FEM-PROCESS-SIMULATION OF HYDROMECHANICAL DEEP-DRAWING

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Introduction

The FEM-Process-Simulation of metal forming processes has been proven to be useful during the design stage of components and toolings. However, this is not valid for relatively new processes, e. g.. hydromechanical deep-drawing. Hydromechanical deep-drawing is related to conventional deep-drawing, but the process is quite different. When using hydromechanical deep-drawing, instead of a rigid female die a counter pressure pot is used to form the sheet metal against the punch. The process modeling and application of conventional deep-drawing is a well-known process with a great amount of practical and theoretical experience. Therefore a large database of knowledge exists. In contrast to conventional deep-drawing, for hydromechanical deep-drawing the practical and theoretical knowledge is limited. Since the application of hydromechanical deep-drawing is becoming more interesting (e.g. for the production of niche cars), the demand of theoretical and practical knowledge is increasing [1] [2].

Hydromechanical Deep-Drawing

Process of Hydromechanical Deep-Drawing

In place of a rigid female tooling, hydromechanical deep drawing uses a hydraulic counter pressure (Fig. 1). This hydraulic counter pressure can be built up either through the compression of the hydraulic fluid using the punch movement (passive) and/ or by using a hydraulic unit (active).

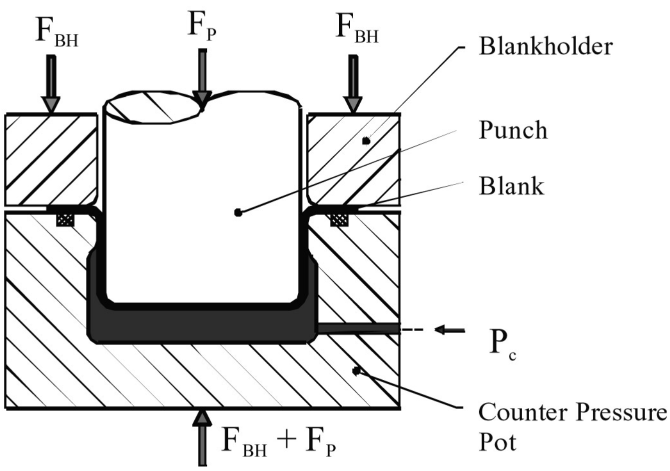


Fig. 1: Hydromechanical deep-drawing of sheet metal parts with vertical walls

During deep-drawing the blank is pressed against the punch by the hydraulic counter pressure. Assuming the validity of Coulomb's law of friction the friction between the sheet metal and punch is increased by this. The greater the counter pressure, the greater the friction forces between the sheet metal wall and punch. Thus, an increasing counter pressure results in larger draw depths.

Furthermore, due to the normal pressure acting on the sheet metal it is possible to produce sheet metal parts with tapered shaped walls in one operation without secondary wrinkles occurring in the wall.

The limit for the counter pressure is the bursting pressure p_{burst} of the sheet metal. The maximum counter pressure must be smaller than the actual bursting pressure (equation 1).

$$p_c < p_{burst} \quad (1)$$

Therefore, during hydromechanical deep-drawing of sheet metal parts with tapered shaped walls the counter pressure versus the punch stroke must be controlled.

Another advantage of hydromechanical deep-drawing is the opportunity of generating convex/concave contours without a female die, because the counter pressure presses and forms plastically the sheet metal against the punch contour, see Fig. 2. The higher the counter pressure the smaller the possible contour radii. Hydromechanical deep-drawing is also possible up to a certain draw depth followed by an active calibration process of the sheet metal part at the highest possible counter pressure p_c.

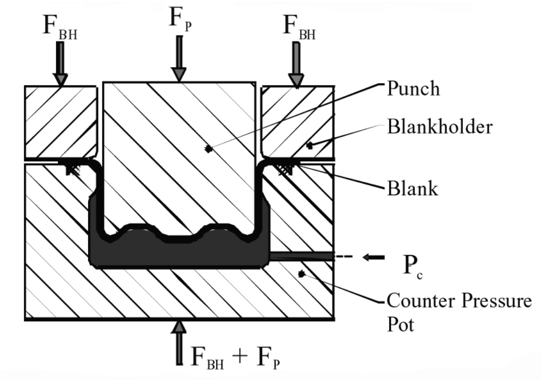


Fig. 2: Hydromechanical deep-drawing of sheet metal parts with convex/concave contours

The punch force F_p for hydromechanical deep-drawing is given in equation (2):

$$F_P = p_c \bullet A_p + F_{id} + FF_{BI/UB} + FF_{BI/LB} \quad (2)$$

Whereby:

p_c = Counter pressure

A_p = Punch cross section area

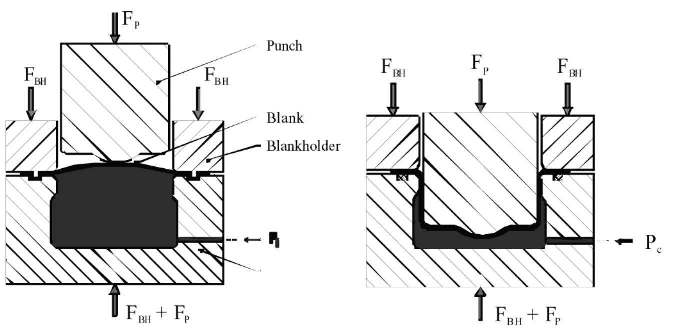
Fid = Ideal forming force

$FF_{BI/UB}$ = Friction force between sheet metal and blankholder (upper binder)

$FF_{BI/LB}$ = Friction force between sheet metal and counter pressure pot (lower binder)

In comparison to conventional deep-drawing it is to note, that the bending force F_{bend} at the counter pressure radius and the friction force FFBI/DR between the sheet metal and the counter pressure radius is not taken into consideration for hydromechanical deep-drawing because a bulge is formed here under the effect of the counter pressure and the sheet metal is not in contact with the radius of the counter pressure pot.

A combination of hydraulic stretch forming with („active“) pressure built-up from an external pressure source followed by reverse drawing and hydromechanical deep-drawing is often used to achieve work hardening in the middle of the part (Fig. 3). For example, this is applicable for flat outer panels of passenger car to get more stiffness and greater resistance to hale impact. This process sequence is also called „Active Hydromec“ or „Pre-bulging“. After stretch forming the panel in the middle area to approx. 2 % of the principal strains, reverse drawing and hydromechanical deep-drawing can be accomplished by traveling the punch downwards. In this case the pressure is generated "passively" by penetration of the punch, i.e. by compression of the hydrostatic medium. However, with reverse drawing the danger of wrinkling is present. For this reason the sheet metal must have contact with the punch in the area of the outer part surface at the end of the pre-forming process, so that during hydromechanical deep-drawing no marks in the outer surface area can happen when reverse drawing [3] [4] [5].



a) Hydraulic stretch forming („Pre-Bulging“/ “Active Hydro-Mec-Process“

b) Reverse drawing and hydromechanical deep-drawing

Fig. 3: Combination of hydraulic stretch forming followed by reverse drawing and hydromechanical deep-drawing

Process Limits for Hydromechanical Deep-Drawing

Compared with conventional deep-drawing, the lower process limit for hydromechanical deep-drawing is not only wrinkling, but also sealing. The blankholder force for hydromechanical deep-drawing must at least overcome the internal pressure. If it does not, the blankholder will open and it will not longer be possible to build up the counter pressure. When this happens, wrinkling occurs. The upper process limit of hydromechanical deep-drawing is tearing. The counter pressure versus the punch stroke proves to be an influencing process parameter as well. When drawing complex or tapered shaped parts the increase of the internal pressure versus punch stroke must be shallow until the blank covers the punch. Otherwise, too much material will flow into the cavity and an undesired bulge against the drawing direction will result (see Fig. 4). Increasing the drawing depth can remove this bulge, so it is possible that the bulge (material aggregation) is partly, in the ideal case completely consumed. It is also possible, that bursting occurs when a critical bending radius is reached or when material is pinched off between the punch and the drawing ring. In both cases, at least undesired plastic wrinkles are generated [5] [6].

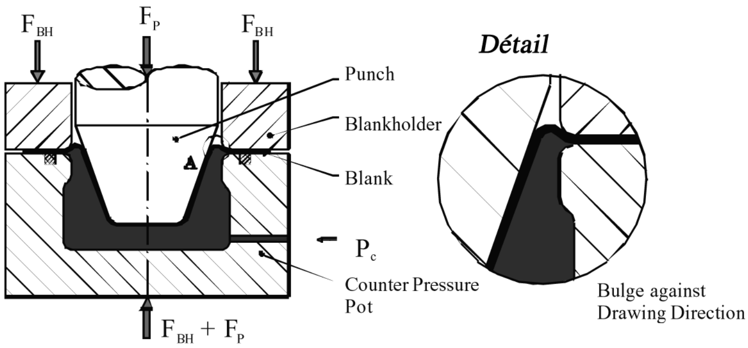


Fig. 4: Hydromechanical deep-drawing of parts with tapered shaped walls

Modeling of Hydromechanical Deep-Drawing-Process

In Fig. 5 the single steps of modeling a hydromechanical deep-drawing process using the preprocessor DYNAFORM is shown. The modeling of the hydromechanical deep-drawing process is similar to that of a conventional deep-drawing process.

The preprocessing starts with the import of the CAD-Data. DYNAFORM can read several file formats (e.g. NASTRAN, LS-DYNA, IGES, VDA, ,..) which will be either read directly into “DYNAFORM” or translated to an “DYNAFORM” file. After all tool parts are imported or created by an offset of the punch, the parts have to be edited and defined for the corresponding process (e.g. single action) [7].

As a further step the meshing of all tool parts are carried out. Furthermore the blank must be imported from CAD or created in DYNAFORM and meshed. After the meshing is done the boundary and the normal vector of each tool part and the blank have to be controlled. Before all parts can be positioned the blank material and properties have to be defined.

Then the counter pressure vs. time, the punch traveling vs. time and the blankholder force vs. time have to be imported from the data base or described as load curves which can be saved and modified for an other simulation.

Furthermore a boundary curve which exhibits the inner contour of the counter pressure pot must be imported from CAD or created in DYNAFORM. By means of the boundary curve only blank elements within the closed area of the curve are put under pressure during the simulation.

Before writing an output-file several parameters (e.g. adaptive mesh control, mass scaling) have to be set. Then the output-file has to be saved and edited. An extra routine called “loadmask” has to be included in the output-file. This extra routine contains the x-y-coordinates of the boundary curve within the pressure acts. Now the simulation can be started.

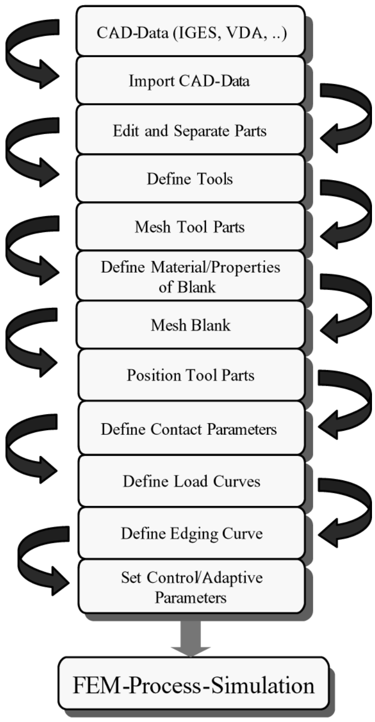


Fig. 5: Modeling of the hydromechanical deep-drawing process using DYNAFORM

FEM-Process Simulations of Hydromechanical Deep-Drawing at the IFU

In order to investigate the hydromechanical deep-drawing process at the Institute for Metal Forming Technology (IFU) of the University of Stuttgart a research cooperation with 18 member companies was established. For practical investigations several toolings have to be built up. Two toolings are already in use. With the first tooling it is possible to investigate the hydromechanical deep-drawing process for a part with tapered walls and different corner radii („Hishida Tooling“). This geometry tends to secondary wrinkling. In order to prevent the secondary wrinkling the influence of several parameters (i.e. counter pressure vs. draw depth, counter pressure vs. blankholder force) on secondary wrinkling has being investigated.

The second tooling is being built up to investigate the hydromechanical deep-drawing process of a door handle. Due to the shape of a door handle the problem of an inherent strain field occurs. This strain field leads to an improper surface quality around the door handle. The goal of the experiments and FEM-Simulations using the “door handle” tooling is to investigate the influence of the process design on the component’s quality.

The third tooling for an outer body component will be built up for a motor-hood. Since for conventional deep-drawing of this motor-hood a complicated 3-D shaped blankholder is necessary, the first investigation will focus on the feasibility of using a flat blankholder when hydromechanical deep-drawing the hood. In the following the different FEM-simulations and models will be discussed.

“Hishida” Tooling

Fig. 6 shows the actual “Hishida” tooling as it is used for experiments on hydromechanical deep-drawing. The tooling consists of the counter pressure pot (lower binder), which is mounted on the press table. The upper binder mounted to the ram, comprises a segmented elastic blankholder and a 10-point draw-cushion system to control each hydraulic cylinder individually. The advantage of the 10-point draw-cushion system with a segmented-elastic blankholder (SEB) is a clear correspondence between the blankholder forces and the blankholder surface pressures.

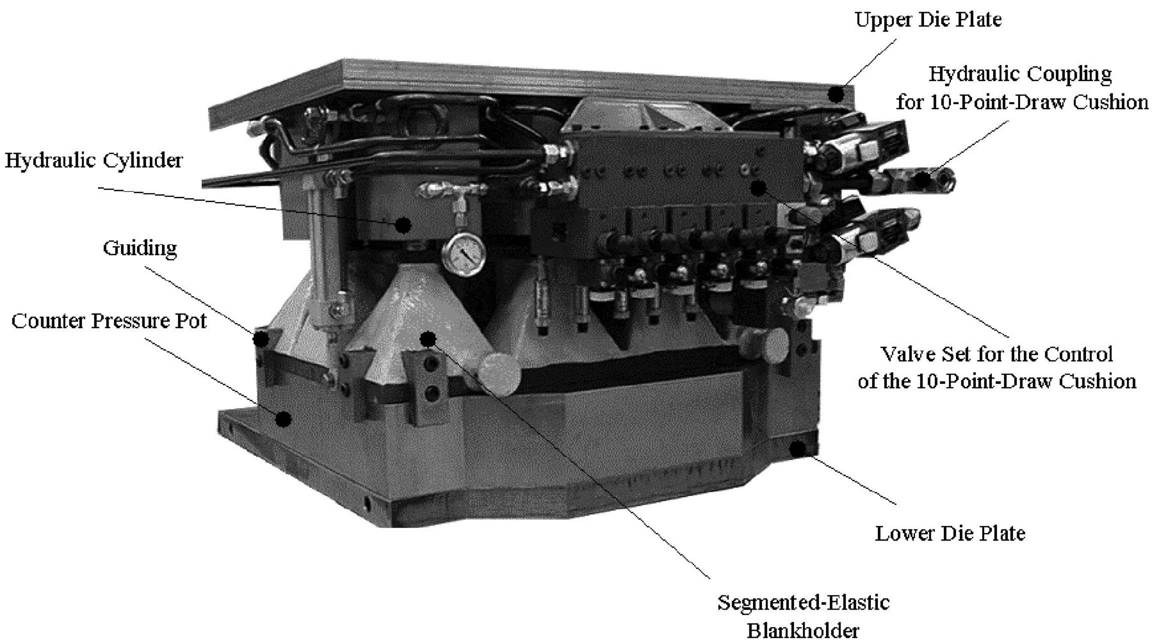


Figure 6: "Hishida" tooling for hydromechanical deep-drawing

The FEM-Model for the process simulation is shown in Fig. 7. The model comprises the three tool parts punch, blankholder and counter pressure pot and the blank.

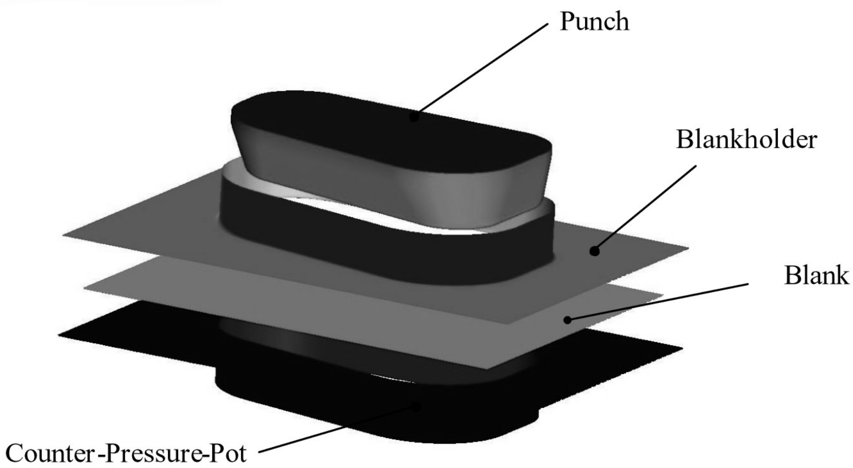


Figure 7: FEM model of the "Hishida" Tooling

For the different FEM-Process-Simulations the blank size, blank material, blank properties and the process parameter (blankholder force, counter pressure vs. draw-depth, friction coefficient, etc.) were varied and compared with the actual experiments. It could be shown that the results of the process simulation match the results of the practical experiments. Fig. 8 shows exemplarily the results of the FEM-Simulation and Fig. 9 shows a experimental result of the corresponding part made of high-strength steel.

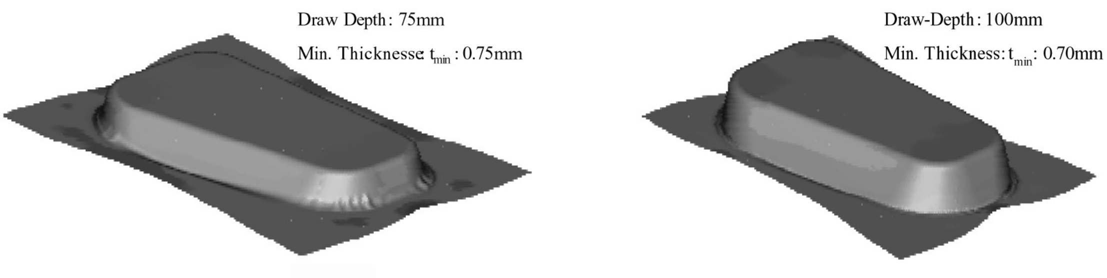


Fig. 8: Results of FEM-Simulation (Material: ZSTE 340, t = 1.0 mm)

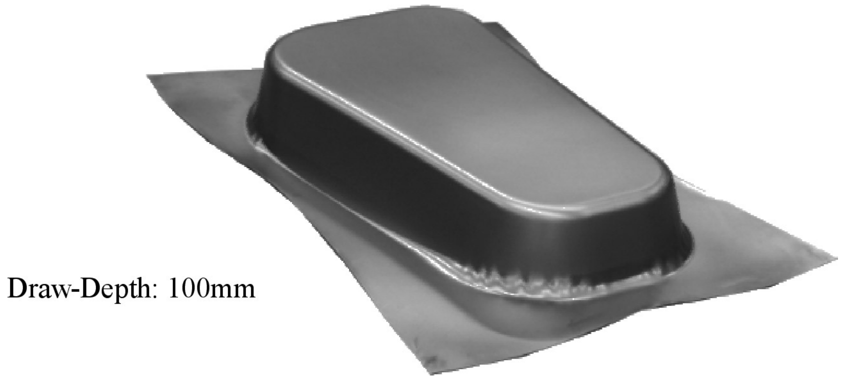


Fig. 9: Result of Experiment (Material: ZSTE 340, t = 1.0 mm)

"Door-Handle" Tooling

Fig. 10 shows the model of the "Door-Handle" tooling used for the FEM process simulation on hydromechanical deep-drawing. The model consists of the three tool parts counter pressure pot, blankholder and the punch. A further part of the model is the blank.

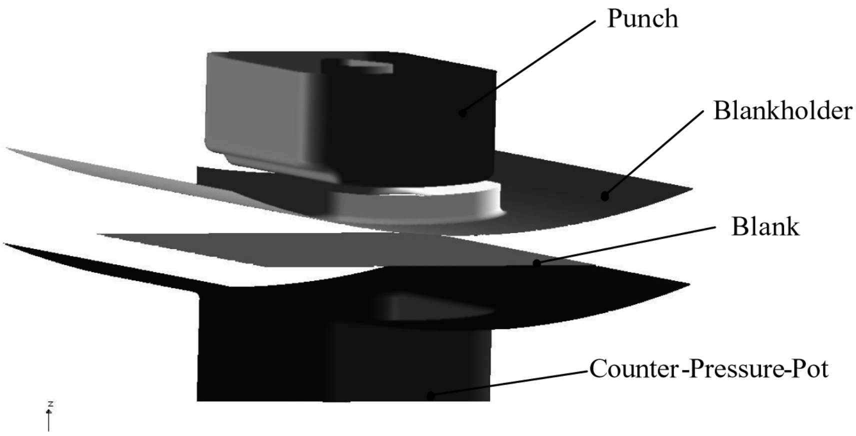


Fig. 10: FEM model of the Door-Handle Tooling

Due to the arched geometry of the blankholder the simulation carried out were separated into two processes. First the closing of the tooling and than the hydromechanical deep-drawing process were simulated. As above mentioned when stamping an outer door panel including the door handle it is problematic to get an equal strain distribution around the door handle. Therefore the door handle tooling is used for several investigation regarding a modified hydromechanical deep-drawing process. The first experiments and FEM process simulations will investigate if the strain distribution can be affected by different process modifications (e.g. bulging the door handle or drawing back an inner punch). Fig. 11 shows the wall thickness reduction of an FEM simulation for bulging the door handle.

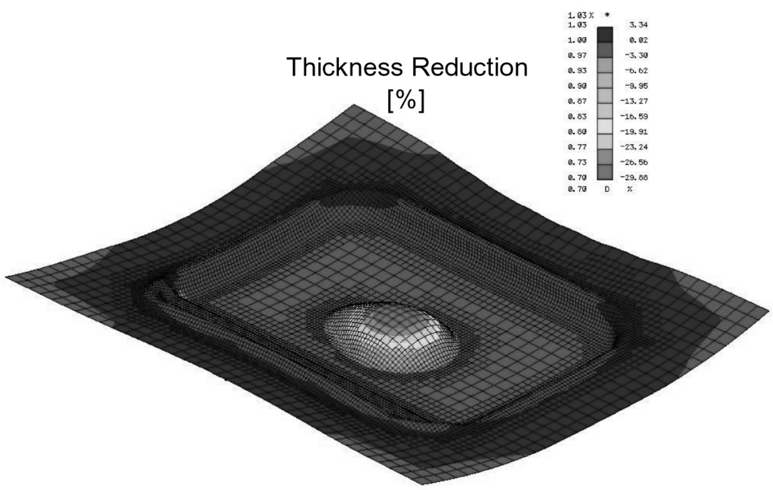


Figure 11: Result of FEM Simulation for freely bulged door handle

Summary and Outlook

The FEM-Process-Simulations carried out for the “Hishida” tooling matched the results of the experiments. Compared with experiments the influence of the counter pressure versus drawing-depth is more sensitive in the FEM process simulation as in the experiments. The maximum draw-depth and the occurrence of secondary wrinkles could be predicted using the FEM process simulation. In order to keep the experimental time and the costs low further FEM-simulations for the “door handle” tooling will focus on modifications of the hydromechanical deep-drawing process.

In order to choose a feasible design for the motor-hood tooling FEM simulation with a flat or simple shaped blankholder (a flat blankholder is cheaper and less manufacturing and computing time consuming) will be conducted. Fig. 12 shows the model for investigations regarding the feasibility of a flat blankholder for hydromechanical deep-drawing the motor hood. Additional investigations will be carried out to determine the maximum counter pressure for different materials in order to calibrate the smallest radii of the motor hood

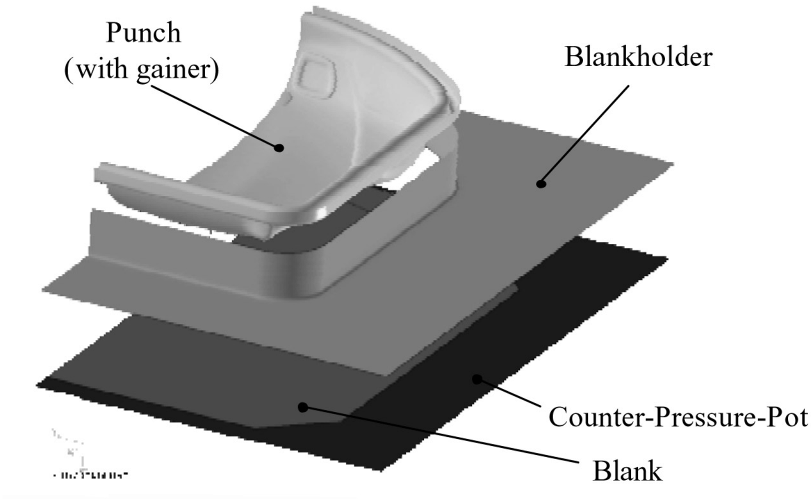


Figure 12: Model for the FEM-Simulation of a hood

References

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