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COMPENSATION OF SPRINGBACK DEFORMATION IN SHEET METAL FORMING ANALYSIS

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Abstract

Process of metal forming in automotive parts construction becomes more and more demanding due to tightened up tolerance and trials to realize very complex and in many cases unworkable design in mass production. Moreover, it is required to cut and limit costs of die production and simultaneously keep high quality. Furthermore, construction elements are more often produced from materials which belong to High Strength Steel or Ultra High Strength Steel. Application of this kind of materials considerably reduces construction mass due to high durability. Nevertheless, it results in appearance of springback effect. Springback value depends mainly on used material as well as part geometry and in extreme cases deviation value from target part might reach in some areas high level. Designing of dies requires using of appropriate Finite Element Method software to make them more economic and less time-consuming. Therefore, analysis of forming process alone is not enough to be taken into account. During the design process, it is needed to include the die compensation to reach optimized blank sheet. Prediction of springback effect by tryout method and then correction of deviation is difficult arduous and painstaking. Virtual compensation methods make it possible to receive precise result in a short time. This way gives a huge economic advantage eliminating useless milling and allows producing of die just in time. Optimization process can relate to individual operation as well as take into consideration intermediate stages in the final result, at the same time increasing the accuracy. Die compensation with software application was experimentally verified by prototype die.

Keywords*: springback, compensation, optimization, simulation analysis, metal forming*

1. Introduction

Forming processes are widely used during manufacturing of vehicles construction parts. Their main attribute is high efficiency, repeatability and first of all economy, simultaneously keeping the proper surface condition in mass production. Efforts are made to replace construction elements with aluminium alloy, magnesium alloy and composites.

In 2002, constructions contained about 0.5% magnesium and 8.8% aluminium but in 2010 respectively 2% and 12% [1]. There are some trials of mass production of construction elements as integral composite parts. Moreover, their durability is similar to high mechanical parameters Advanced High Strength Steel (AHSS).

Their main advantage is low mass 40% less than in the same elements made from conventional steel. However, the composite is not able to provide all properties that have stamp parts. It is caused by lack of repeatability with divergence even about 30%.

Technologies of composite materials are said to be transferred from construction of high-performance vehicles to automotive. However, the problem occurs concerning possibilities of servicing cars after crash. In fact, damage of composite material structure eliminates a capability of their repairing, especially it is not as easy as for steel elements.

Parts of automotive industry that are made on mass scale by plastic forming ought to be characterised by:

– good mechanical features, especially high ratio of material strength to its density,
– good workability for plastic forming,
– large own stiffness,
– good energy absorption during possible crash,
– minimized amount of operations,
– good resistance to corrosion and good weldability,
– good fatigue strength during operating,
– productivity [2].

Main qualitative expectations of customers are: exterior look, safety, comfort, high engine performance and low fuel consumption. Higher standards of comfort and safety cause continuous rise in vehicles weight [3, 4]. Due to restrictions of Euro 5 norms engines are forced to reduce their mass and fuel consumption. Therefore, new solutions are still being searched in order to ensure optimal mass supporting structure and positive crash tests results. Creating some brand new steel grades with strong mechanical properties had a groundbreaking contribution in steel researches. These materials are divided into groups according to ultimate strength values:

– conventional steel with High Strength Steel (HSS) 300<Rm<600 MPa which continuously contain High Strength Low Alloy (HLSA), Bake-Hardenable (BH), Carbon-Manganese (CMn) and partially Dual Phase (DP);
– Advanced High Strength Steel (AHSS) with 600<Rm<2000 contain Dual Phase, Martensitic Steel (MS) and Transformation-Induced Plasticity (TRIP);

The results of many researches done by joint international projects during latest 15 years are AHHS materials. They enable obtaining high endurance materials at the same time preserving good plasticity. Although these two parameters do not go hand in hand and the increase of one of them is at the expense of the other, some material groups have beneficial values of both.

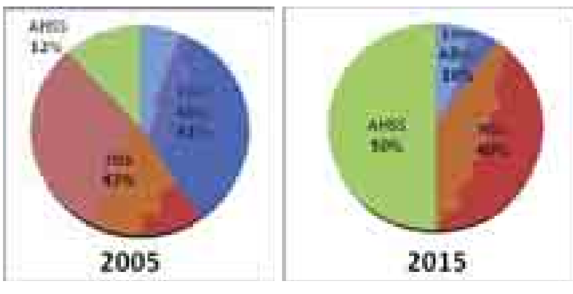

Fig. 1. Usage of steel type for car construction in 2005 and 2015 [2]

These competitive properties and economic considerations are the main reasons that steel is dominant material in automotive. According to the forecast, for the next years the stake of HSS and AHSS materials in car's body is about 90% (Fig. 1). These trends are about to meet the requirements regarding decrease of overall construction mass, simultaneously increasing the safety and decreasing fuel consumption [2].

Traditional methods of designing and production were mainly based on designers' experience. However, the effective method of stamping processes designing must use CAD/ CAM capabilities as well as join abilities of numerical analysis and the one based on optimization methods. Currently for the analysis of forming process as well as designing of forming tool, the Finite

Element Method (FEM) software is widely used.
In automotive, the numerical analysis is used to explore and predict forming possibilities in practice, in order to avoid some drawpieces mistakes. The potential problems of stamping process during designing of the tool can be eliminated by virtual software rather than by a process of trial and error. The advanced and complex software enables fast and certain verification if the assumed method is correct, what gives an advantage over traditional methods of trials. The most up to date methods of designing, manufacturing and planning of production must be used to meet demands of the market. Planning is one of the most important stages of designing the tooling technology to shorten the time of manufacturing process start. For the process of sheet, stamping this stage is not only extremely crucial but also difficult. It is not easy to predict the number and type of forming stages, the accuracy of springback effect and to take into account inhibitory factors such as: wrinkling, cracking [5, 6].

Generally, it is required to use parametric methods of car designing what enables fast modification and implementation of essential constructional changes.

More and more often the optimization of all parts geometry finds the application. They are produced in many forming processes, creating the assembly, which is built by components manufactured in different ways. One of the examples is combination of part made by cold forming and the one made by hot forming. The entire assembly joined by binder must fulfil the assumptions made at the beginning of designing process. Therefore, the optimization corresponds with complex chain of forming stages rather than single operation.

The manufactured parts are very often made by AHSS steel, which are less deformable and show bigger tendency to springback effect than mild steel. Springback compensation by means of tooling geometry change is necessary to be situated in narrower tolerance intervals. The quality of stamped parts has greater and greater importance. It influences the assembling stage and the final quality of product. One of the factors affecting the quality of drawpiece is the shape-dimensional accuracy connected with material springback. Researches done during last years caused the constraint of tolerance range in constituent components as well as in assemblies.

2. Compensation

The main idea to correct the die consists in application of classic springback compensation used in technological conditions, which is extra overbending or sheet overpress during forming, in order to reduce the springback effect. For simple forming, the problem comes down to the additional sheet overbending. However, if the geometry is more complicated, it is not easy to predict the behaviour of material.

Development of compensation methods based on successive approximation methods with the possibility to define the measure direction and quality of compensated elements enables accurate finding of unstressed surface. The algorithm of the die correction, with the use of dislocation in elastic range, assumes iteration procedure of springback effect compensation [7].

The main compensation targets are:

- identification of tooling geometry which adjusts the surface to minimize the distance between assumed geometry, in such way, that the initial tooling geometry will be modified (overbent),
- compensation should be studied in virtual, numerical way to reduce classic ways of modification to minimum (e.g.- trial and errors method) or omit them totally:
  - presentation of compensation range with the use of tool mesh,
  - description of surface in CAD format (e.g. IGS),
  - description of surface including the history of all surfaces during consecutive iterations,
- transformation of compensation result by the surface description:
  - mesh transfer with the modified die surface,
  - possible formats of transfer (Ansys, Asci, Ideas, Nastran).

It is possible to obtain CAD surface as a clean mesh based on reverse engineering method but the most often it leads to the low surface quality.

There are die and part compensation, which are closely connected. However, in industrial conditions the compensated surface of the tool is searched, which necessary during the process of stamping die is designing. It means the modification of tool surface geometry during designing of forming process and the necessity to optimize the effect. The algorithm of die correction assumes iteration procedure of springback effect compensation. It often happens that optimization can end up successfully on condition that entire forming process linked in correlation chain (forming, trimming, bending and separating operations) will be analyzed. The most often springback occurs after cutting and separating operations. The natural restriction to apply methods of die shape correction are drawpieces which have vertical walls because after correction we get tools of wall angles bigger than 90 deg, what requires special tools for shaping. Similar restrictions appear for die stampings, which have a big area of flat surface [8].

FEM software enabling optimization of full process chain is not enough. It happens due to the fact that such programs do not generate surface in CAD but only as the collection of nodes. It is enough for theory but not in the industrial conditions.

Creation of the die stamping requires milling of each of its part. Therefore, in the next step it is necessary to convert the mesh in the form of different formats (e.g. Nastran, Ansys files) into more general CAD formats (e.g. IGS). The most often transition between two softwares generates imprecisions in the form of non-tangency discontinuity and small surface smoothness. The die optimization requires the input data, which include the original compensated mesh, and CAD data of the die. The adjustment of nodes to the 3D model of the part takes place so that the surface is stretched on the mesh. The process is implemented by PanelShop software (iCapp) [9].

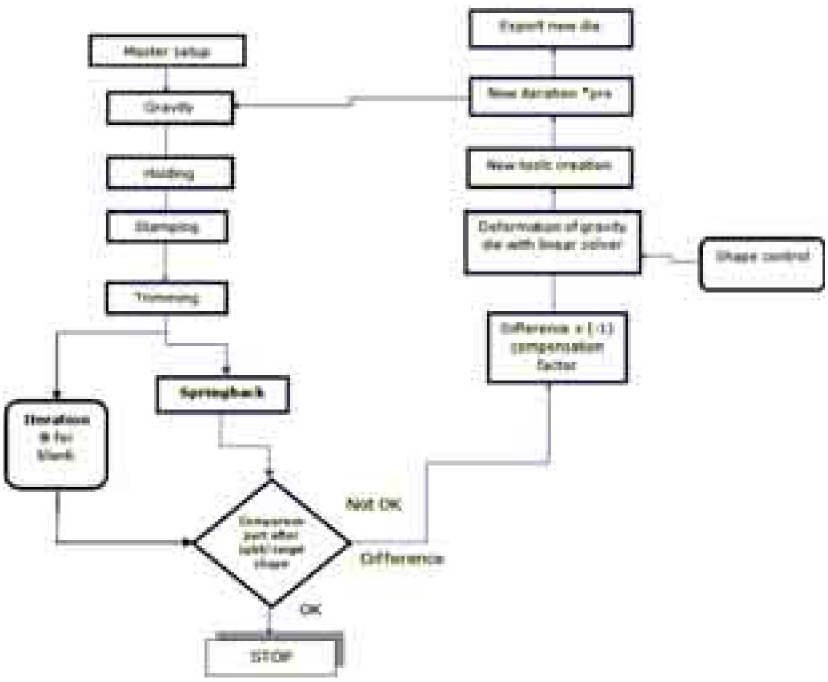

Fig. 2. Process of die compensation [9]

3. Numerical model

The subject of the work is analysis of the part shown in the pictures. PAM-STAMP 2G software version 2011.1 was used to the computing. It enabled the numerical analysis of the forming process and the complex, full- chain optimization of the forming die OP-20 and OP-50. The numerical analysis FE made for material model Hill 48 explicit and implicit uses computing methods according to the advice given by the software suppliers with the aim to minimize the time of computing, simultaneously keeping the satisfactory accuracy. The process of forming the U-shaped surface of the part during the deformation of the sheet joins two ways of load by bending and stretching forces.

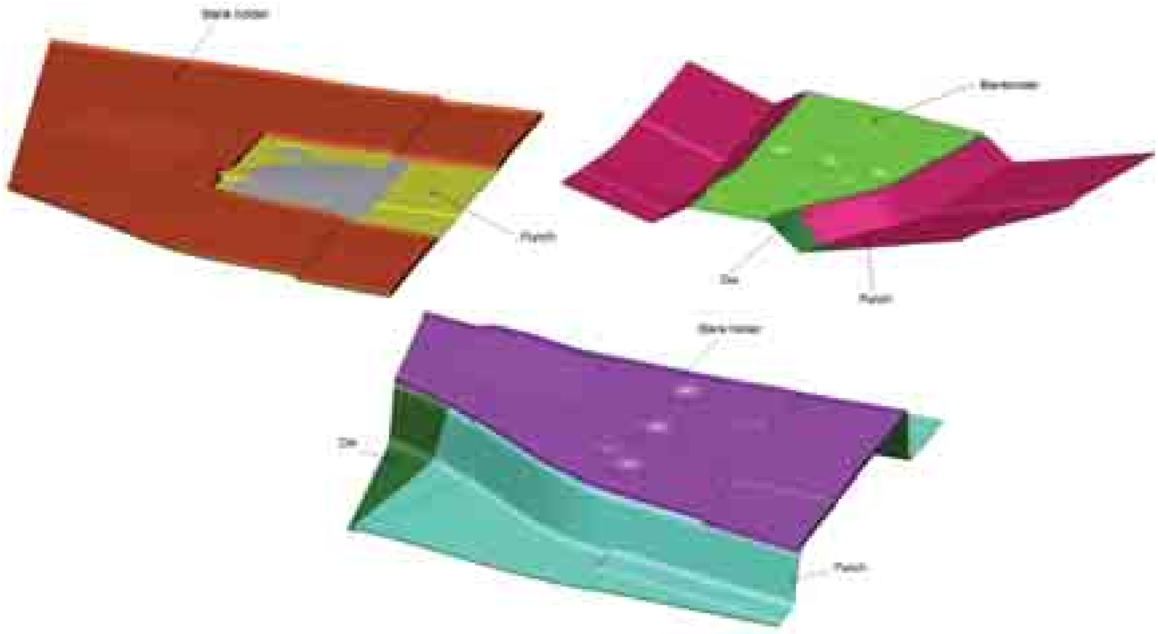

Fig. 3. Forming method with marked elements for: OP-20, OP-40 and OP-50

As the result, the complex state of stress is received which is not always easy for analytical notation as the reduced strength hypothesis. The material used in forming process has the nominal thickness 1.5 mm whereas the dimension of blank is 539 x 470 mm. For the sake of the simulation producing from the left and right part, the single blank sheet symmetry can be used, what has shortened the computing time. Springback was computed also taking into consideration the plane symmetry due to the cutting operation before the restraining of the tool. Use of the symmetry caused the necessity to include the boundary conditions. It means that six translations must be locked by the statically determined way.

The elements of triangle and quadrangle surface type of nonlinear stress distribution towards thickness were used. They are based on Belytschenko- Tsay model, which relies on uniform, coherent and reduced integration. The number of elements was optimized relatively to the computing time, so that the accuracy reflects the reality. Forming die OP-20 contains 48124 elements and 47710 nodes, OP-40 adequately 63080 and 62105, OP-50 relatively 95307 elements and 92825 nodes whereas blank sheet initially contained 5346 elements and 6397 nodes in such way that in the final stage of the process attained about 34470 elements and 37137 nodes. It needs to be stressed that the number of triangle for blank sheet is 335 at the beginning and in the end of process. However the number of quadrangle is variable, at the beginning it amounts 5011 and in the end 34135. Triangle elements result from using blank of initial stage, which was found during FEM pre-analysis.

4. Material model

Applicated HC340 LAD material is steel that belongs to HSS group, cold rolled. Micro-alloyed steel has good formability in relation to its own mechanical properties. Positive properties are gained by microalloy additions of: Nb, Ti or V, which comminute steel structure. Hill 48 material using isotropic hardening curve was approved despite of the fact that software uses criterion of isotropic-kinematic consolidation hypothesis. Chosen material requires following basic parameters describing material.

Young Modulus E=210GPa, Poisson coefficient υ=0.3; density ρ=7.8E-6 g/cm^3, rolling direction along shorter edge of blank sheet (local x axis) and blank thickness g_0=1.5 mm.
Reference parameters function (G,H,F,N) are expressed by anisotropy coefficients for characteristic rolling directions 0°, 45°, 90° (called also as Lankford coefficients).

$$F = 0.41, \quad G = 0.56, \quad N = 1.59, \tag{1}$$

Coefficient describing normal anisotropy r is regarded as the average value, which can be determined from the formula:

$$r = 0.25(r_0+2\, r_{45}+ r_{90})= 0.25(0.77+2*1.14+1.07)= 1.03. \tag{2}$$

Hardening curve determined by static test of bumping for 0° direction after calculating stress value and actual strain. Next, the curve was extrapolated in order to increase the range of actual strain [11]. To reach that, the Krupowsky formula was used:

$$\sigma_w = K(\varphi + \varphi_0)^n = 0.6908(\varphi + 0.008798)^{0.1494} \tag{3}$$

Fig. 4. Hardening curve for HC340 LAD g0= 2 mm

The hardening curve is not enough during forming analysis. Forming Limit Diagram (FLD) must be used additionally, in order to precisely verify the nodes, which are critical in terms of maximal stress. It is a diagram of steel drawability shown with the use of main straining. The curve can be calculated by the Nakajima Test or by other experimental method e.g. Marciniak test (used usually for aluminium) [11, 12].

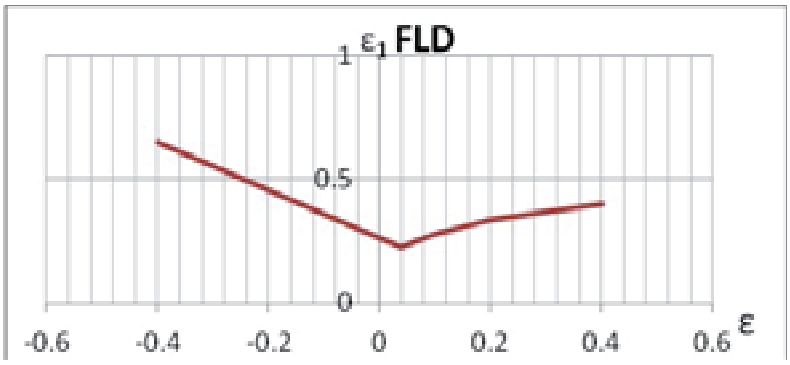

Fig. 5 Forming Limit Diagram for HC340 LAD with g0= 2 mm [10]

5. Numerical parameters

The blank sheet is treated by default as the middle layer without thickness. Contact between the die and blank was adopted as automatic. It means that solver adapts the type of contact depending on corresponding conditions and type of calculation, at the same time giving user the chance to verify the correctness of that choice anytime. In OP-20, OP-40 and OP50 the blank-holder was used in order to decrease the wrinkling. The defined forces equal relatively 100 kN, 60 kN and 80 kN. The speed of blank-holder has been defined as 2 m/s, while the speed of forming as VBC (Velocity Balanced Curve) as maximal value of 5 m/s. The friction model as Coulomb's coefficient has been defined as constant value μ= 0.12. Level of refinement of the mesh is based on criterion of minimal radius value r=3 mm (OP-20), r=2 mm (OP-40, OP-50) what enforced refinement degree for OP-20 on 5 level and the minimum element value of 0.94 mm, while for OP-40 and OP-50 refinement level 6 with the minimum element value 0.69 mm.

6. Finite Element Analysis

The conducted analysis of stress state is acceptable, although initially a tendency to superposition of material and the area of cracking found propagation.

Fig. 6. Initial problems with wrinkling

The change of geometry of OP-50 clamp surface and optimization of flanging method enabled adjustment of the most proper process parameters.

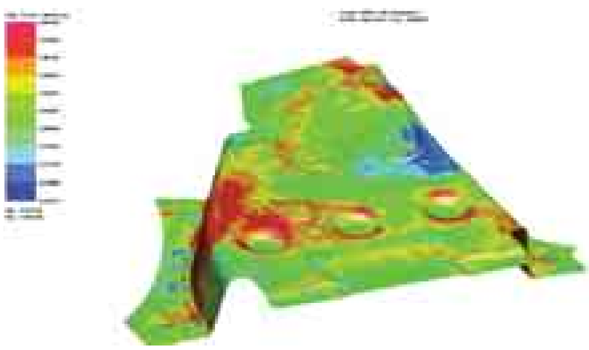

Fig. 7. Stress distribution in OP-50 and OP-40

Before FEM analysis, the maximum value of springback was provided for according to initial computing on the level of 4 mm in the direction of local z axis [4]. It can be also calculated analytically from the formula:

$$\Delta\alpha = 0.0143 * R_m^{0.94} * \left(\frac{R_i}{t}\right)^{0.1} = 0.0143 * 450^{0.94} * \left(1.5\frac{3}{1.5}\right)^{0.1} = 4.78[deg]. \quad (4)$$

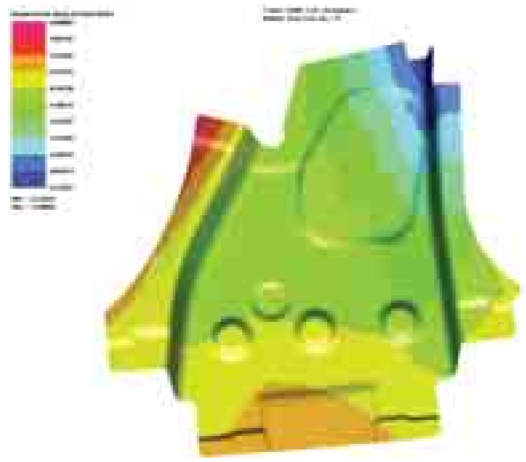

Fig. 8. Springback value in z direction

As demonstrated numerically and experimentally, the values reached similar level around 3 mm for OP-50, which contains optimized OP-20 surface, what reduced the value of springback effect.

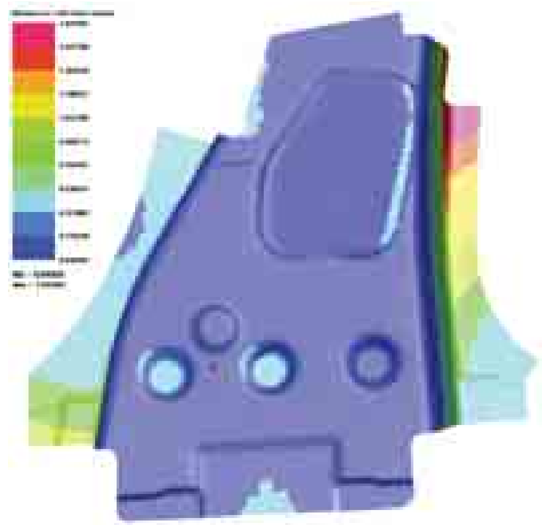

Fig. 9. Compensated part without full chain optimization

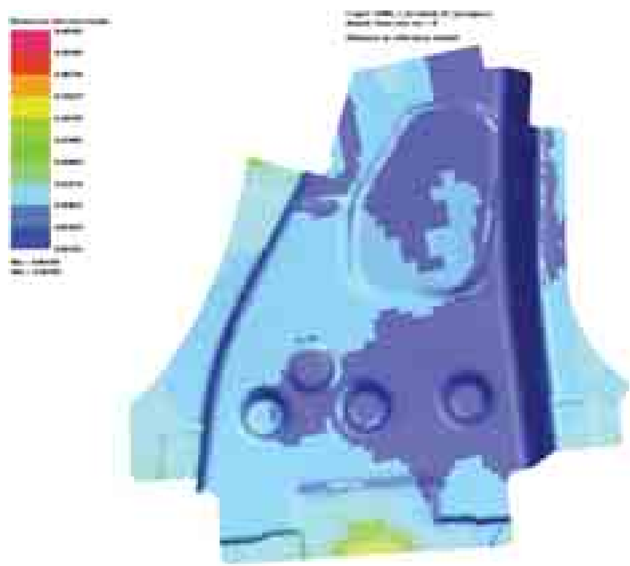

Fig. 10. Compensated part with full chain optimization

The numerical analysis showed that the initial tool compensation without full chain compensation brought unsatisfactory result. The manufactured parts did not meet requirements of imposed tolerance +/- 0.5 mm. However, use of complex springback compensation resulted in good parts, which reached the tolerance required by the customer.

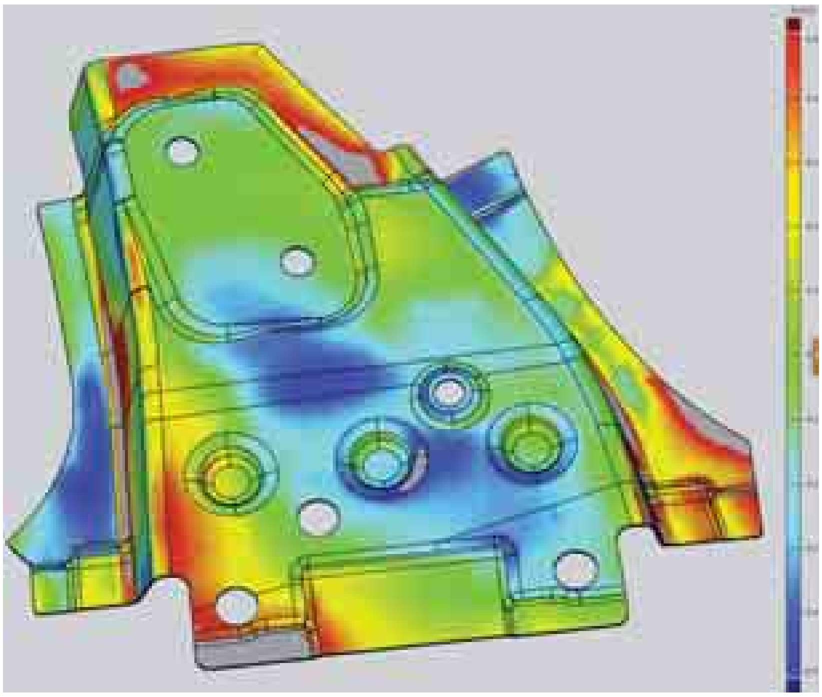

Fig. 11. Measurement of formed part by optical system

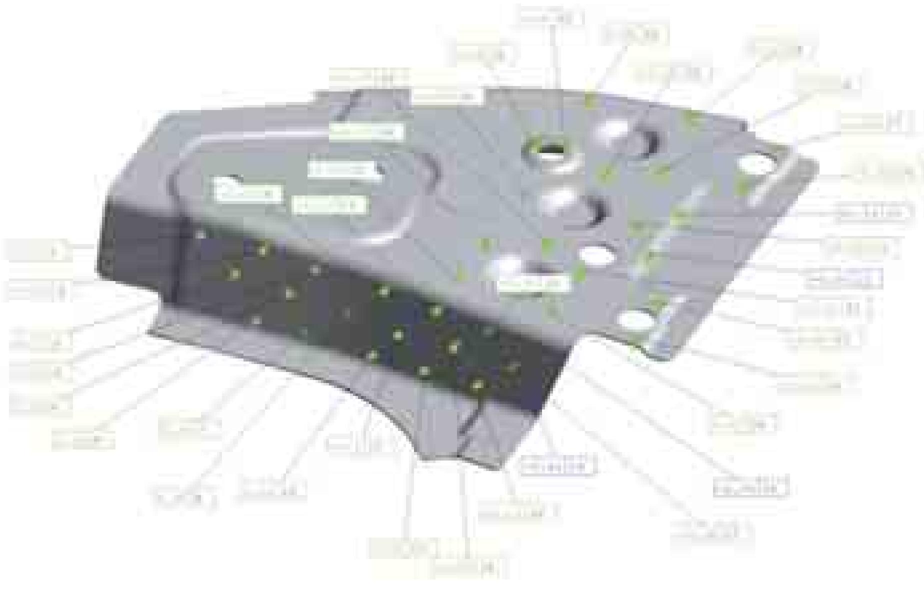

Fig. 12. Measurement of formed part by Coordinate Measuring Machine

7. Summary

Quality requirements regarding products of sheet stamping process are very high due to the technologies of automatic assembly of formed components. Springback, as the main source of drawpieces inaccuracy, is the function of material data, shape of tools and process parameters. Therefore, springback deformation becomes critical problem especially for AHSS steel when the geometry is complex. Hence, it is necessary, not only to find springback effect value but also include it during early stage of designing by tooling designers. As the numerical analysis and experiment confirmed, not taking into consideration springback during forming process, leads to reception of parts, which do not comply with the requirements.

Many factors need to be taken into consideration to get the compensated surface, which will meet the assumed tolerance.

First of all, the most important is accuracy of simulation, which allows for exact data concerning material, boundary conditions and process parameters. The material model is so important that it should take into account material data of the specific supplier already during springback calculation. If the exact value and type of element is allowed for, it guarantees keeping necessary accuracy and saving time. Defining of tool correction range influences calculation time so that taking into consideration only partial correction may be enough. It is also required to build the correct surface from nodes of defined coordinates to obtain uniform CAD surface of the tool. Compensation is determined so much by springback calculation accuracy that if they are not exact, then in the practice it will make it impossible to achieve the required result.

The breakthrough of compensation quality has occurred recently with the use of multi-operation compensation. It enabled the better simulation of reality by correction of individual tooling stations, what increased the precision of computation.

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