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NUMERICAL SIMULATION OF HYDRO FORMING AT ELEVATED TEMPERATURES WITH GRANULAR MATERIAL USED AS MEDIUM COMPARED TO THE REAL PART GEOMETRY

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ABSTRACT: Modern automotive bodies are made of high and ultra high strength steel up to 90 mass percent of the body in white. These steels do not only possess a high light weight potential but also increase crash performance of the passenger cabin. The described benefits are facing the problems of forming these steels. With a low formability at room temperature and high flow stresses the complexity of parts out of these materials is limited. In a warm forming process with temperatures up to 600 °C the formability could be increased and the process forces could be decreased. Especially high complex parts are produced by hydroforming a technology allowing undercuts and uniform strain distributions in the part. For temperatures up to 600 °C there is a need of an appropriate medium for hydroforming. Fluids normally used at room temperature are only temperature stable up to about 350 °C and tend like gases to leakage. Using a granular material like small ceramic beads allow high temperatures and reduce the risk of leakage. The Drucker-Prager-Cap material model allows to describe this medium for the numerical simulation. The accuracy of the numerical simulation with the gained material model is compared with different experiments in which the parameters were identified and a real part geometry of a cup formed with granular material as medium.

KEYWORDS: Hydroforming, elevated temperatures, granular material, numerical simulation

1 INTRODUCTION

The automotive industry focuses on building cars with low fuel consumption. These efforts are caused on the one hand by the CO_2 debate and on the other hand by new laws. Beside the aerodynamics and high efficient motors the reduction of car weight are the main possibilities to reduce the fuel consumption. A weight reduction can be achieved by using materials with low density like aluminium or magnesium alloys or by reducing the sheet thicknesses and increasing the material strength. High and ultra high strength steels suffer the problem of poor formability at room temperature, so a warm forming is preferred. At elevated temperatures the formability of these steels increases and the process forces decrease [1, 2]. While warm forming in deep drawing process is state of the art, hydroforming at elevated temperatures for complex parts e.g. parts with undercuts is limited by the used medium. Common fluids for hydroforming are only temperature stable for temperatures up to 350 °C [3]. Like gases fluids tend to leakage so that high blank holder forces are necessary to seal the cavity. For higher temperatures and a reduced risk of leakage granular material like small ceramic beads with a diameter of 650 µm-850 µm can be used as medium. The physical properties of this material are shown in Table 1.

Table 1: *physical properties of ceramic beads*

Specific density	*3.85 g/cm^3*
Bulk density	*2.3 g{cm^3*
Young's-Modulus	*300000 N/mm^2*
Hardness	*60 – 65 HRC*
Low plastic deformations / breaking to fine powder	

For a fast and modern process design numerical simulation is necessary to reduce costs and time afford. The characterisation of blanks at elevated temperatures is state of the art while the characterisation of granular material is still done for relatively low pressures in soil engineering and process engineering.

2 DRUCKER-PRAGER-CAP MATERIAL MODEL

The numerical simulation of granular material can be done by describing the material behaviour with the Drucker-Prager-Cap material model. It allows plastic and elastic deformations and can also describe the compressibility of the material [4]. To determine the parameters for the material model it is necessary to build

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up experimental setups for pressures up to 100 MPa. With these experimental setups some of the parameters of the Drucker-Prager-Cap material model can be measured directly, others can be calculated. To gain the necessary parameters a uniaxial compression test and a modified shear test according to the Jenike shear-cell [5] are used. In [6] it is shown that die pressing and sintering of powder can be investigated by numerical simulation by using the Drucker-Prager-Cap material model in ABAQUS.

3 EXPERIMENTAL SETUPS TO DETERMINE MATERIAL MODEL PARAMETERS

3.1 UNIAXIAL COMPRESSION TEST

The uniaxial compression test can be used to determine compressibility of a bulk case of ceramic beads and the horizontal load quotient. The horizontal load quotient is a value describing the quotient of applied axial load to resulting radial forces. Figure 1 shows a schematically drawing of the compression test.

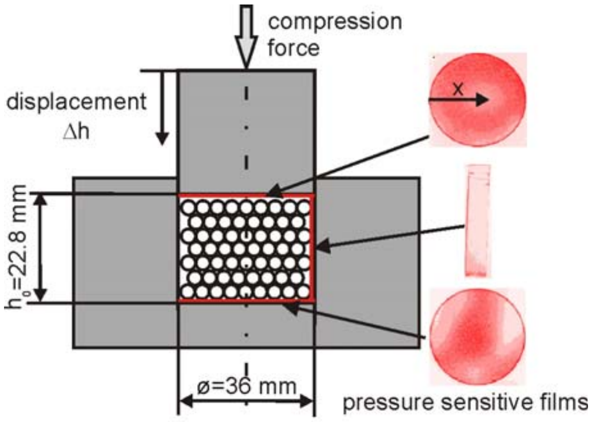

Figure 1: *Schematically drawing of uniaxial compression test*

A cylindrical volume (diameter 36 mm / height 22,8 mm) of ceramic beads is enclosed in a steel tool and compressed by a punch. The tool is loaded by a universal testing machine. For the determination of compressibility the data of universal testing machine can be directly used. Information on pressure distribution can be gained by using pressure sensitive films changing the colour from white to red and strain measurement strips on the outside of the tool. These data can be used to calculate volumetric plastic strain and pressure to describe the cap of Drucker-Prager-Cap material model.

3.2 HIGH PRESSURE SHEAR TEST

High pressure shear test gives information on shear stiffness of the compressed bulk case. The schematically drawing of the tool in shown in Figure 2. Main components of the tool are the punch, the fixed shear plate and the movable shear plate. At the beginning of the test the cylindrical cavities of fixed and movable shear plate are concentrically aligned and the cavity is filled with ceramic beads. After that the movable plate is displaced 5 mm out of concentricity and the punch applies a compression load by a hydraulic cylinder. With applied compression stress the movable plate is displaced 10 mm through the position of concentricity. By this it is possible to determine pairs of compression stress σ and shear stress τ [7]. These pairs of values describe directly the Mohr-Coulomb material model which can be transferred by calculations to pressure and v. Mises stress in the Drucker-Prager material model for plane strain deformation states [8].

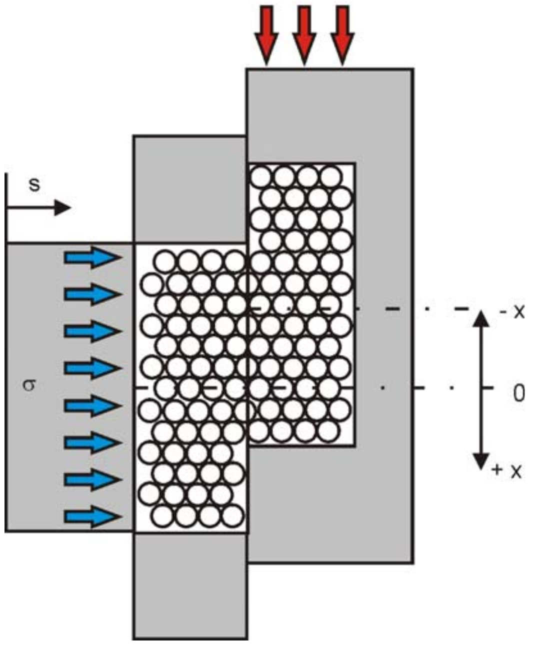

Figure 2: *Schematically drawing of high pressure shear test*

4 VERIFICATION OF MATERIAL PARAMETERS BY NUMERICAL SIMULATION OF EXPERIMENTS

A verification of the gained material parameters for the Drucker-Prager-Cap material model can be done by numerical simulation of uniaxial compression test and shear test. The differences between the data gained in the experiments and the results of numerical simulation gives information on how good the material parameters fit to real material behaviour.

4.1 UNIAXIAL COMPRESSION TEST

Comparing the force-displacement curves of the universal testing machine with the results of an axis symmetric numerical simulation gives a good fit like shown in Figure 3.

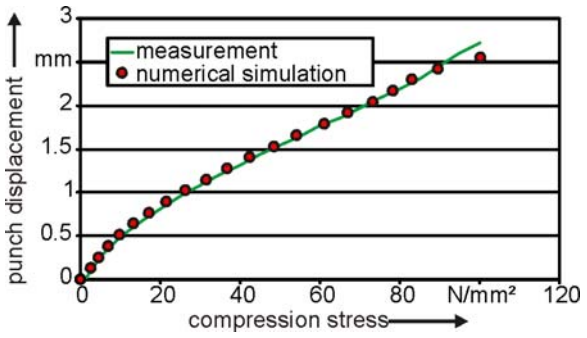

Figure 3: *comparison of compression in measurement and numerical simulation*

The numerical simulation also shows the measured loos of axial stress of about 12% between the top and the bottom of the testing volume as a horizontal load quotient of 2.1 like shown in Figure 4. As compression stresses the values are all negative.

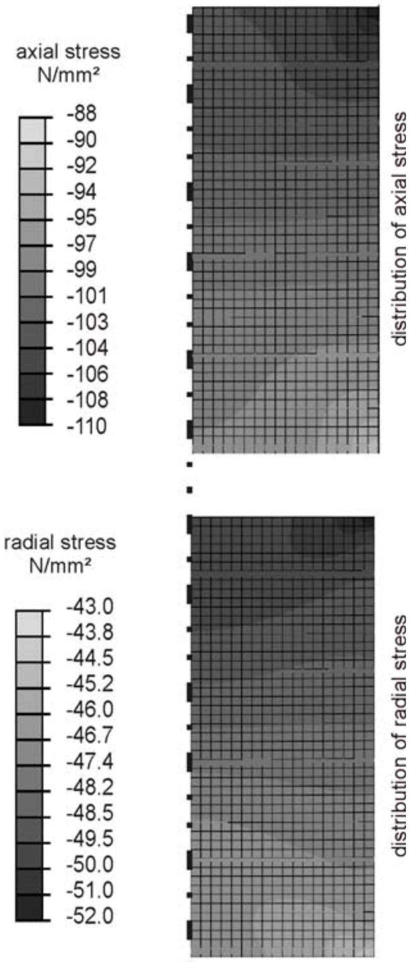

Figure 4: *pressure distribution in uniaxial compression test with a punch load of 100 N/mm²*

4.2 HIGH PRESSURE SHEAR TEST

Using the transformation from Mohr-Coulomb to Drucker-Prager material model described in [8] the numerical simulation of the shear test shows good accordance to the measurements. Figure 5 shows the comparison of shear stresses at concentricity of moveable and fixed shear plate at defined compression stresses.

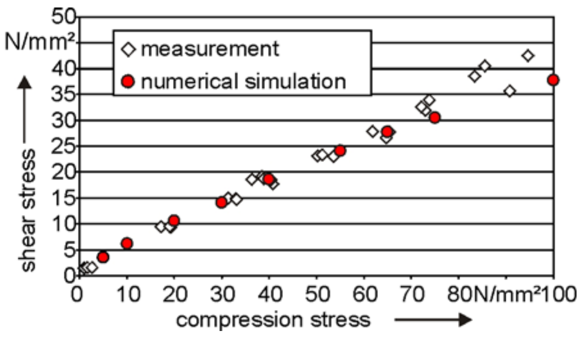

Figure 5: *comparison of shear stress at defined compression stress in numerical simulation and measurement*

The good accordance of experiments and numerical simulation in shear test and uniaxial compression test allows using the Drucker-Prager-Cap material model with the gained parameters for first numerical simulations of hydroforming processes using granular material as medium.

5 EXPERIMENTAL TOOL FOR HYDROFORMING WITH GRANULAR MATERIAL AS MEDIUM

In addition to the experimental determination of material model parameters and the verification by numerical simulation an experimental tool was build up which allows forming cups using granular material as a medium. The tool itself can be heated up to 500 °C but using preheated blanks it also can be used for higher temperatures. Figure 6 shows the tool for hydroforming using granular material.

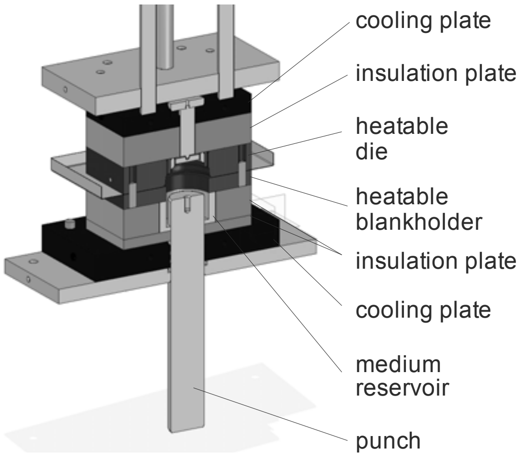

Figure 6: *experimental tool for hydroforming using granular material as a medium at elevated temperatures*

5.1 EXPERIMENTAL RESULTS

For the first experimental investigations three different sizes of ceramic beads with the diameter distributions 600 µm - 850 µm, 250 µm - 450 µm and 63 µm - 125 µm were used. Blanks out of standard deep drawing steel DC04 were formed to a cup at room temperature using different beads only to see the differences caused by the beads diameter and to have no temperature effects. The ceramic beads inside the reservoir are pressed against the blank by the punch until a predefined load is reached. The geometry of the cups was measured by a coordinate measuring machine, the middle surface calculated and compared in Figure 7.

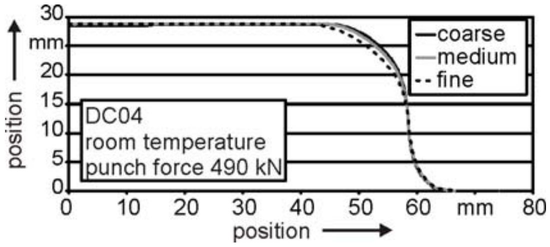

Figure 7: *geometry comparison of cups formed with ceramic beads of different diameters*

Like the numerical simulations also the measurements on real part geometry show less forming, especially in the die radii if fine or medium beads are used. This is according to the lower horizontal load quotient that could be measured in uniaxial compression test.

5.2 COMPARISON OF NUMERICAL SIMULATION AND EXPERIMENT

Comparing the geometry of a cup out of DC04 formed with the coarse medium at room temperature with results of the numerical simulation shows great differences. The simulation seems to suffer a problem of friction coefficients and blank holder forces leading to a reduced blank draw in. In Figure 8 the geometries are shown. Additional the diameters of the formed cup are marked on x-axis.

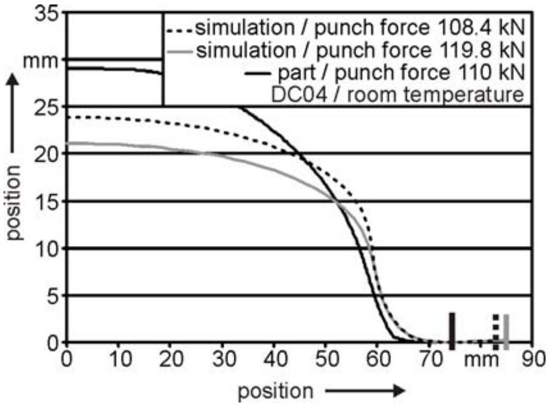

Figure 8: *comparison of real geometry and numerical simulation*

Especially the insulation plates with a thickness of 75 mm show elastic deformations up to 2 mm during the forming process making it hard to control blank holder forces.

6 CONCLUSIONS

Small ceramic beads can be used as medium for hydroforming but compared to gases or fluids there is no hydrostatic pressure distribution possible. The horizontal load quotient affects the forming result significantly. So in cup forming it is essential to change the punch geometry so that higher radial loads can be achieved.

Further investigations have to be done regarding the stiffness of the insulation plates at different temperatures and the thermal elongation so that real blank holder forces are available for numerical simulation.

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