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BEHAVIOR OF ADVANCED HIGH STRENGTH STEELS IN DEEP DRAWING PROCESSES

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Abstract: Current requirements for vehicle safety and weight reduction in automotive industry lead to the increased use of advanced high strength steels (AHSS). These materials are multi-phase steels which contain martensite, bainite and/or retained austenite, and they are usually used for manufacturing of dedicated car body components like rails, A and B – pillars or hood reinforcements, for which safety is superior criterion. These materials have less drawability, while springback amount after deep drawing process is tremendously higher compared to mild steels. Also they have greater tendency to wrinkle due to lack of adequate capacity of part holder and often a reduction in sheet metal thickness. This paper discusses behavior of the AHSS in deep drawing process with the emphasis on formability and springback compensation.
Keywords: Advanced high strength steels, deep drawing, formability, springback

1. INTRODUCTION

Nowadays, the automotive industry is challenged by increasing environmental regulations as well as continously enhacement of the standard requirements regarding to passengers safety. One of the ways to decrease fuel consumption and carbon dioxide emissions of the vehicles is to reduce the weight of the car body. The use of advanced high strength steels (AHSS) for manufacturing the structural car body components offers exceptional opportunities for reducing the weight of the vehicle as well as increasing the crash performance [2]. Despite the environmental, also safety regulations have accelerated the use of the AHSS into vehicle structure.

In the last few years the use of AHSS is tremendously increased. It is necessary to emphasize that the steels mentioned above do have very high levels of tensile strengths at relatively low values of elongation at fracture as well as relatively low anisotropy values. These mechanical properties mean that AHSS usually do not have good formability, a strong tendency on wrinkling and a tremendous elastic recovery or springback after forming.

Nevertheless, the formability, wrinkling criterion and springback amount are most important indicatiors to predicit if it is possible to form a certain part geometry without any failures.

The use of high strength steels is actually increasing already existing problems in the manufacturing process considering quality control requirements and process robustness. In order to form these materials with a die it is necessary to define forming processes with new boundary conditions, but keeping the manufacturing costs as low as possible [3]. In Fig.1 the representation of different materials used in Audi A3 car body structure is shown. High and ultra high strength steel grades are used in many body areas, such as the floor, center tunnel, roof arch, side sills, etc. In order to decrease the weight of the vehicle, large parts at the front of the car are produced of aluminum.

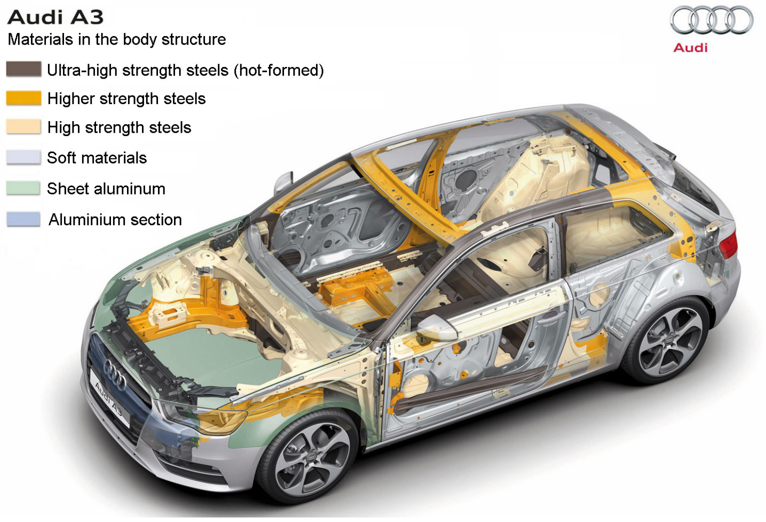

Figure 1. Representation of different materials in the car body structure (source: Audi)

Strategies to define the forming process considering sucessful production of the component without cracks as well as to design appropriate tool surfaces to reduce springback amount down to a given range are significantly changed if compared to the forming of mild steels. While such new steel alloys are becoming increasingly stronger, they are simultaneously more difficult to form into automotive parts. Larger amounts of springback are affected by many parameters such as sheet metal thickness, blank shape, level of ultimate tensile strength, hardening rate, Young´s modulus, method plan, tool radii, clearance between outlines of punch and matrice and forming conditions as well. Additiononaly inhomogeneous strain distributions along the formed part toghether with the elastic-plastic behavior of the workpiece material also affects springback occurence.

2. ADVANCED HIGH STRENGTH STEELS

The capability to absorb emerging dynamic loads of a car body during its use, especially in crash events, is one of the key design requirements on car body structures. One possible answer to this requirement in automotive industry is the use of AHSS for manufacturing the inner body parts such as beams, main floor or roof reinforcements. Nevertheless, the use of materials with increased strengths requires higher press capacity for forming process as well as an increasing need for springback compensation and dimensional control of component.

When using AHSS in the body structure in order to replace mild steels or other more easy to form materials objecting reduce of car body weight on the one hand and simultaneously to increase its crash performance, reduced forming limits in sheet metal forming processes reduce stability of production in any case. Fig. 2 shows the relationship between total elongation and tensile strength for different material grades.

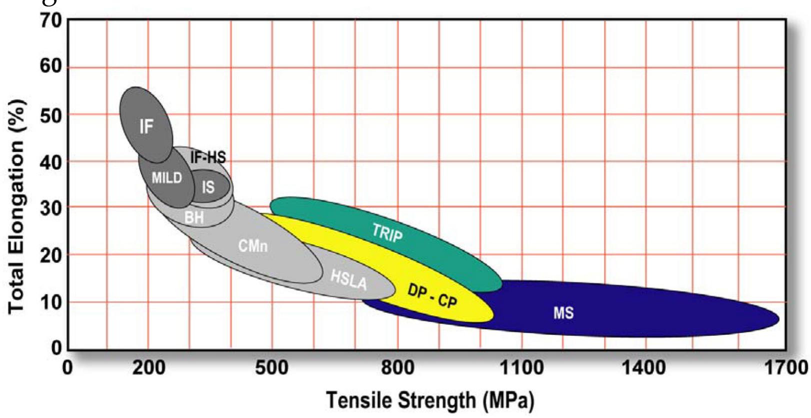

Figure 2. Mechanical properties of different steel grades [8]

The qualitative indicator for formability of the materials can be the achievable elongation together with anisotropy parameters (r-values). Fig. 2 shows that Dual Phase (DP) and Martensitic Steels

(MS) only allow a level of strain below 8 % before cracks will arise. This means that from formability point of view materials mentioned above are requiring less complexity of product design.

3. FORMING OF ADVANCED HIGH STRENGTH STEELS

To make forming process for AHSS sheet metals more stable it is necessary to consider and to analyze several manufacturing parameters. Objecting to form AHSS a strong press machine is needed, which will provide required stamping force and capacity to form the part as well as to provide sufficient blankholding capacity, or even adjustable local blank holding force during forming process. Today modern servo presses are available that can sucessfully deal with these issues. To achive robust processes, the tool assembly has to be designed stiff enough in order to decrease deflections which can cause non reworkable errors in manufacturing during forming process like wrinkles, necking, etc.

When designing the part shapes to be formed by AHSS sheet metals from manufacturability point of view it is important to take care about the part feature dimensions. It is important to mention, that sharp part edges after deep drawing process can lead to the failures like cracks or necking. So part design plays an important role in development of dimensionally reproducible parts.

3.1. SIMULATION OF THE FORMING PROCESS FOR A-PILLAR

In order to analyze the behaviour of the AHSS, forming of an A-pillar geometry was simulated with the AutoForm software. Fig. 3 shows formability and elastic recovery of the part after the forming process. HCT 980X (DP 1000) sheet metal was used for the forming process with the following parameters: R_m=1089,1 MPa (Ultimate tensile strength), $R_{p0,2}$= 774,8 MPa (Yield strength), E =210000 MPa (Young modulus), n =0,104, r_0 =0,9, r_{45} =0,95, r_{90} =0,85 (anisotropy parameters considering to rolling direction), with a sheet metal thickness of t= 1,4 mm. The deep drawing process was simulated with a blank holder force of 2500 kN. Press force for current forming conditions and before defined holding capacity was calculated with 7018 kN.

To get required part shape of A-pillar as metioned the following manufacturing steps were applied in this case: deep drawing and laser cutting. The simulation results show that the deep drawing of the required geometry is possible without cracks. Fig. 3.b shows the formability of part after laser cutting, while Fig. 3.c shows elastic recovery after the final forming step. In three different cross sections the deviation between reference geometry and part shape that is taken out from the tool is presented.

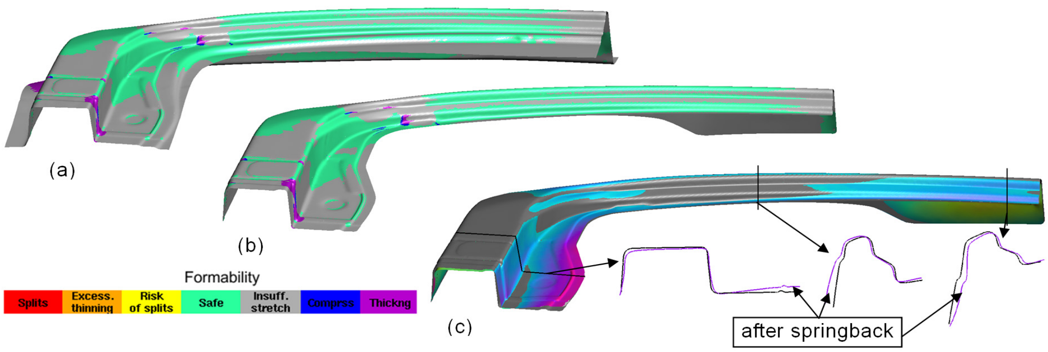

Figure 3. Formability of the A-pillar after final operation

3.2. SPRINGBACK ANALYSIS

If the elastic recovery is analyzed as a function of ultimate tensile strength, HCT 980X (DP 1000) has tremendous tendency to springback. Nevertheless, the result of elastic recovery due to residual stresses is induced by the deep drawing forming process. From the elastic recovery point of view for that reason one should develop a part design which will lead to minimized springback tendencies. However, springback amount (angle change, sidewall curl and twisting) can be decreased by adding features like beads or darts or steps into the part shape, while these features are serving as stiffeners of shape [1,8]. Fig. 4.a shows the springback amount after forming process

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measured in normal direction regarding to reference geometry: the flange of the A-pillar disclose a high amount of springback (up to 8,9 mm).

In order to decrease such springback of the flange and sidewalls, one stiffening bead is added into both sides of the part shape. Fig. 4.b shows springback amount after forming the part that is defined with stiffer geometry. It can be seen that the movement of the parts flange as well as the other features in the closed area is decreased comparing to the previous part shape shown in Fig. 4.a (e.g. movement of the flange caused by elastic recovery is reduced on the same place from 8,9 mm to 5,37 mm). It means that a stiffer part geometry will lead to a lesser amount of springback, but sometimes implementation of stiffening features is limited by the assembly requirements.

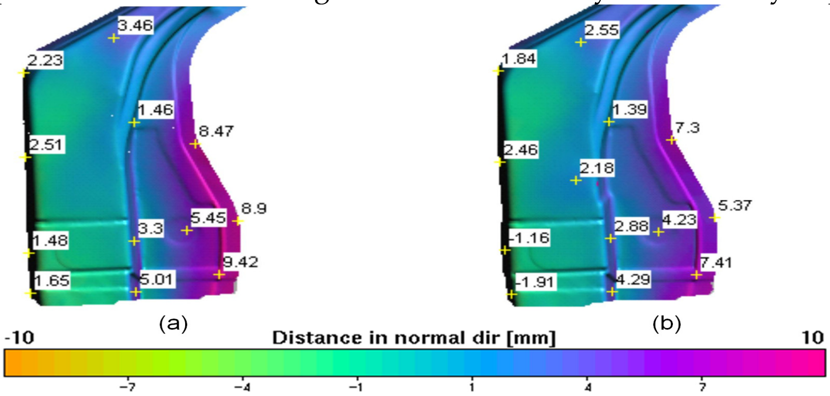

Figure 4. Springback amount of the part; (a) without stiffening beads at the sidewall and (b) with the implemented stiffening beads

So it is possible to find information that for formability and springback issues during the design of reinforcement car body parts it is recommended to specify open sidewall angle at the part of at least 6° for DP 600, 8° for DP 800 and 10 ° for DP1000 [8]. This advantage in the tool design phase gives an option on over-bending of part walls, which is a common technique for reducing springback. However, in the part designs where the sidewall angle is to small for over-bending technique, it is needed to find an more sophisticated process to minimize springback.

3.3. SPRINGBACK COMPENSATION

Research activities on managing springback of different steel grades have been conducted since more than 30 years, but as the strength of the parts increases, the work an emphasis on springback compensation is becoming a bigger and bigger challenge. From the previous example (Fig.4) one can conclude that it is possible to decrease springback amount considering to easier compensation after, by applying geometrical methods such as implementation of stiffening features into the part shape as well as by addendum and binder surface modifications [5,6]. The other possibility which can contribute to achieve the final goal, considers a range of methods based on modifying the stress-strain conditions in the part by appropriate arrangements such as additional restraining forces or even adjustable and controllable holding capacities which are time-dependent to punch stroke travel, as well as by application of the tool with elastic blank holder segments. From simulation point of view in order to produce the part whose shape will be in acceptable limits regarding to reference geometry (part CAD model), it is necessary to apply correct forming conditions which will contribute to the decreasing of springback amount. After the simulation results are obtained, it is needed to define a compensation strategy (which surfaces have to be overbend and which springback results have to be used as a reference), and compensate the tool surfaces (punch and die), and afterwards again, with the new surfaces to simulate springback again.

Compensation activities can be repeated until obtaining the part unloaded shape which is within given limits regarding to standard or quality requirements. During iteration it may happen, that in the next springback analysis iteration results are not converging to the reference geometry. One of the reasons for this can be insufficient stretching in different areas of the part during forming. In this case it is necessary to modify forming conditions by applying mechanical or geometrical methods mentioned before, which will contribute to achieve final goals like part accuracy and repeatibility as well as process robustness. Fig. 5 shows the schematic procedure which defines all important steps for springback compensation.

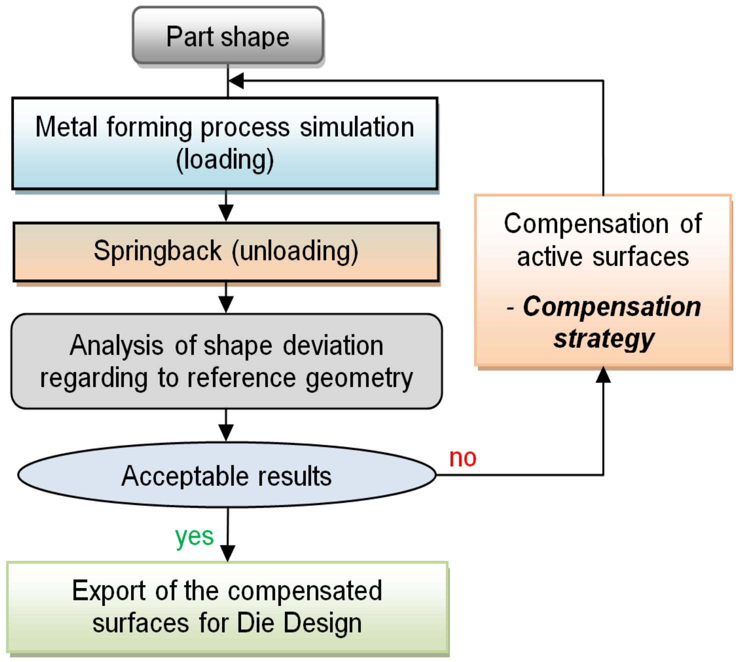

Figure 5. Procedure for springback compensation

In Fig. 6 is shown the difference between springback amount if the deep drawing process was done with the theoretical tool whose geometry corresponds to the original part shape (Fig. 6.a) and if the deep drawing process was done with the compensated geometry (Fig. 6.b). After deep drawing with the non-compensated tool geometry and taking the part out from die cavity, the part has quite high shape deviations (e.g. gray colored: areas of the part, where deviation between formed shape and reference is higher than 4 mm). Springback amount is measured in normal direction regarding to reference geometry, where measuring points from Fig. 6.a are corresponding to the points depicted in Fig 6.b.

It can be seen that after compensation and several iterations by using appropriate compensation factors springback amount reduces significantly. Also, in order to make springback convergence more stable for next iteration, binder force was defined with 3000kN in order to increase the stretching in the part sidewalls.

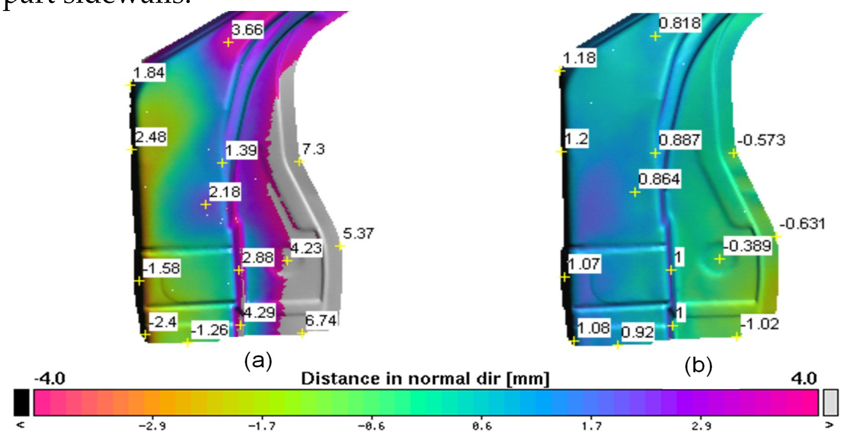

Figure 6. Springback amount: (a) after forming with theoretical and (b) with compensated tool geometry

4. CONCLUSION

Use of HCT 980X (DP 1000) for manufacturing of the car body reinforcement parts gives an great advantage for weight reduction. However, processing of these materials in cold stage still it is not on acceptable level, while there is a lack of information on formability limits when taking non-linear strain paths into consideration.

In this paper, simulation results demonstrates to deep draw an A-pillar with the defined geometry as well as to affect springback occurence with different methods made of HCT 980X sheet metal. Deviations of the formed parts compared to reference geometry were reduced by implementing appropriate stiffening beads within allowed design space. Springback amount was significantly decreased if comparing with the results when deep drawing was done with the original part shape (Fig. 4.a).

Afterwards, the virtual tool was compensated by modification of the geometry regarding to obtained springback results together with increasing restraining force. It means, that it is very often necessary to modify part design in order to develop robust forming processes for AHSS.

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