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SIMULATION OF INCREMENTAL FORMING OF SHEET METAL PRODUCTS

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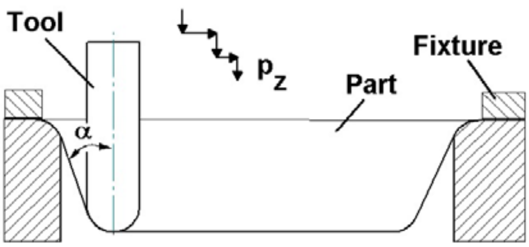
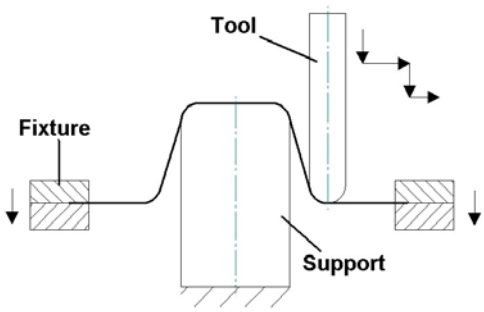
Abstract: *In machine design, parts made of sheet metal are widely used. For manufacturing of parts with conventional sheet metal forming techniques, for example deep drawing, dedicated tools are needed. They are highly specialized, expensive and time consuming to produce.*
Recently new sheet metal forming technique, incremental forming, has been introduced. It is based on using of simple spherical tool, which is moved along CNC controlled toolpath. The part is produced by deforming the sheet locally. In order to study the process of incremental forming, finite element analysis has been performed. Both types of analyses, 2D and 3D, have been performed to be able to understand the physical phenomena involved in incremental forming.
Key words: *Incremental Forming, Dieless Forming, Finite Element Analysis, Sheet Metal Forming.*

1. INTRODUCTION

In modern world it is a general trend that product development period is decreasing, but on the other hand, more variants of products has to be offered. At the same time, the design of products is becoming increasingly more complex, higher quality level has to be achieved.
In machine design, parts made of sheet metal are widely used. For manufacturing of parts with conventional sheet metal forming techniques, for example deep drawing, dedicated tools are needed. They are highly specialized, expensive and time consuming to produce.
Recently new sheet metal forming technique, incremental forming, has been introduced. It is based on using of simple spherical tool, which is moved along CNC controlled toolpath. The part is produced by deforming the sheet locally. The sheet blank is fixed in sheet holder. The tool deforms the sheet blank drawing a contour on horizontal plane, then makes step downwards and draws next contour and so on until operation is completed. For the process universal 3 or more axis CNC machining centre can be used. To prepare the NC –code general purpose Computer Automated Manufacturing (CAM) software can be used. Fig. 1 helps to understand the principle of the process.



(a)



(b)

Fig. 1. Two different incremental forming processes: (a) forming without support; (b) forming with support.

As expensive and highly dedicated tools are not needed and the duration of processing a part using incremental forming is relatively long, it is especially suitable for production of prototypes and for small series production.
There are two main variants of incremental forming process. Firstly, forming without support (Fig. 1 (a)). Secondly, forming with support (Fig 1 (b)).
Several scientific papers have been devoted to incremental forming last few years.
An approximate deformation analysis for the incremental bulging of sheet metal using a ball has been developed by Iseki (Iseki, 2001). The incremental bulging method has been applied for non-symmetric shallow shells. In (Iseki, 2001) the plane-strain deformation model has been proposed. This model makes an approximation that the sheet metal in contact with the ball stretches uniformly. The friction at the interface between tool and sheet, the plane anisotropy and Bausinger effects of the sheet material are neglected. The closed form expressions for the uniform strains $\varepsilon_x, \varepsilon_y$ and ε_t of the deformed shell are pointed out. The tensile force is determined from the condition that the undeformed part is rigidly moved by the stiffness of the shell. The results, obtained by the approximate deformation analysis, FEM analysis and experiments are in good agreement. However, the complete incremental bulging operation has not been modeled in (Iseki, 2001). Vertical wall surface forming of rectangular shell using multistage incremental forming is studied in (Iseki & Naganawa, 2002). A method of calculating for the approximate distribution of thickness strain and the maximum bulging height has been proposed using a plane-strain deformation model with a constant strain gradient. In (Dai et al, 2000) a mapping relationship between the blank and its formed specimen under the condition of even strain is obtained.
A simplified calculation model is developed in (Kim & Yang, 2000) assuming that all deformation occurs only by shear deformation. The intermediate shape was determined from the predicted thickness strain so as to distribute the deformation uniformly. Next, the sheet metal has been

deformed by a double-pass forming undergoing the calculated intermediate shape. The proposed method has been applied to the analysis of an ellipsoidal cup and a clover cup.

The formability in incremental forming of sheet metal is studied in (Shim & Park, 2001; Kim & Park, 2002; Kim & Park, 2003). In (Shim & Park, 2001) a forming tool containing a freely rotating ball was developed. The results observed in the tests were examined by grid measurement and finite element analysis. A unique forming limit curve was obtained. In (Kim & Park, 2002) the effects of process parameters (tool size, feed rate, plane-anisotropy) on formability are studied.

In their study, Shim & Park and Kim & Park (Shim & Park, 2001; Kim & Park, 2002) used a commercial finite element analysis code, PAM-STAMP, for the analysis of sheet metal incremental forming. It was used to analyze the deformation that occurred in the straight groove test.

It is difficult in general to predict the thickness strain distribution of the initial state of a deformation after the accumulation of numerous incremental deformation passes. One option to calculate the thickness strain during the whole deformation process is by using finite element analysis. Nevertheless, it has some difficulties when applied to the incremental sheet metal forming process. The most critical problem is the large number of calculation steps, which means very long time for calculation. Compared with the general sheet metal forming processes, the incremental sheet metal forming process has a simple deformation mechanism but the deformation path of its moving tool in this process is much longer. If the entire process has to be analyzed, too much time is required. (Kim & Yang, 2000)

2. SIMULATION MODEL

For simulation of the incremental forming process commercial finite element analysis system ANSYS was used.

Both, 2D and 3D analyses have been performed in order to study the physical phenomena involved in incremental forming. Because of the nature of the process, there are several nonlinearities involved in the simulation of incremental forming. In addition, usually large number of elements has to be used and the tool moves along a relatively long trajectory. This all causes finite element analysis to be complicated and time consuming.

As extensive experimental study has also been made on incremental forming by the authors (Pohlak et al, 2004) then, in order to compare the results, similar parameters and material property values have been used in study on simulation.

2.1 Simulation procedures

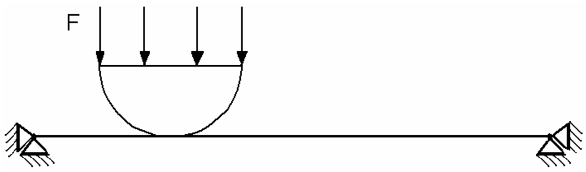
Simulation of incremental forming processes consists of several steps as follows:

- Building CAD models (blank, tool, support, part with desired shape);
- Generating toolpaths for controlling tool movement;
- Building finite element model, applying boundary conditions, defining material properties, contact parameters etc;
- Solving model, post processing.

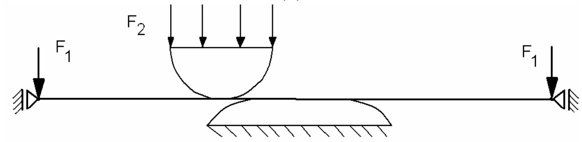
Toolpath generation is a step that is usually not needed in simulation. However, for simulation of incremental forming it is used to make tool moving along predefined trajectory. In simple cases the coordinates for toolpaths can be calculated by spreadsheet program, but in current study the Computer Automated Manufacturing system was used.

2.2 Calculation scheme

On Fig. 2 basic calculation schemes are presented. In general, contact calculation cannot be avoided, replacing contact with multipoint constrains or modeling it in some other way to shorten computation time was not found feasible.



(a)



(b)

Fig. 2. Calculation schemes of incremental forming processes: (a) forming without support; (b) forming with support.

In modeling incremental forming with support, the workpiece-support interface was also modeled using contact calculation (see Fig. 2 (b)). Using contact calculation in sheet fixture area was assumed to be unnecessary.

As in experimental study carried out by authors (Pohlak et al, 2004), simulation of forming without support was also performed at 10 mm distance from the sheet holder. So, it was decided not to model the rounds on the holder, because it was assumed to have insignificant effect on results.

2.3 The control of tool movement

In simulation of the process the effects of acceleration were assumed to be insignificant to the results under consideration, so static analysis was made. The tool movement was controlled using predefined displacement constraints in several load steps.

2.4 Material models

Generally, there are several nonlinear material models available in finite element systems. They require different material property values to be input and results are also slightly different. In simulation described in current paper multi-linear isotropic strain hardening anisotropic plasticity material model was used to model sheet blank.

Tool and support were modeled using simple linear elastic material model.

2.5 Element types

For all 3D simulations in current study 3D shell elements were used. Two types of shell elements were used in similar applications for comparison purposes. Firstly, shell with 4 nodes, and secondly, shell with 8 nodes. Both of them have nonlinear capabilities and they account for thickness change.

3. SIMULATION OF THE PROCESS

As it has been said before, simulation of the incremental forming could be very time consuming. Today simulation of the full forming process of machine parts without using some kind of supercomputers or computer clusters is unrealistic. To perform simulation high approximation level has to be used. There are two main parameters on which solving time depends on most, the number of nodes/elements (element size) in the model and the number of toolpath segments (number of load steps).

All simulations were performed on Windows XP PC with single 1.6 GHz CPU.

3.1 Determining modeling parameters

In order to be able to estimate the effect of element count to the solving time two simulations of incremental forming with support were performed. The size of the models was reduced to shorten simulation time – sheet size 50 x 50 mm, thickness 1 mm. Tool radius was 5 mm and support was rectangular shaped with size of 15 x 15 mm, corner radiuses 5 mm. Stretching force applied on sheet edge was 1 N. Tool was moved along rectangular toolpath, the size of downward step was 0.5 mm and the total downward moving distance was 2.5 mm.

In the first simulation the element edge length on the tool and support was 1 mm and on the sheet 2.5 mm. Elements with 8 nodes were used. It took 14 hours to solve the model, but stress distribution in some areas was unrealistic, which could indicate the need for smaller elements.

In the second simulation the elements on the sheet blank were refined. Now the edge length of 1 mm was used. Other parameters remained the same. This model took 120 hours to solve.

In post processing it was found that thickness values of the sheet after forming were unrealistic, which could indicate the need for using of even smaller elements.

Because of the long duration of simulation on last case, it was not tried to perform more simulations with smaller elements.

3.2 Simulation of incremental forming

As it was found in previous section, very simplified model took long time to solve. So, it was decided to make more thorough simulation of forming without support because it needs less elements and contact regions and therefore takes less time to solve.

In more detailed simulation sheet edge was fully constrained. Tool radius 5 mm was used and sheet dimensions were 100 x 100 mm, thickness 1 mm. Element edge length used on the tool was 1 mm and on the sheet 2.5 mm. On the sheet shell elements with 4 nodes and on the tool shell elements with 8 nodes were used. The tool was moved along rectangular toolpath, with downward step size 1 mm. The total downward moving distance was 20 mm.

The spring-back effects were also considered in the simulation.

The model took 72 hours to solve.

3.3 Validation of simulation model

To find out how well the model is able to represent the reality comparison with experimental study was made. A part was produced using test fixture and 3 axis NC milling machine. Tool was moved along same toolpaths as in simulation, all other parameters were also as similar to ones used in simulation as possible.

When the part was complete, its geometry was measured and compared with simulation results. Maximum positive normal deviation of the form was measured 0.439 mm and maximum negative normal deviation was measured -1.295 mm.

It can be concluded from validation that model was not accurate enough. The boundary conditions used did not represent reality well enough. The second source of errors is most likely element size. It was found that elements used were too large and did not give accurate results, especially in areas with large strain.

4. CONCLUSION

In modern manufacturing industry flexibility of production technologies is becoming more important. The role of optimization of processes is becoming essential. The optimization can be carried out using computer simulations. Finite element simulation based on shell theory was applied to study incremental forming processes. The analysis results were validated by comparison with results of experimental study. It was found that finite element models need to be made more accurate, but the most important obstacle in this is duration of calculation. The simulation runs more than 100 times longer than it takes to actually produce the part, so highly simplified models need to be used.

In future studies, the series of simulations with different parameters should be made using computing cluster for higher performance in order to study the influence of various parameters to the results.

5. ACKNOWLEDGEMENTS

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