Production and Assembly of Car Body Fifth Door with Use of Dual-Phase Steel HCT500X

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Abstract. Due to environmental concerns and safety standards in the automotive industry, the development of durable and lightweight cars has become an important topic. Lowering the weight of the car body has become a crucial topic for all manufacturers, regardless of using combustion, electric or hydrogen engines. To fulfill this need a material with a higher strength to weight ratio must be used. Dual-phase steels seem to provide the right combination of mechanical properties for the production of particular car body panels. The goal of this research is to develop robust production of the fifth door part from HCT500X steel (DP500). The goal of this article is also to depict the forming of the selected part and the fifth door assembly for 4th generation ŠKODA Octavia. Numerical simulation is accomplished within the AutoForm Forming R8 and AutoForm Assembly R9 solutions. Different aspects influencing numerical simulation accuracy and topics relevant to the production chain are discussed in this article. This research is carried out in cooperation with ŠKODA AUTO, a.s.

1 Introduction

Digitalisation is an essence of ongoing Industry 4.0. This matter of fact impels OEMs and their suppliers towards modelling of manufacturing process of every car component. Within achieving this goal, digitalisation must cover all production processes that precede and follow-up the final product. Facts, as mentioned earlier, require software solution which covers the production of the whole Body-in-White (BiW). This backbone solutions must include forming, joining and painting and should be connected to ERP systems. Thus, modification of part geometry or part of the process should be right away projected into connected processes.

Another driving factor is that modifications of already manufactured forming tools are costly. Additional engineering and try-out (including milling, spotting, finishing, surface coating deposition) considerably lowers the profit and possibly delays subsequent processes. Digital modifications are considerably faster, cheaper and provide sought agility. Achieving a reliable digital design, designers must thoroughly set-up the process and to keep up with state-of-the-art tools.

The goal of this article is to depict the forming process design of outer car body part made of high-strength steel HXT500X and subsequent assembly process of fifth door outer for current generation of ŠKODA OCTAVIA.
2 Aspects of numerical simulation and its set-up

The techniques of modelling metal forming processes generally have three primary objectives. First and foremost, the analysis is focused on optimisation and the elimination of possible errors in the draft of the manufacturing process or tool. Secondly, this analysis allows the user to modify a body part so that makes for simple and effective manufacturing. Thirdly, the simulation allows the user to resolve sudden issues, which can occur in an already established manufacturing process. Thus, the application of numerical simulations gives a better insight into the process at hand and also provides the means to reduce tooling costs.

Drawing operation is a very significant step in the stamping process. During this operation, the blank is formed into the primary shape of the final part, except specific surfaces and flanges that are formed during subsequent operations. This first operation is distinctive from the subsequent ones due to the considerably higher rate of reshaping. Due to this fact, the majority of part defects emerges during the drawing operation.

An essential aspect of the sheet metal forming process is the springback effect. This effect takes place due to the release of the stress and the ensuing equalisation of elastic strain, which results in shape changes. Precise prediction of the springback effect is necessary because the modern-day trend focuses on using advanced high-strength steels, see Figure 1. However, these advanced steel are considerably more prone to the effects of springback due to their higher mechanical properties, namely their yield strength. This tendency results in a higher shape warping due to the release of elastic strain. It can potentially jeopardise the part compatibility and thus directly affect the process of mechanical joining and hemming. Accurate springback analysis is also a crucial point in proper detection of visual defect and audit problems: surface imperfections detected with stoning (wrinkling, surface lows), projected light stripes evaluation in light tunnel (zebra lines). Structural parts greatly influence the overall springback of the assembly. It is important to note that accurate springback results for assemblies can be achieved when all of the assembled parts contain deformation history, thus stamping process for each of these parts was simulated. [1, 2]

![Graph showing stress vs. strain for different materials](image_url)

**Figure 1.** Springback effect, High-strength steel, Mild Steel, Aluminium Alloys
In numerical simulation, material definition significantly influences sheet behaviour. Material cards usually consist of hardening curve, yield locus and fracture limit. It is recommended to define a material card based on data measured for a particular material to obtain more accurate results. Available solutions allow press-shops to measure mechanical properties for each blank with eddy current (based on tensile test reference). This measurement can be amended with thickness, surface roughness and coating layer measurement. This method provides a relevant range of data which enter the stamping process and use it in numerical simulation set-up. Tensile test at elevated strain rate, tensile test with higher strain rate or tension/compression test which provides kinematic hardening curve can also significantly improve prediction of splits and springback. [3, 4]

Tribology is a complex item in numerical simulation. Single value of friction coefficient, $\mu$, does not correctly represent contact behaviour. $\mu$ is a function pressure, strain, temperature, relative velocity of tool and the sheet, amount of lubricant, sheet and tool roughness and should be calculated for each element. Effect of pressure and strain is shown in Figure 2.

![Figure 2. $\mu$ value, effect of pressure and strain (HCT500X)](image)

Mesh settings (FEM element type and size) greatly influence computing time and should always respect the maturity of the process. Tool displacement step should be smaller at the end of the stroke, since a large portion of strain occurs at this moment.

As the computing capacity improves throughout the years, it allows calculation of robustness of the process. Since input in reality varies, the numerical simulation should also provide a cloud of results, e.g. concerning material parameters, blank shift and fluctuating blank holder force. Provided that the cloud of numerical results fits the cloud of real stamping results, simulation can be considered precise. The robustness is also an essential tool in respect to shrinkage of feasibility window as more demanding design features appear on the car.

Proper tool definition should always correspond with reality. Drawbead definition is a deciding factor for simulation accuracy and together with spotted, relieved and offset areas must always correlate with a reality. Thanks to modern methods of optical measurement, tool-shops can easily compare CAD data and the geometry of the tools. [5]

Results evaluation (post-processing) is a crucial step and must correspond to reality. The positioning of the measured part and the order of closing clamps play a significant role for thin outer car body parts.
The driving factor for this research is an ongoing competitiveness in the automotive market and increasing restrictions for carbon footprint. European Union is charging car manufacturers for exceeding the set limit of CO₂ emission. The fleet-wide average emission target is 95 g CO₂/km in 2020. Thus, one of the OEM’s R&D goals is to reduce the mass of Body-in-White. A partial solution is to use materials, which provide more favourable strength to weight ratio.

Part selected for this research is a fifth door outer lower and is highlighted in Figure 3.

Figure 3. 4th generation ŠKODA Octavia, fifth door outer lower

The production material is a dual-phase steel HCT500X (commonly referred as DP500 or CR290Y490T-DP according to standard VDA 239-100). HCT500X steel is a part of dual-phase steel family; the structure consists of ductile fine-grained ferritic matrix and hard martensitic phase dispersed in the form of islands. In comparison to mild steels (e.g. DC05), HCT500X provides higher strength properties; therefore, a thinner sheet is used (0.60 mm), and the blank cost is comparable to mild steel.

Based on the ŠKODA methods and recommendations stated in chapter 2, the numerical simulation was set-up. Material card was verified within prior research task [7]. Due to reduced ductility of HCT500X, the part geometry had to be modified to fit inside of feasibility window. Surface shape, trim angles, flange length and radii had to be adjusted as seen in Figure 4. [6, 7]

Figure 4. Highlighted modifications of fifth door outer lower
Forming simulation (AF R8, default Final Validation settings) does not exhibit risk of splits or wrinkles. A robustness analysis was performed to evaluate springback stability, since springback is very sensitive towards input noise. **Figure 5** shows springback results based on ±10% variation of mechanical properties, sheet thickness, blank holder force and blank shift. Input scatter is based on production of same type parts in ŠKODA AUTO. Springback specification limits (± 0.80 mm) were not exceeded, and this result is considered stable for production. When exceeding tolerance, either part geometry must be modified, or input variation must be restricted.

**Figure 5.** Springback variation; Distance from ref in the normal direction (AF Forming R8)

The Springback of fully assembled fifth door, including all the structural components, is represented in **Figure 6**. However, structural components from external contractors are defined as rigid since the simulation outputs were unavailable during the time of this research. Therefore, the behaviour of the entire fifth door assembly from the simulation cannot be fully compared to a result of the actual manufacturing process, since the behaviour of the individual structural part is omitted. **Figure 6** shows a considerable amount of deviation in the highlighted areas. The normal distance from the reference reaches a maximum value -2.5 mm. The edge at the base of the roof also shows a significant deviation of nearly -1.4 mm.

**Figure 6.** Fifth door assembly springback results (AF Assembly R9)
4 Conclusion

Obtained results demonstrate benefits and the requirement for digitalisation in manufacturing processes for all assembled parts in sheet metal forming and subsequent processes. Fifth door outer lower part made of HSS steel HCT500X meets springback specification limits. Since the springback results of assembled fifth door exceed specification limit for springback, springback must be compensated. It is efficient to compensate only the most influencing parts in the assembly in order to obtain a satisfying result (springback compensation of an assembly in not covered in this article). This approach can significantly reduce costs connected to tool modification and help to achieve a genuinely robust result of the simulation.

The field of numerical simulation is quickly developing and gradually tries to meet customer requests. In future, further attention must be paid towards, e.g. realistic stiffness of the tools, which is highly influenced by its construction, and towards temperature effects. Temperature plays a key role in friction during forming. Uneven temperature gradient during paint baking (simultaneously glue curing) can result in dimensional accuracy of BiW and visual defects in outer parts. Presented results demonstrate the need for digitalisation of all parts, and its manufacturing process, that enters the assembly. Fulfilling this request will allow OEMs to reach an unequivocal and robust result. Therefore, a fully-fledged application of these simulations will require close cooperation with respective structural component suppliers.

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