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NUMERICAL STUDY OF A VARIABLE WALL ANGLE MADE OF DC01 STEEL BY INCREMENTAL FORMING PROCESS

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Abstract: *Nowadays, there is a high demand for rapid prototyping parts and for products manufactured through plastic cold deformation. Incremental forming process is one of many which presents numerous advantages for fast production of complex shape parts. The purpose of this study is to develop a numerical model through finite element analysis to simulate the incremental forming process. For this analysis a variable wall angle part (VWA) which ranges from a 45° wall angle at the higher base of frustrum cone to a 70° wall angle at the base of the shape was proposed. The numerical model showed where the maximum strains are localized, how big the forces are during the process and how much the material thinned. Although the model does not indicate a possible failure of the material, the integrity of the structural stiffness was altered due to a minimum thickness reached of just 0.26mm.*

Key words: *single point incremental forming, variable wall angle, deformations, forces, simulation*

1. Introduction

The incremental deformation process is part of cold or hot plastic deformation processes and is defined by the permanent change of the contact area between the tool and the sheet blank, an area that evolves incrementally along a predetermined toolpath until the desired shape of the part is obtained [1], [2]. In comparison with other classic deformation processes, in the present case, certain elements are required to carry out the incremental deformation process, 3 of which are indispensable to the process: the sheet blank, an active element that directly produces the deformation of the sheet blank, one or more elements supporting the sheet blank [3].

The incremental deformation process is relatively new to the industry due to the fact that over the years various researches and experiments have been carried out but it has not been implemented on a large scale in the industry due to some small constraints. The main characteristics of the incremental deformation process, as well as the differences from the classic plastic deformation processes, are: the incremental deformation process is used as an alternative to the classic plastic deformation processes; the incremental deformation process is carried out without the help of a mold, only the clamping and fixing elements of the sheet blank being necessary; the process has the advantage of removing the expensive elements from the classical processes, namely tools and molds, so that the elements producing deformations are relatively cheap; high flexibility of the process due to the dimensions of the parts that can be processed by this process; the time to make a product is high compared to classic processes and depends a lot on the size of the part, the path chosen for the tool and the number of increments on it, the speed of the tool and the power of the chosen equipment [4], [5].

Frustrum cone parts made by incremental deformation have in most cases a constant wall angle. In this case, the parts made of different materials have an uneven distribution of material thickness in the wall

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area. In the incremental deformation process, the deformability of a material or sheet metal can be quantified as a function of the maximum wall angle that can be machined without breaking the material. The error given by the thinning of the material must be kept within certain limits, because below certain values the material no longer exhibits stiffness even if failure does not yet occur [6]. To determine the maximum angle of processing a material, quite a few experimental trials are needed, but Kurra proposes a method in which the wall angle shows a continuous variation VWACF (varying wall angle conical frustrum) [1].

The aim of this paper is to investigate the deformations and forces of a frustrum cone part with variable wall angle (VWA) made of DC01 steel. The type of material is well suited for high deformability process like in the case of incremental forming.

2. Method and model description

In this paper for this research, it was developed a numerical model which from which we are able to determine the necessary results such as deformations and forces. The numerical model is developed in ABAQUS software and the results are obtained throughout the finite element analysis method. The chemical composition of DC01 sheet blanks is presented in Table 1.

Table 1: Chemical composition of DC01 steel

Composition	C	Mn	P	S
Wt %	0.12	0.6	0.05	0.045

In Table 2 are presented the mechanical properties of DC01 steel sheets after uniaxial test of specimens.

Table 2: Mean values of DDC01 uniaxial test

Rolling direction	E modulus (MPa)	Tensile stress at Yield (MPa)	Strain hardening exponent	Maximum tensile stress (MPa)	Tensile strain at break (%)
0°	78422.9	176.2	0.2472	270.7507	31

The numerical model consists of two retaining rings which are used to fix the sheet blank. The sheet blank used has the dimensions of 250 x 250mm and a thickness of 0.8mm. The retaining rings are considered to be discrete rigid parts, whereas the sheet blank is modeled as deformable. The punch that follows the variable wall angle toolpath is modeled as a semispherical tool which is analytical rigid. The reason for this is because we are not interested in the deformations and stresses which may appears on the retaining rings and punch. The lower retaining ring was encastred, whereas on the upper retaining ring was applied an axial force of 5kN. For the punch all the rotations were suppressed and only the X, Y and Z translations were allowed. In Figure 1 are presented all the elements involved in the numerical simulation of the incremental forming process and how they were modeled in ABAQUS.

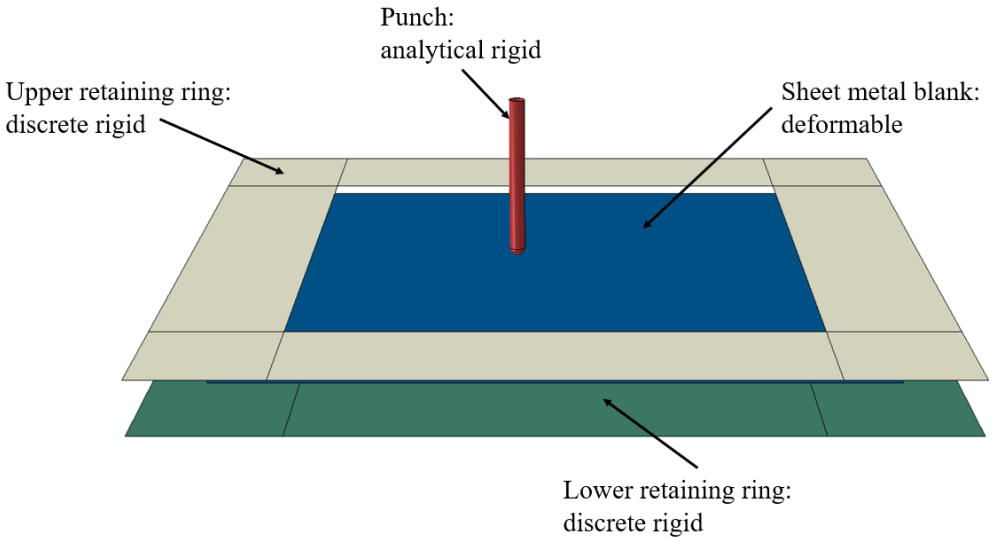


Figure 1: Simulation model with parts

The only component which does not require to be meshed is the punch. For the retaining rings R3D4 elements were used and for the sheet blank S4R elements. The frustrum cone was designed with a total height of 40mm and the large base of 85mm. The initial wall angle at the large base was 45° and the maximum wall angle reached at the bottom was 70°. The toolpath for the punch was developed in SprutCAM after the CAD import of the part. In SprutCAM the toolpath was described as a continuous spiral with a vertical step of 0.5 mm. The punch radius used was 5mm.

3. Results and discussions

After performing the finite element analysis of the frustrum cone with variable wall angle the following results were obtained: major and minor strains, shear angle and thickness reduction. In addition to these results also the reaction forces of the punch were obtained. In Figure 2 it is observed the graphical distribution of major strains and in Figure 3 the graphical distribution of minor strains.

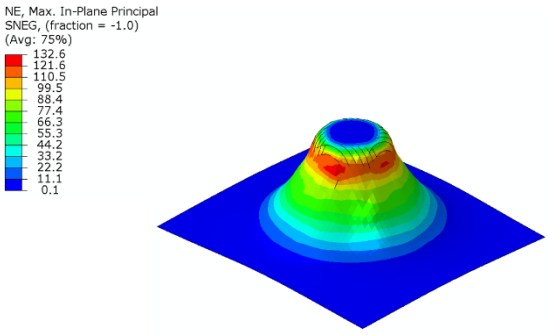


Figure 2: Major strain of VWA frustrum cone

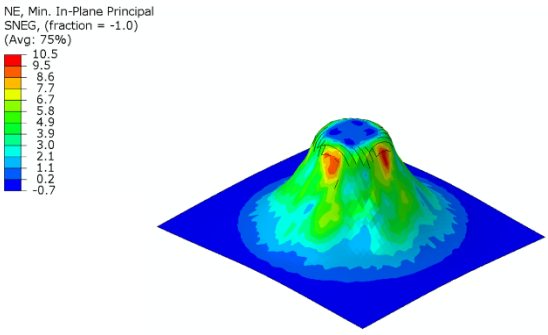


Figure 3: Minor strain of VWA frustrum cone

From Figure 2 we can observe that the maximum strains obtained are localized at the bottom of the frustrum cone where the wall angle reaches 70° with the value of 132.6%. In the case of minor strains, we recognize the same behavior as the major strain and the maximum value is 10.5%. Also, one important aspect is the shear angle of the part which in this case the maximum values are 38.1° as can be seen in Figure 4.

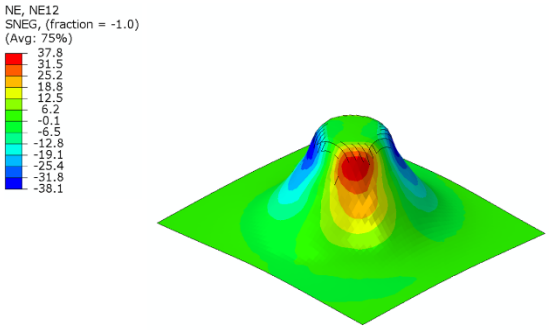


Figure 4: Shear angle of VWA frustrum cone

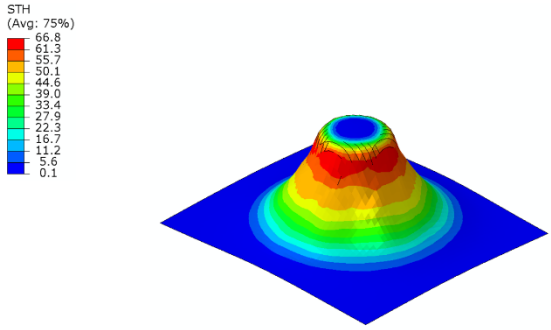
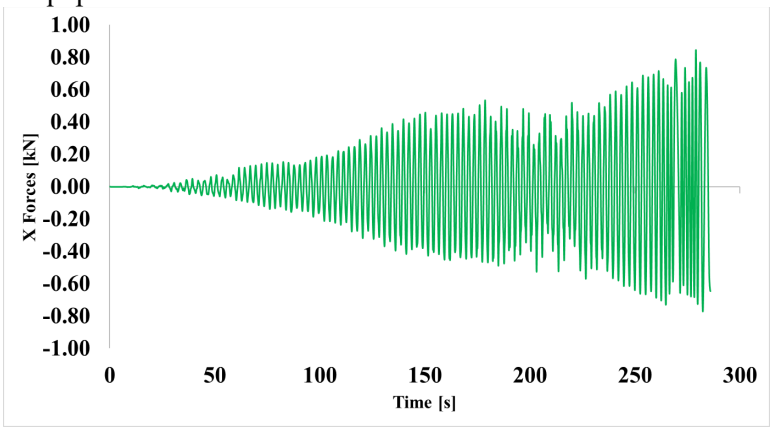


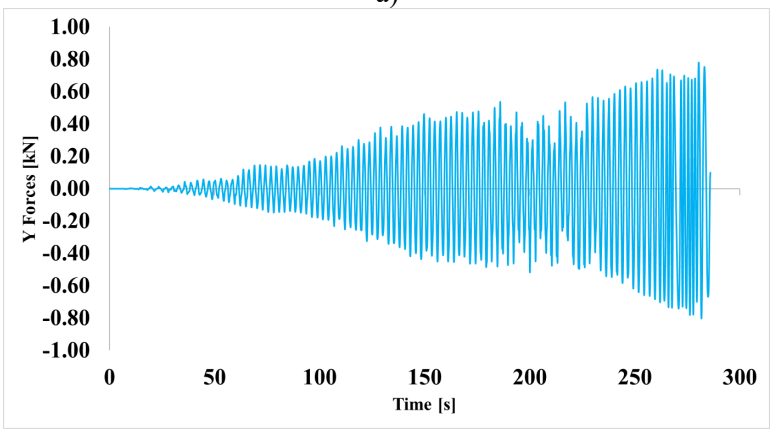
Figure 5: Thickness reduction of VWA frustrum cone

Another important aspect of the plastic deformation process is the material thinning. This problem may cause the part not to exhibit stiffness even if failure does not yet occur. In the case of the analyzed VWA frustum cone the maximum values for the sheet blank thickness reduction are 66.8% which translates to a minimum wall thickness of 0.26mm. These minimum values are localized also at the bottom of the frustrum cone, where the wall angle is increased. The sheet blank thickness in that area is very low, which means that failure can occur during the manufacture process.

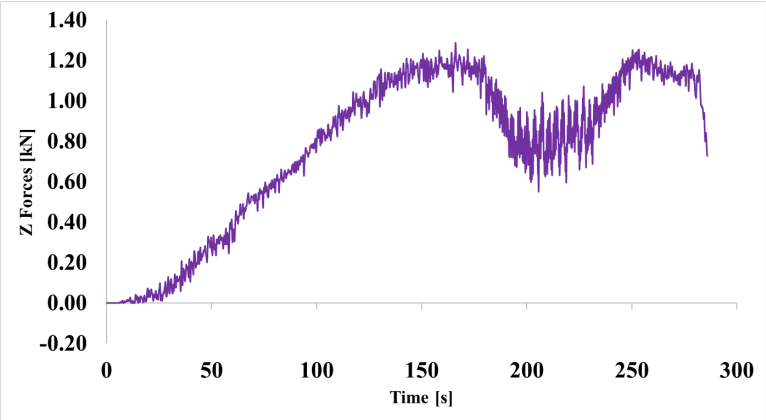
From the finite element analysis of the VWA part forces over three axes are obtained. The forces are presented in Figure 6. They are important in order to have a good knowledge about the maximum values necessary for suitable equipment to be chosen.



a)



b)



c)

Figure 6: Forces obtained during VWA frustrum cone part: a) X forces; b) Y forces; c) Z forces

From Figure 6 we can observe that for X and Y axis the maximum values are around 0.8kN, whereas for the Z axis, the maximum forces reached 1.2kN. The drop in Fz forces, which can also be seen in X and Y axis is caused by the toolpath due to the fact that after it has ben generated with the CAM software, we reduced the number of points in order to be able to do the simulation in a relatively small time. Anyhow the total time of simulation exceded 72 hours. For this reason, it may happen that sometime durind the process the punch does not stay in contact with the sheet blank or the values of the points from toolpath were smaller than the one introduced in ABAQUS software.

4. Conclusions and discussions

In this paper a numerical model was successfully developed in order to determine the strains, material thickness and forces for incremental forming process. The shape of the part simulated was a frustrum cone with variable wall angle in order to study where are the peak values of strains and other results localized. As it can be seen from the pictures presented, major and minor strains as well as material thinning are more pronounced at the small bae of the frustrum cone, where the wall angle of the part is higher. From the material thickness reduction figure, it is observable that the maximum values are 66.8% which for the sheet blank with initial thickness of 0.8mm as in this care translates to a minimum thickness of 0.26mm. The model does not show that with certainty the material will fail, but it is obvious that the material stiffness is affected beyond the limits of parts structural integrity.

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