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Authors: Ireneusz Wróbel, Andrzej Graboś

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Numerical compensation of torsional hardening deformations of parts made by hot stamping

Numeryczna kompensacja skrętnych deformacji hartowniczych wytłoczki wyprodukowanej metodą tłoczenia na gorąco

IRENEUSZ WRÓBEL
ANDRZEJ GRABOŚ *

The article presents an analysis of hardening deformations for a typical door beam of a passenger car. A calculation model for the hot stamping process of the analyzed beam was developed. Such a model was used to simulate which resulted in hardening deformation and to compensate for these deformations.

KEYWORDS: hot forming, FEM simulation, hardening distortion

Constructors of car bodies of passenger cars strive to reduce the mass of designed structures. To this end, new types of materials and new technologies for their processing are used. The car body elements of the premium class are manufactured from steel sheets, from aluminum alloy sheets and from composite materials based on carbon fiber. Car bodies of popular cars are made of steel with normal or high strength.

More and more elements of the car body are manufactured from the well-tempering 22MnB5 steel, intended for hot stamping, ensuring simultaneous shaping and hardening of the extrudate. Before the thermoplastic treatment, the steel has a ferritic-pearlitic structure, and after processing the structure turns into a martensitic one. Under the effect of hot stamping, mechanical properties also change. The yield strength increases from approx. 450 MPa before heat treatment to approx. 1050 MPa after heat treatment, strength limit - 600 MPa to 1500 MPa, and hardness - from 190 HV to 420 HV. As a result of the hot stamping process, the strength and hardness of the steel increase more than twice.

Purpose of research

When analyzing the hot stamping process, it was observed that the hardened stampings tend to uncontrolled deformation, which is the main cause of dimensional and dimensional inconsistencies. These discrepancies are observed when the target die has already been made and a batch of prototype extrudates has been produced. In industrial practice, to compensate for these discrepancies, it is necessary to change the shape of the working surfaces of the prototype die. This requires carrying out locksmith works, such as surfacing, milling, grinding and covering (this is the so-called adaptation). These works are carried out in loops - until the shape of the working surface of the prototype tool is achieved, which will allow to produce a molding in the shape consistent with the dimensional and dimensional tolerance. After the adjustment process, the shape of the work surfaces is transferred from the prototype tool to the target tool. The described approach generates high costs (related to the implementation of the prototype tool, locksmith work, repeated attempts and tests, long adjustment time).

The research discussed in the article is aimed at identifying - with the use of computer simulations - the phenomenon of hardening deformation of extrudates produced by hot stamping. After identifying these deformations, it is planned to modify the shape of the tool working surfaces to compensate for the deformations in the final extrudate.

Reasons for hardening deformation [1]

Hardening deformation is the effect of the internal stresses that arise during heat treatment, especially during cooling. It is possible to distinguish two phenomena occurring during cooling in hardened machine parts. The first is that the volume increases due to the transformation of the crystal structure from the dense arrangement of atoms (from austenite) into a crystalline structure with less atoms (ferrite, cementite and martensite), while the second - on the formation of own tensions in the heat treated material, which is the result of a large heat shrinkage during cooling. The dominant phenomenon causing self-stresses is the increase in volume due to the conversion of austenite into martensite during cooling. The change in volume is the greater, the faster the cooling takes place and the material loses the ability to adapt to volume change. At the same time thermal shrinkage is created. Both phenomena result in deformations and dimensional changes of the tempered product.

* Dr hab. inż. Ireneusz Wróbel (iwrobel@ath.bielsko.pl) - Akademia Techniczno-Humanistyczna w Bielsku-Białej; mgr inż. Andrzej Graboś - Dział Badań i Rozwoju, Polsmotors sp. z o.o.

Selection of a passenger car body element for the analysis of torsional hardening deformations

To analyze the hardening deformations, which are twisting, the door beam was chosen - a typical element of the car door, which protects the driver and passengers against the effects of lateral impact. The beam has a double U-shaped cross-section (fig. 1) and the following dimensions: length 1000 mm, width 150 mm, sheet thickness 1 mm. On the basis of technical documentation and industry standards, the requirements for dimensional and dimensional tolerance have been specified.

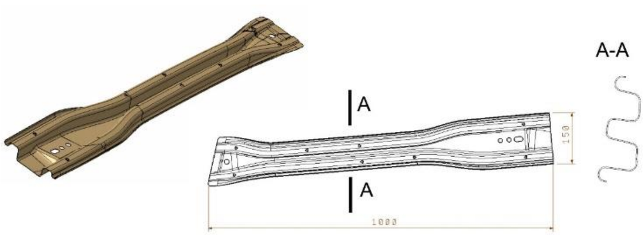

Fig. 1 Beam for testing hardening deformations with twisting character

CAD models of the die and the form

The analysis of hardening deformations in the pressing process was carried out in the AutoForm v. 7 system. First, the shape of the form was determined, which after the hot stamping process would take the shape of the extrudate. The model CAD format and CAD surface models of the die elements were imported into the AutoForm software and then oriented to each other in the same way as in the real die. Fig. 2 presents a discreet model created for the simulation of the hot stamping process. The matrix, stamp and pressure were discretized with rigid finite elements of the surface type, and the form - with deformable finite elements, which were assigned the material properties of 22MnB5 steel and the direction of rolling.

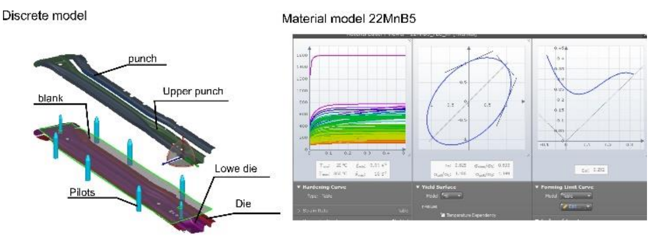

Fig. 2. Discrete model of the die and the form and parameters of the material model for the purposes of hot stamping simulation of the analyzed beam

The interaction between tool working surfaces and the mold was modeled with friction contact elements with a coefficient of 0.45. The position of pilots, which are responsible for the repetitive and stable position of the form relative to the die elements, and the appropriate kinematics of the pressing process were also defined. First, the upper clamp closes the form in the lower clamp. During this time, the middle part of the beam is formed. Then the stamp moves, which closes the form in the die and forms the edge of the beam. The tools (upper clamp and punch) move at two speeds. The first one is the speed of idling (access of the tool to the form), equal to 650 mm/s, and the second - the speed of forming, equal to 80 mm/s.

Thermal parameters of the hot stamping process were also assumed. It was assumed that the format after removal from the furnace has a temperature of 920 °C and is transferred from the furnace to the die within 6 seconds. After the pressing process, the extrudate is closed in the tool for 8 seconds - during this time the hardening process takes place. It was assumed that the tool has a temperature equal to 150 °C, and the force of its downforce to the form during the hardening is equal to 1.5 kN. After hardening, the extrudate is cooled in the open air until it reaches the ambient temperature (20 °C). After this time, hardening deformations are examined.

The described model has been analyzed in the ThermoSolver solver of the AutoForm software.

Analysis results

The most important results of FEM simulations of hot stamping processes, which are analyzed by engineers and technologists, can include FLD (forming limit diagram) contours and extrusion thinning contours.

Fig. 3 shows the results of door beam analysis. Based on them, it can be concluded that the proposed hot stamping process meets the technical and technological requirements set for it. There was no risk of zones with wrinkles and cracks appearing on the extrudate. The extrudate will have the required parameters related to hardening (hardness and structure).

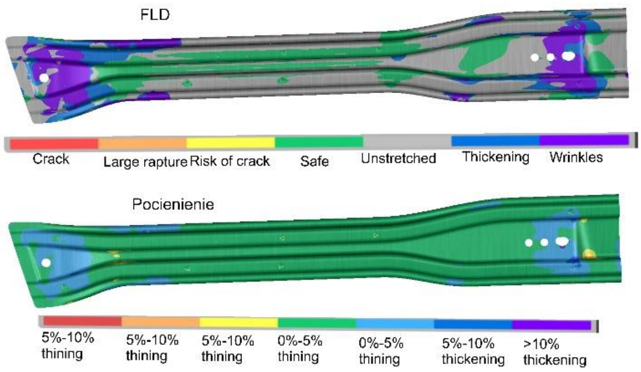

Fig. 3. FLD layers and thinning of the analyzed door beam

Analysis of the hardening deformation of the door beam

The hardening deformations of the beam obtained by simulation were compared with the reference model (CAD) at the RPS points, in which the distance of the reference model from the results of the calculation model is equal to zero. Fig. 4 presents model deformations, analyzed with reference to the reference model, matched at RPS points. The maximum deformation of the beam is +0.8 mm and -2 mm. The dominant form of deformation is twisting.

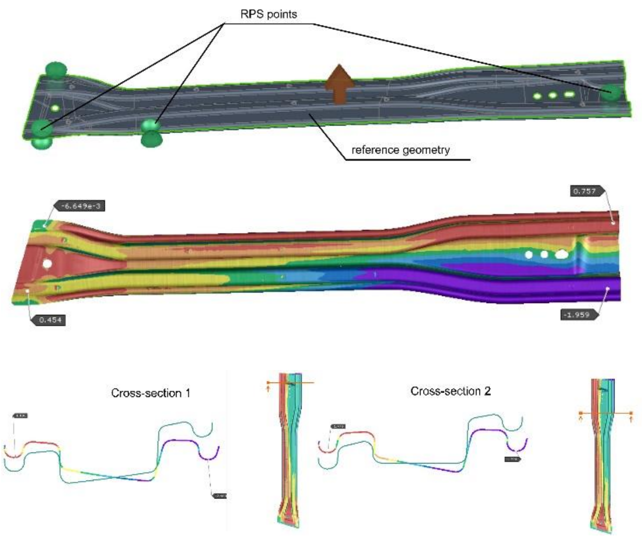

Fig. 4. Hardening deformation (in mm) relative to the reference model, fitted at the RPS points

Compensation of hardening deformations

Hardening deformation values exceed the permissible dimensional and dimensional tolerances given for the beam being analyzed. So how do you correct the shaping surfaces of tools (punches, dies and clamps) to compensate for these deformations? The ultimate goal is to obtain a extrudate which, after hardening, will be within the dimensional and dimensional tolerance.

The AutoForm Compensator tool was used to solve this task. The surfaces of the tools whose shape will be corrected are defined. The hardening deformation compensation task was solved iteratively until the moment when in the last loop the maximum hardening deformations were in the field of the dimensional tolerance of the beam.

The geometrical model of die, punch, top and bottom clamp was selected for compensation. In the second iteration an improvement in shape-dimensional accuracy of the extrudate was obtained. The recommended parameters of the geometry compensation process have been defined: compensation factor and smoothing factor [2].

Fig. 5 presents contours representing values of shape corrections of the die working surface (in relation to the basic tool) after the second iteration of compensation, and in fig. 6 - hardening deformations after the second compensation iteration, measured relative to the reference model fitted at the RPS points. As you can see, hardening deformations have decreased to values that ensure the production of extrudates in the assumed dimensional and dimensional accuracy. The largest deformation value is 0.13 mm. The FLD diagrams, thinning, hardness and the proportion of martensite in the extrudate were also analyzed. There was no risk of defects forming.

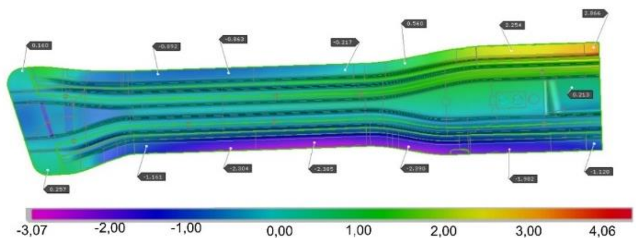

Fig. 5. Layers of corrections of the shape of the die working surfaces after the second compensation iteration

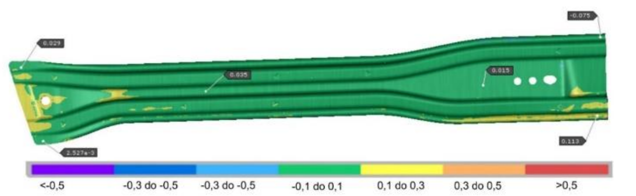

Fig. 6. Hardening deformation (in mm) after the second iteration of the compensation process

Conclusions

Fig. 7 shows a diagram of activities that should be performed during the analysis of compensation for hardening deformations. The process begins with the analysis of the dimensional and dimensional accuracy of the extrudate and the requirements for mechanical parameters after the hot stamping process. The result of this analysis is the detailed requirements for the accuracy of the extrudate - contour tolerances, surface mapping tolerances, manufacturing tolerances and hole positions, etc.

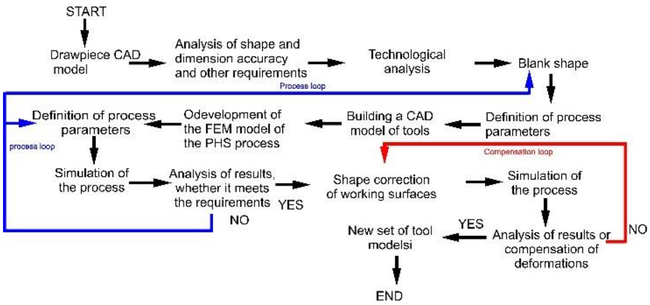

Fig. 7. Diagram of conduct during the analysis of compensation of hardening deformations

The next stage is the analysis of the extrudate's technologicity, which consists in finding the optimal direction of pressing and checking whether the appropriate inclination of the extrusion walls in relation to the direction of pressing has been maintained. Next, the shape of the form is determined and the following elaborates: assumptions for the manufacturing process of the extrudate production, the concept of the tool construction, extrusion molding sequences, etc. Based on the CAD model, the extrudates model all the elements of the tool - they are surface models. Next, the FEM model of the technological process of making the extrudate is developed and all technical parameters related to the process are defined. After the FEM simulation, the results of FLD and thinning are analyzed as well as the results related to the hardening process (hardness and martensite content in the extrudate). If the results do not meet the requirements, certain assumptions are changed to the technological process (e.g. the extrudate sequence), the shape of the form (in a small range) or selected process parameters (e.g. transfer time from the oven to the press), and then simulations are performed again. Simulations are carried out in loops (blue in fig. 7) - until the correct results are obtained. When the simulation results confirm that the analyzed extrudate meets the requirements of the plastic and heat treatment process, in the next step the hardening deformations are analyzed in order to compensate them. First, the FEM model is built with compensated tool models that are simulated. As a result, compensated hardening deformations are obtained, which should be smaller and smaller after each loop. Simulations are carried out in loops - to obtain deformations that meet the requirements for dimensional and dimensional accuracy of the analyzed extrudate.

The final effect of the analysis is a set of CAD models of tools, the shape of which (obtained through computer simulation) enables the production of extrudates in the assumed dimensional and dimensional accuracy. These models will serve as a base for constructing the elements of the die.

Computer analysis of hardening deformations will eliminate costly and time-consuming processes of adapting tools at the stage of starting production, as well as the need to build prototype tools for testing hardening deformations.

The presented methodology may be a collection of best practices in solving such problems.

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