required in order to characterize these models properly. Tested models are presented in Figure 1.

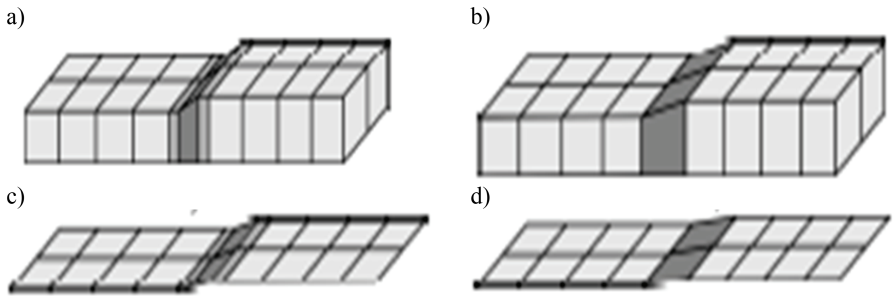


Fig. 1. Finite element models of tailor blank: a), c) 5 zone model, b), d) 3 zone model

FEM studies were carried out to characterise welding, finite element method (FEM) based numerical simulations have been used as an additional aid to study the complex thermal-mechanical-metallurgical interaction during welding. These studies made possible to carry out parameter studies more cheaply than by doing so experimentally.

These studies have been done by IPPT-PAN. Temperature distribution and evolution has been analysed. Residual stresses have been obtained in the weld zone. Development of weld macroscopic constitutive model: the improvement of the model formulated together with CIMNE, IPPT-PAN, IST and SUT to the mathematical formulation of the macroscopic material behaviour of the weld heat affected zone (HAZ) [3–7]. It is a simple model, with few input parameters, relatively accurate but simple for non weld-expert users. Development of complete weld seam behaviour model: the inclusion of the combined geometrical effects such as sheet alignments (different sheet thicknesses welding top-top, bottom-bottom, centre-centre, etc.) that produce bending and torsion forces along the weld with the weld material constitutive effects (virgin material, HAZ, transition zone, etc.) were done. A series of preliminary tests have been carried out and simulations of the experimental work on the blanks will provide initial verification that the models work correctly. The numerical model was completed in the finite element code STAMPACK [8]. Verification tests have been completed to show that the numerical model correctly represents complex deformation of TWBs. Adaptation of user-interface for tailor-blank modelling (TL) – the already existing STAMPACK user interface to enable the user to easily define tailor blanks and the characteristics of the weld-line were done by QUANTECH A. Z. The basic idea is that the user define the different blank zones as well as the weld-seam – this will obviously be more complicated that the current method of just defining the blank material.

3. Blank, material properties and tools definition

An explanation of the initial available information for the simulation of B-Pillar process allowed its final STL representation. The final B-Pillar piece STL representation, shown in Figure 2, was obtained by optical digitalization technology. The inverse engineering process was starting from it to design the tailor welded blank (TWB) deep drawing process. Moreover the advantages, disadvantages and limitations of this kind of technology are shown. The experimental and simulated results comparison is done too. The forming limit curve (FLC) has been used as failure criterion. The STL definition from optical digitalization of final piece was proposed by Silesian University. In Figure 2 a general view of final piece described by 195079 triangular facets, is shown.

Through STL definition, a complete simulation of B-Pillar process has been done. This inverse engineering process was done thanks to SIM-TWB project specific software (STAMPACK).

The main advantages of optical digitalization technology are:

- The simplicity. In one operation, without manual manipulation, the geometry of final piece is obtained.
- Moreover, one file and one layer content all the blank definition. The output format of optical digitalization is totally compatible with software used in simulation. The lecture was OK. It had zero warning or error messages.

- The surface description quality is high. The density of triangular facets is function of curvature. The stretching effect is used to reduce the total number of facets: If there is one curvature direction only, high relation aspect is used.
- The surfaces normal sense is uniform all over the piece.

However, optical piece digitalization also has disadvantages:

- It is not possible to know the exact geometry of tools (die, punch, blankholder) because the final piece is affected by springback effect. In B-pillar case there are some walls that have negative slopes.
- If the process has two steps, is not possible to know the tools geometry of the first operation.
- If drawbeads were used during the deep drawing its profile is acknowledged. Only in blocking drawbeads case, the profile of them is reproduced approximately in the final shape.
- The optical digitalization reproduces one face of the final piece, only. The steps in punch, die and blankholder are not visible in function of the face used for digitalization task.
- It’s impossible to know where the blank initial positioning is.
- The STL mesh definition has not the suitable position to define the optimal forming direction.

Fig. 2. Geometrical description of final piece (195 079 triangular facets)

The main limitation in simulation of the process is that the geometries of different tools (blankholder, punch and die) were not defined. To simulate the process an approximation from the available geometric information (STL mesh) was done. However, this approximation is not possible to do without errors. The exterior limit of accordance radius of die is used to define the inner border of blankholder.

Other important parameters must be defined by the user:

- blankholder force,
- blankholder velocity (in clamping),
- punch velocity,
- frictional coefficients,
- damping coefficients.

The suitable information to simulate the process is the blank boundary definition (in IGES format for example) or a complete dimensional definition of the initial blank. In this case the information available is shown in Figure 3.

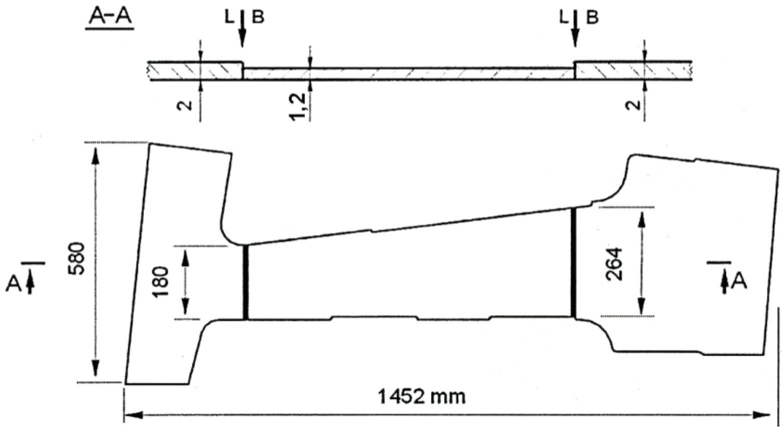


Fig. 3. Partial description of blank dimensions

However, through STAMPACK pre-processor, a good approximation of the blank format in its initial configuration was done. The methodology to create the initial blank format is:

- Take the Figure 5 as background of STAMPACK pre-processor.
- Draw the figure contour with lines (straight or NURBS), and also the radius of the figure using Stampack edit geometry facilities.
- Define the weld lines and heat affected zones (HAZ).
- Scale the model to real dimensions.

A good approximation of the localization of weld lines have been done by the method explained above. Once the model geometry is succeeded the mesh could be done. This method is a good approximation of the real blank shape. In the Figure 4 the measures of the STAMPACK geometry is shown.

To define the HAZ (heat affected zones) and weld lines (WL) dimensions has adopted a strategy similar to that is explained in [1–7]. In B-Pillar process an additional zone must be defined in order to improve the CPU times. That's because the element sizes of the HAZ and WL zones are lower that the element size all over the sheet. Small element size imposes limitation on the time step length in the explicit integration scheme. This leads to large number of time steps required for the solution. A commonly used method to increase efficiency of the solution consists in scaling the mass (density) of small elements [9] to increase the critical time step. Mass scaling should be introduced carefully in order not to increase inertial effects excessively. Based on our experience the density has been scaled 20 times in transition zone and 40 times in HAZ and WL. Hence, the zones dimensions are:

- 1 mm of width in HAZ,
- 0.5 mm of width in WL,
- 6 mm of width in transition.

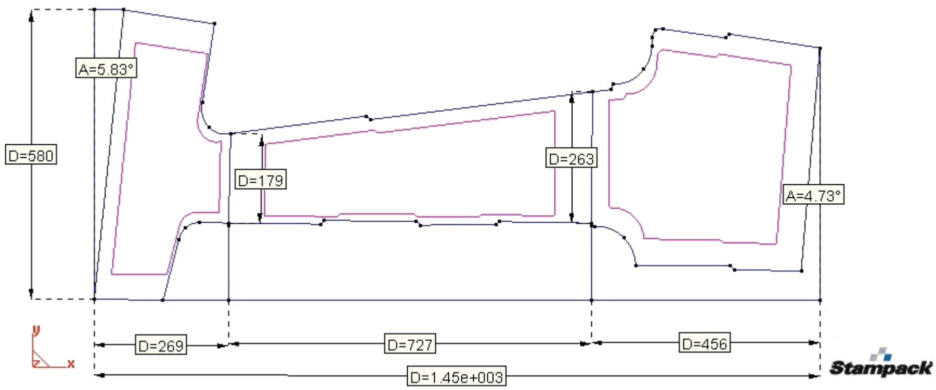


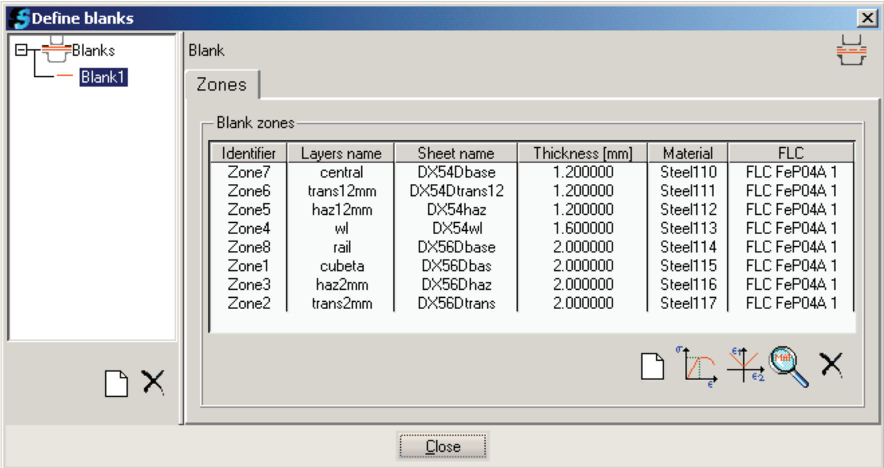
Fig. 4. Initial blank geometry in STAMPACK

The assignation of the blank materials is more complex than in non TWB process, and in this case the difficulty is higher because the blank have 8 different zones, where 7 different materials have to be informed in the specific interface. The different zones and its parameters for steel simulation are explained in the Table 1. In Figure 5 a graphical interface menu of zones definition is shown.

Table 1. Steels mechanical characteristics (partial) by zones

Zone Name	Material	Thickness (mm)	Density (kg/m^3)	Mec. Properties
cubeta	DX56D	2.0	7800	Std.
trans2mm	DX56D	2.0	156000	Std.
haz2mm	DX56D	2.0	312000	10% increased
wl	DX54D	1.6	312000	20% increased
haz12mm	DX54D	1.2	312000	10% increased
trans12mm	DX54D	1.2	156000	Std.
central	DX54D	1.2	7800	Std.
rail	DX56D	2.0	7800	Std.

The tools definition has been done from the final piece. The tools geometries were done by inverse engineering process. In this case both the punch, as the blankholder as the die had to be created. Every simulation parameters were assigned into mesh, because the geometry of the tools did not exist. To create the punch, a cut of STL mesh was done. The interior part of the cut was the punch. It has 184481 triangular contact faces. In Figure 6 the punch is shown. The blankholder was created from the sum of two zones: the interior zone (near to accordance die ratio) and the exterior zone.



Identifier	Layers name	Sheet name	Thickness [mm]	Material	FLC
Zone7	central	DX54Dbase	1.200000	Steel110	FLC FeP04A 1
Zone6	trans12mm	DX54Dtrans12	1.200000	Steel111	FLC FeP04A 1
Zone5	haz12mm	DX54haz	1.200000	Steel112	FLC FeP04A 1
Zone4	wl	DX54wl	1.600000	Steel113	FLC FeP04A 1
Zone8	rail	DX56Dbase	2.000000	Steel114	FLC FeP04A 1
Zone1	cubeta	DX56Dbas	2.000000	Steel115	FLC FeP04A 1
Zone3	haz2mm	DX56Dhaz	2.000000	Steel116	FLC FeP04A 1
Zone2	trans2mm	DX56Dtrans	2.000000	Steel117	FLC FeP04A 1

Fig. 5. Interface zones definition

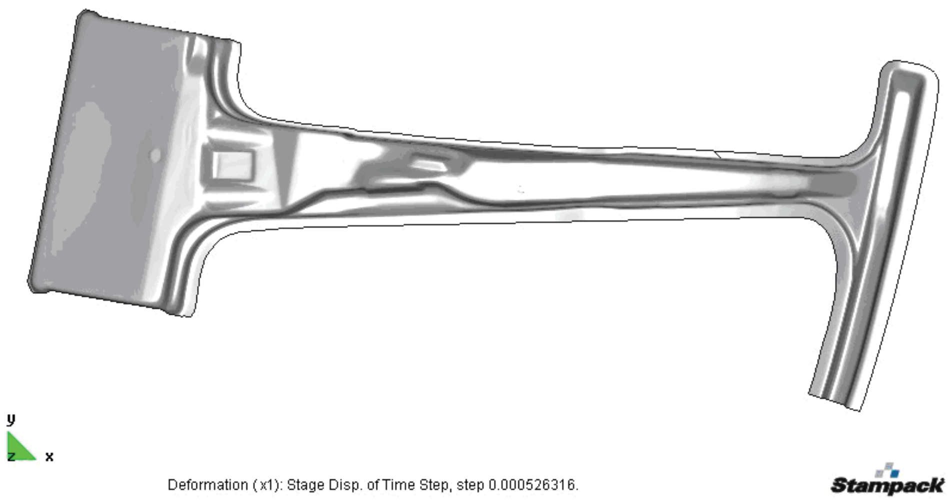


Fig. 6. Punch definition

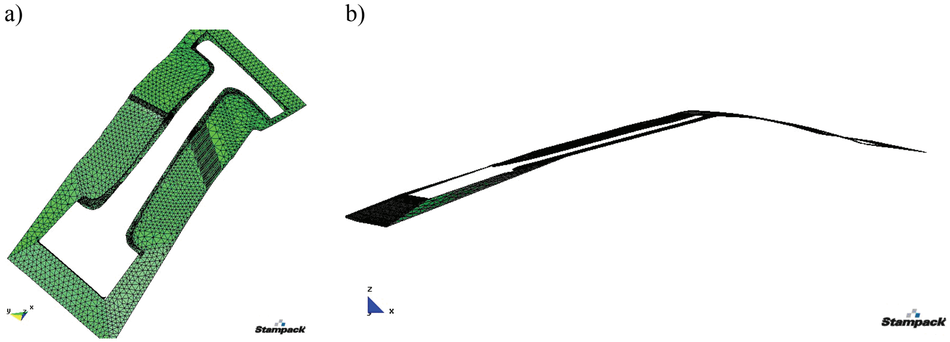


Fig. 7. a) Complete blankholder – interior and exterior, b) blankholder curvature

The blankholder has 12831 triangular contact faces in total. The interior zone was obtained by a cut of STL mesh. The exterior zone was done from STL file. This file was imported in STAMPACK environment, then was exported in *.dxf files, and then opened in STAMPACK environment once again. By this way, the final format of the blank could be worked like geometry (not in mesh mode).

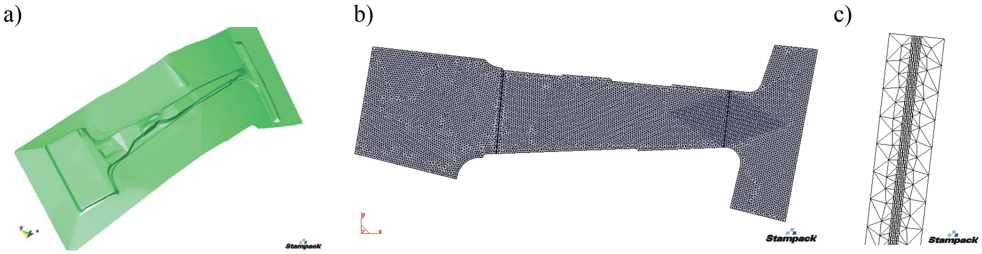


Fig. 8. a) Die smoothed mesh, b) general blank's mesh, c) mesh in weld area

Fig. 9. Initial tools and blank positioning

Once the final blank format was opened in STAMPACK as geometry, the copy of exterior points were done to get the interior line of exterior zone. The exterior part had to be the same curvature that the rest of the blankholder. The complete blankholder and its curvature are shown in Figures 7 respectively. The die is the sum of final blank format (sent in STL file) added to the exterior zone of the blankholder. The die has 198232 triangular contact faces. In Figure 8 the die is shown.

The mesh criterion was obtaining a regular element size in the different zones. The element size searched was 7.5 all over the blank, except in the HAZ and WL that was 0.5 in width and 2 mm on length (Figure 8c). In the transition zones the element size increases from 2 to 7.5 mm. The blank mesh total elements are 19824 BST (Basic Shell Triangle) elements (see Figure 8b).

The relative position of blank and die is necessary to simulate correctly the process. In this case, we supposed that the tools were on correctly position (not the most optimized) and it is also supposed that the blank was horizontal. In this case, the punch stroke is optimized, and the initial positioning of tools and blank is shown in Figure 9.

4. Simulation results

For prepared model of blank, dies and blankholder for forming B-pillar, the simulation results for steel (DX54D and DX56D) are shown. There is also described one geometric limitation in simulation and its cause is explained. The strokes of the model are:

- blankholder stroke: approximately 275 mm,
- punch stroke: approximately 105 mm,
- the punch is not activated at the beginning.

The main contact parameters of the model are:

- cut off: 1e-5,
- penalty: 0.1,
- frequency: 1000.

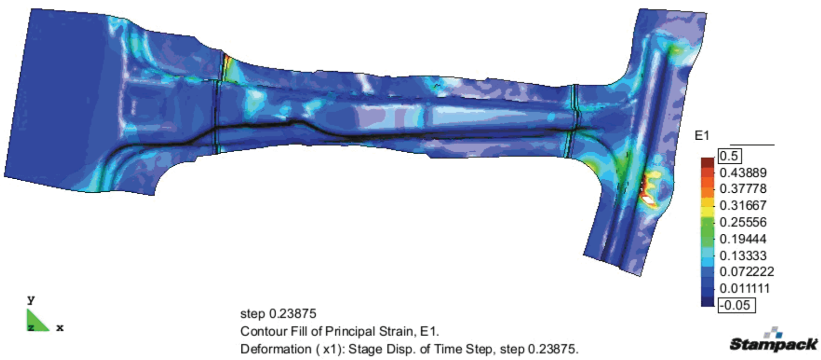


Fig. 10. Simulated distribution of main strain (ε_{11}) at the end of the process of stamping B-pillar

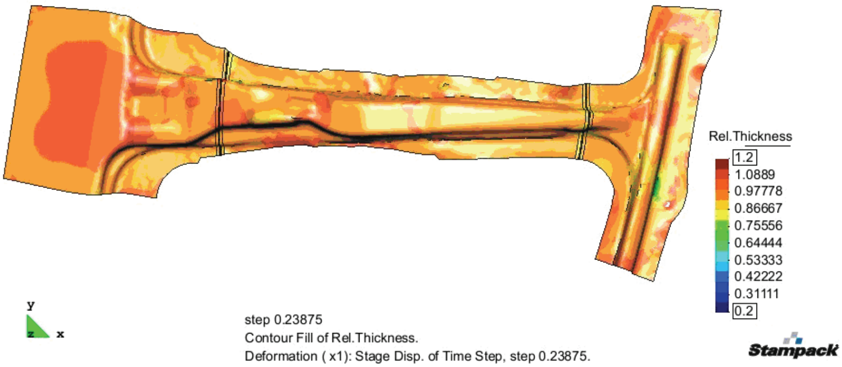


Fig. 11. Simulated relative thickness at the end of the process of stamping B-pillar

Other parameters are damping in blankholder stage: 50% in 0.01 seconds and damping in forming stage: 50% in 0.1 seconds. The results obtained in tested model are shown in Figures 10 and 11. In some zones the results are not quite good. That's because the tools were not fine defined because the punch and the die are equal (extracted from STL file), and the final piece had springback with negative walls. That's the reason of the blank's penetrations in the tools.

5. Experimental results comparison

The experimental results comparison has been done with model formed in steel material and the FLC curves made by the Silesian University of Technology. In experimental results four zones have been studied. These zones are shown in the Figure 12.

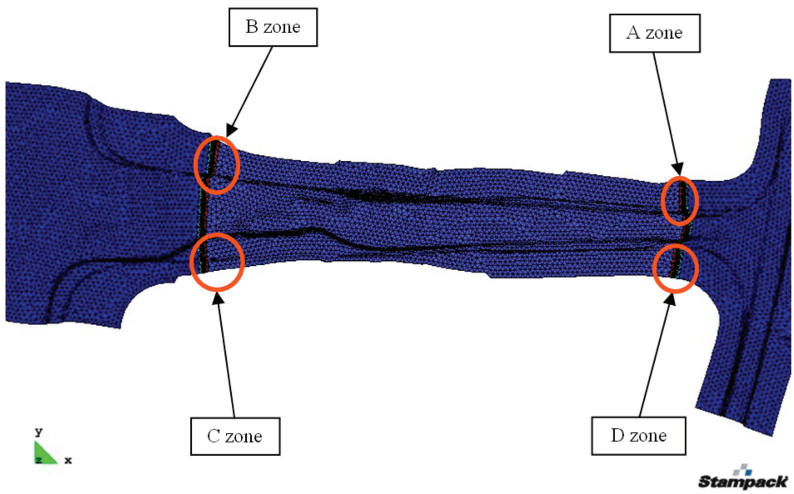


Fig. 12. Experimental study zones in B-Pillar

There were analyzed the experimental FLC for joined sheet blanks and results of stamping B-pillar in four zones. Exemplary comparison of experiment and simulation FEM results is shown for zone B (Figures 13 and 14) and zone C (Figures 13 and 15).

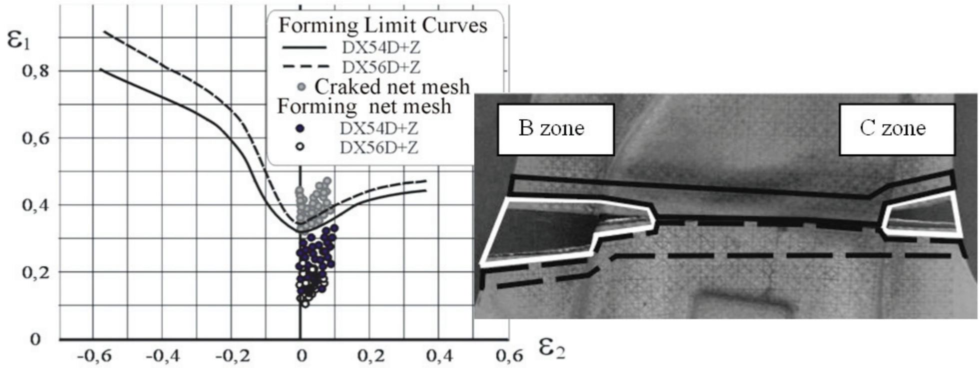


Fig. 13. Experimental results in B zone of B-pillar

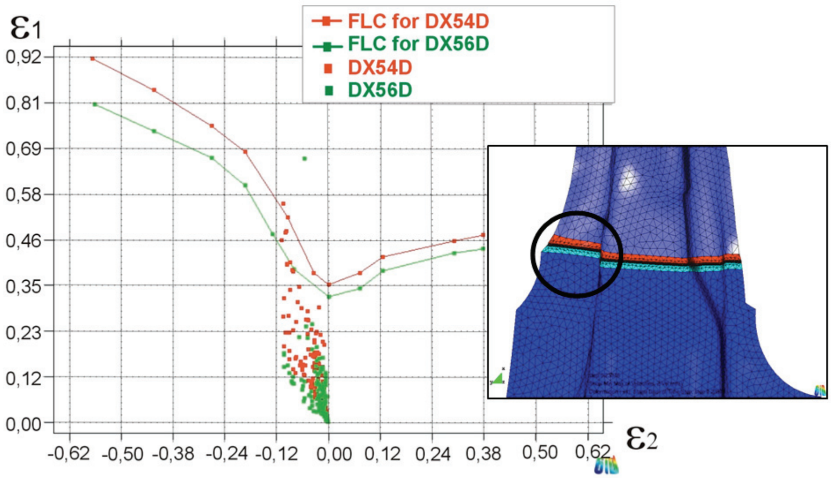


Fig. 14. Simulation results in B zone of B-pillar

Defined method of TWB drawability evaluation based on laboratory tests with seam weld behaviour analysis in according to forming limit curves of joined sheets, laboratory tests and hardness measurements on cross section of weld area have helped to define 5-zones model of TWB and applied this model to accurate simulation. Laboratory tests for TWBs joined of different materials and using different welding techniques, allowed to choose proper joining techniques for steel materials. Possibility of experimental work on sheet blanks and Tailor Welded

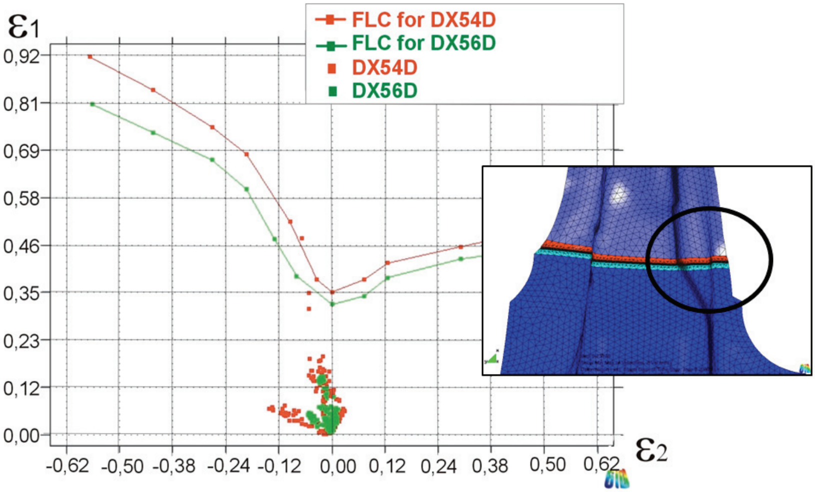
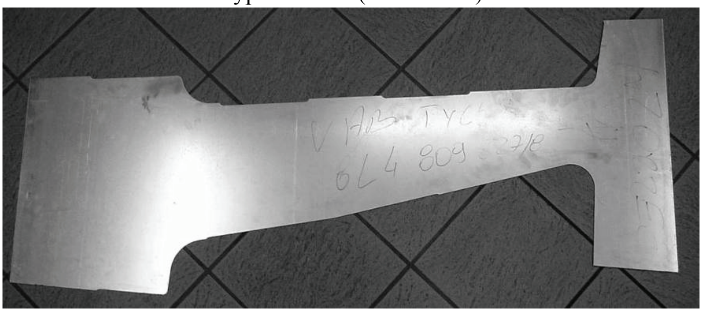
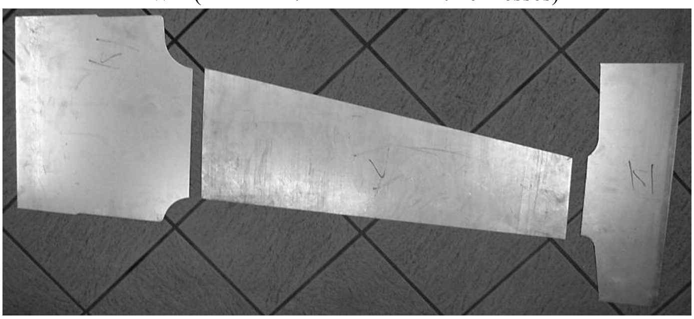


Fig. 15. Simulation results in C zone of B-pillar

Table 2. Blank type for B-pillar comparison of weight

Blank type for B-pillar	Weight
Typical blank (2 mm thick) 	11.50 kg
TWB (2 mm + 1.2 mm + 2 mm thicknesses) 	9.61 kg
Weight reduction result (16%)	1.89 kg

Blanks (TWB) has been defined. Steels TWBs have prepared by IST and Polish Welding Centre of Excellence (PWCoE). After materials for testing had been defined, sheet alignment of TWBs has set. At Magna Cosma FORMPOL Sp. z o.o. stamping plant in Tychy was realized industrial application of TWBs base on earlier industrial experience on TWBs. Industrial tests have been provided to manufacture drawpiece of B-pillar from accurate designed TWBs. The major aim of designed TWBs was to reduce thickness of sheet (in the end to reduce the weight of blank – see exemplary figure) and execute it in proper area of the blank. Tests of welding techniques and study on proper laser welding parameters made by IST and PWCoE, allowed to execute good welds, it means welds of good drawability properties and accurate for stamping processes. Industrial test of stamping B-pillar from TWBs obtain 16% weight reduction for designed blank (see table 2). It corresponds with planed vehicle weight reduction.

The data consists of basic properties, drawability properties and FLCs coordinate for testing and simulated materials PS has delivered. All partners could use it. PS has prepared numerical model of B-pillar geometry and CIMNE, based on it, has done simulation of stamping using Stampack software for this drawpiece.

6. Conclusions

The conclusions extracted in this industrial TWB benchmark (B-Pillar) are:

- Through an inverse engineering an approximation of tools can be defined.
- The contact forces are lower than 4000 KN, which is the maximum capacity of the press machine.
- The STL transfer information from optical digitalization was quite well and acceptable. The STL mesh file had not errors.
- With STAMPACK geometry edition capacities, from a figure of initial blank the geometry of the blank can be created.
- The planar strain distribution, from simulation, approximates the experimental results. Some variations in blankholder parameters, tools definition (punch and die) could be done to optimize the process.
- In weld seam (weld line and HAZ) the behaviour of $\varepsilon_1/\varepsilon_2$ relation is near to Poisson coefficient in most cases.
- The CPU times have been optimized with density scale and regular element size.

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Praktyczna weryfikacja rezultatów symulacji numerycznej tłoczenia elementów karoserii samochodowej z wsadów spawanych laserem

W ramach cyklu badań nad zastosowaniem wsadów spawanych laserowo, prowadzonych w Katedrze Technologii Materiałów Politechniki Śląskiej oraz w ramach projektu Europejskiego SIM-TWB opracowano model WSL i przeprowadzono szereg symulacji numerycznych MES procesu tłoczenia zróżnicowanych konstrukcyjnie elementów z blach spawanych laserem. W artykule przedstawiono praktyczną weryfikację wyników symulacji tłoczenia wybranych wytłoczek karoseryjnych, a mianowicie: słupka B oraz wzmocnienia podłogi bagażnika, tłoczonych z wsadów spawanych laserowo. Do symulacji zastosowano komercyjny program STAMPACK oraz opracowany model 5-warstwowy wsadu spawanego. Weryfikacja praktyczna wykazała dobrą zgodność wyników symulacji i eksperymentów praktycznych tłoczenia obu wybranych wytłoczek, a co za tym idzie opracowanego modelu wsadu spawanego.