

Topology Preserving Shell Mesh Modification for Stamping Die Rounding Shape Optimization

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ABSTRACT

In order to reduce trial-and-errors in die design and production, CAE systems to analyze stamping tools have been introduced at the initial design stage, recently. However, for optimal design, tedious work for modification of CAD models, mesh generation, and stamping simulation should be performed iteratively. To solve this problem, in this paper, we developed an interface program that will modify the die rounding shape in a CAD model and generate a finite element mesh from this model. The new mesh has the same topology and the same IDs of nodes and elements with the original mesh. In addition, we also proposed and implemented a framework for optimization of die rounding shape by integrating the existing commercial CAD and CAE systems. In virtue of the interface program, the iterative design-analysis iteration can be performed automatically, and three steps of the current design-analysis iteration can be reduced to two steps: mesh modification and stamping simulation.

INTRODUCTION

The sheet metal forming process has been widely spread in the area of mass production of automotive body panels. Most die manufacturers for sheet metal forming have introduced CAD/CAM systems for design and production of dies as the die shape usually contains complicated three-dimensional freeform surfaces. Furthermore, recently, in order to reduce the number of trial-and-errors in a try-out press, CAE systems has been introduced and utilized for analysis of stamping process at the die design stage. Since these CAE systems can reduce large amount of time and man-hours in the trouble shooting process, they are accepted as an essential tool for productivity improvement in automobile manufacturing processes [1-4].

The current iterative process for design and analysis and of stamping tools using CAD/CAE systems is composed of three steps as follows [4]:

[Step 1] Shell meshes of CAD models for stamping tools including die, punch, and blank-holder are generated by an automatic mesh generation program.

[Step 2] The stamping process is simulated for formability evaluation using a CAE system such as PAM-Stamp™.

[Step 3] According to the analysis result, if necessary, the process parameters are changed or the CAD models are modified locally using modeling functions of the CAD system such as rounding operations. Then, go to [Step 1] and repeat the cycle until the analysis result is satisfactory.

In this process, however, the whole meshes for a modified CAD model should be regenerated for each iteration, although only a small part of the model is modified. In addition, if an automatic mesh generator does not provide perfect meshes that can be used readily for the simulation, CAE engineers must correct the meshes interactively for each iteration. If the mesh generator is not imbedded in the CAD system, CAE engineers may have to repair the imported CAD data before performing mesh generation, because currently it is almost impossible to transfer CAD data completely from one system to another. Moreover, in order to modify CAD models, CAD systems are occupied, and the labor of CAD operators may be required to support CAE engineers because CAE engineers are usually not skillful in the manipulation of CAD systems. Therefore, if CAE engineers can modify meshes directly instead of CAD models, the design-analysis cycle can be accelerated, and resources for CAD work can be saved.

To solve these problems, Lee et al. [4] proposed local modification capabilities for shell meshes, which give a constant or variable radius of rounding directly to sharp edges of a die shoulder in a tool mesh. Using these capabilities, CAE engineers can modify meshes directly instead of CAD models. As a result, the above three steps of the current design-analysis iteration can be reduced to two steps: mesh modification and stamping process simulation. However, in this method, the numbers and IDs of nodes and elements are changed after rounding operation because the elements on the area of rounding area are deleted and then new elements are generated and implanted there. If the numbers and IDs of nodes and elements in mesh data file are unchanged throughout the whole process, the

above design and analysis cycle can be performed automatically.

To meet this requirement, in this paper, we propose an automatic shell mesh modification method using existing CAD/CAE systems. In this method, the numbers and IDs of nodes and elements in a FEM mesh model remain constant although the positions of nodes on the modified rounding area are changed. In addition, this method is applied to the rounding shape optimization problem for stamping tools so that its usefulness may be verified.

STAMPING DIE ROUNDING SHAPE OPTIMIZATION

OPTIMIZATION OF ROUNDING SHAPE FOR STAMPING DIES

Definition of Optimization Problem

Figure 1 shows finite element models for stamping tools for an oil pan of an automobile. We selected these models as a case study of the rounding shape optimization problem in this research. The oil pan looks like a square cup with rounded edges. Since this type of parts may have tear defects during stamping process, modification of the rounding radii for the edges of the die shoulder is adopted as an effective way to prevent tears. Therefore, we defined the optimization problem as the problem of finding the rounding radii for the die shoulder edges that give the smallest thickness-thinning rate over the part, while the material extension rate for the bottom face of the part should be over a certain critical value. Table 1 shows the mechanical properties of the blank selected in this work.

Definition of Design Parameters

As illustrated in Figure 2, the rounding radii at nine points, P0 to P8, are defined as the design parameters. These parameters are varied in the reflection of the analysis result during optimization process.

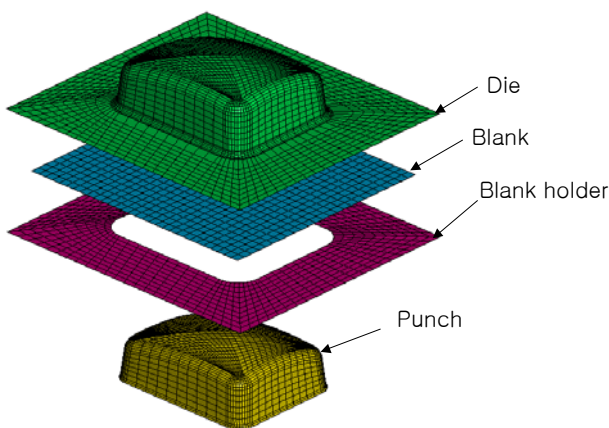


Figure 1: FE model of the optimization problem

Table 1: Mechanical properties of the blank

Properties	Nom.	Unit	Value
Thickness	t	mm	1.8
Strength coefficient	K	(MPa)	624
Offset strain	ε_0	-	0.006
Lankford coefficient for normal anisotropy	R	-	1.0
Hardening coefficient	n	-	0.176
Yield stress	Y	(MPa)	254
Elastic modulus	E	(GPa)	210
Poisson ratio	ν	-	0.3
Density	ρ	kg/mm ³	7.8×10^{-6}

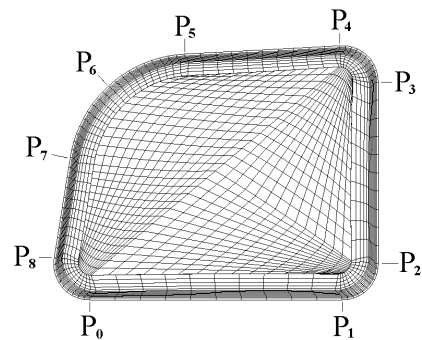


Figure 2: Positions of variable rounding radius of die

Objective Function

As the objective of the optimization[5] is to reduce the possibility of tear defects, we define the objective function as follows:

$$f = t_0 - t_{min} \quad (1)$$

where t_0 is the thickness of the blank at the initial stage, and t_{min} is the minimal thickness after stamping work. Refer to Yin et al. [6] for more investigation about constraints and sensitivity analysis.

AUTOMATIC GENERATION OF CAD/CAE MODELS FOR ROUNDING SHAPE OPTIMIZATION

In this research, I-DEASTM [7-8] and PAM-StampTM[9] are used for design and analysis of stamping tools. I-DEASTM provides a unified modeling environment for CAD models and FEM mesh models. According to the

analysis result, the rounding shape of the die shoulder is modified by changing the radii of the variable-radius rounding features on the die shoulder edges, and then a new mesh is regenerated. The numbers and IDs of the nodes and elements of the initial mesh are maintained unchanged throughout the whole optimization process. By adopting this method, the load and boundary conditions can be applied to the same nodes and elements throughout the whole process.

Optimization Process

Figure 3 illustrates the system configuration and workflow for shape optimization. The whole process consists of the following several steps. The basic input data for the optimization is generated manually in the steps (1) to (4), and then the analysis and redesign work is carried out repeatedly in the steps 5 to 10.

[Step 1] The surface model for a stamping die is created using a CAD system and is saved in a neutral file format for data exchange such as IGES or STEP.

[Step 2] The user imports this data file into I-DEASTM, and then creates a CAD model of I-DEASTM based on the imported model. Variable-radius rounding features are applied to the die shoulder edges. The mapping data and window data are established for the iterative optimization process.

[Step 3] Mesh data for the CAD model is generated in I-DEASTM. In this step, some constraints are established between the CAD model and the mesh so that new mesh may be generated satisfying these constraints.

[Step 4] Using the mesh generated in the step 3, the mesh for the blank holder and the punch are generated

in PAM-Generis. Once all the meshes for the tools are obtained, their topology data are unchanged throughout the whole optimization process.

[Step 5] The constraints and the load conditions are established, and based on them and the mesh data, the input data for PAM-Stamp™ is generated by our system (initially by the user).

[Step 6] Analysis is carried out by the PAM-Stamp™.

[Step 7] The analysis result is analyzed and evaluated by the system.

[Step 8] According to the analysis result, the parameters that need to be changed are determined, and their new values are chosen by the system or the user.

[Step 9] The CAD interface module modifies the CAD model by changing the rounding radii with the values chosen in the step 8, and generates the die mesh from the modified CAD model. The topology of the mesh is preserved, and the IDs of nodes and elements in the mesh are unchanged. Only the positions of the nodes on the modified area are changed into new positions.

[Step 10] The steps from 5 to 9 are repeated until the optimized radii are obtained.

As illustrated in Figure 2, the rounding radii at nine points, P0 to P8, are defined as the design parameters. These parameters are varied in the reflection of the analysis result during optimization process.

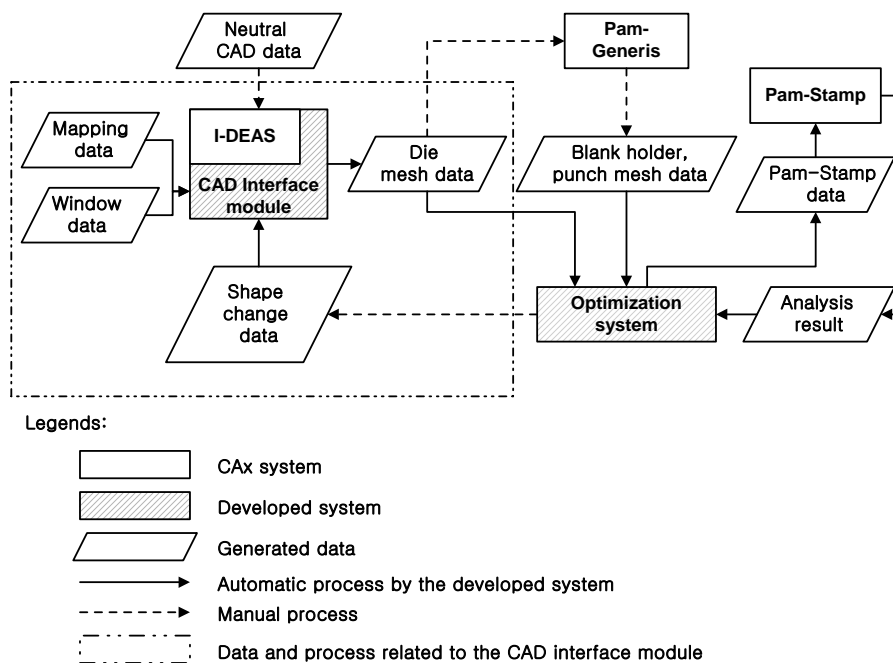


Figure 3: FE model generating system layout

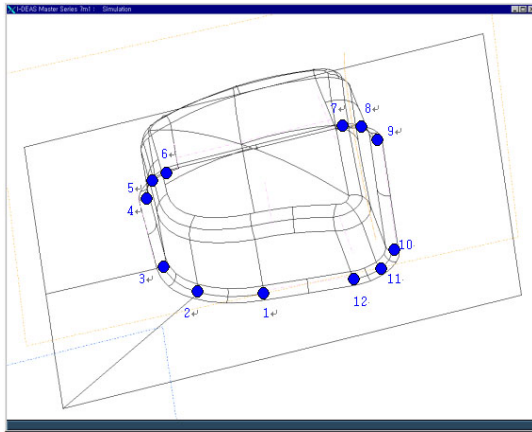


Figure 4: Shape modeling in I-DEAS™

Generation of CAD Models

Geometric modeling methods for die shape with rounding features can vary with CAD systems. There are two kinds of rounding methods in I-DEAS™: the one is constant-radius rounding method and the other is variable-radius rounding method[7].

In variable-radius rounding method, different rounding radii can be given to different positions. In I-DEAS™ the variable-radius edge rounding operation requires two radii at starting and ending vertices of an edge as user input. Thus, if one want to change rounding radii at several points on an edge, it is necessary to split the edge into several ones. In the sample model shown in Figure 4, the edges at the corners are split into two. The IDs from 1 to 12 are assigned to the vertices on the die shoulder edges. Note that these IDs may not be coincident with the parameter IDs shown in Figure 2. The rounding features and modeling history are recorded in the database of I-DEAS™, and the rounding shape is modified afterward on the basis of this information.

Mesh Generation

Figure 5 illustrates the mesh generation process for the modified CAD model. This diagram represents a part of the whole process diagram shown in Figure 3. In this algorithm, two kinds of data is required to proceed optimization: the one is the data for mapping the IDs given to the vertices in Section 3.2 to the features of I-DEAS™, and the other is the data for window setting.

The algorithm for the automatic CAD/CAE model generation in the optimization process is illustrated in Figure 6. In this algorithm, the position IDs and their rounding radii are established newly and then a program written in DOS commands is executed. Our program generates macro commands of I-DEAS™ from the given data, and then executes them to generate CAD and CAE models automatically [7, 8].

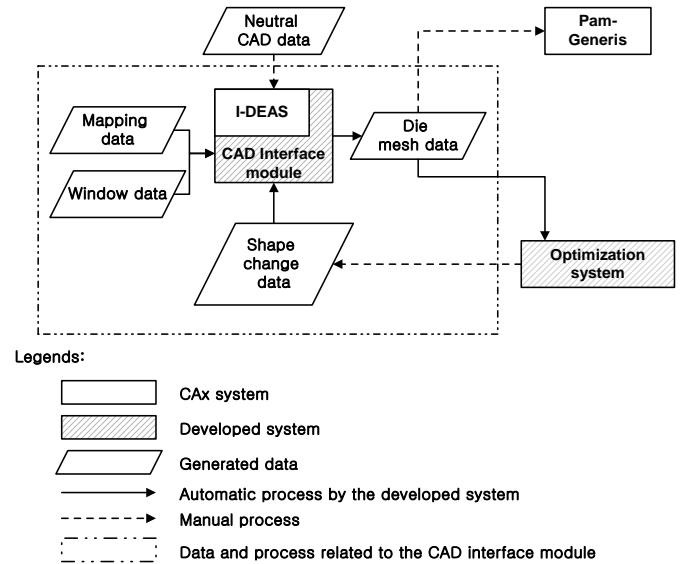


Figure 5: Diagram of modifying CAD model and generating FE model

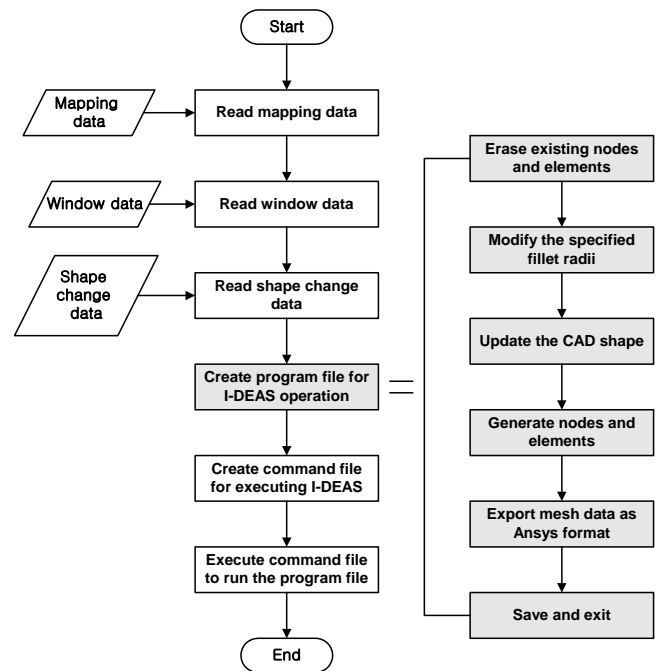


Figure 6: Algorithm of the interface with CAD system

RESULTS AND DISCUSSION

Initially, all the rounding radii for the die shoulder were set at 10 mm as illustrated in Figure 7(a), and their upper and lower limits of variation were set 5 mm and 15 mm respectively. The process was finished by a total 13 times of iterations, and the resultant shape of the die is represented in Figure 7(b). Table 2 shows the initial and final values of the rounding radii. As shown in Figure 7(b) and Table 2, the optimized die model has different

radii for edge rounding features. Figure 8 shows the distribution of thickness thinning rates before and after optimization process. As shown in Figure 8(a), the thinning rates at two bottom corners are so high that tear defects can occur at these areas. To prevent tears, the rounding radii P1 and P2 need to be increased. Figure 8(b) shows the thickness thinning rate after finishing the optimization process. The maximum rate was 33.3% at initial stage, but it was reduced to 29.6% finally. The optimization results proved that the rounding shape optimization approach proposed in this paper is effective to prevent forming defects.

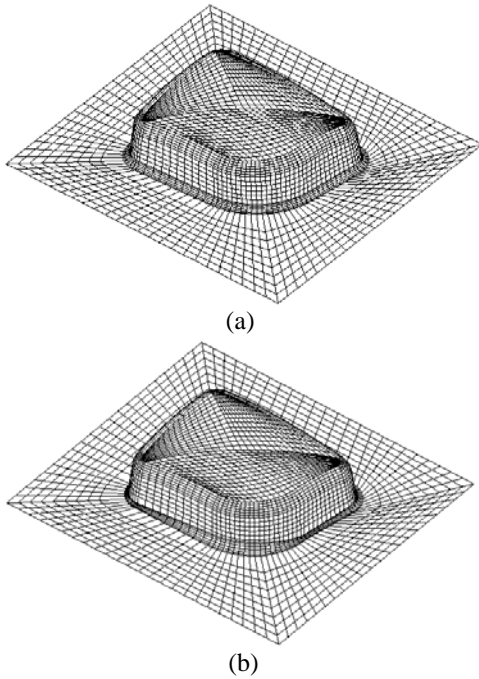


Figure 7: Comparison of die shoulder rounding mesh

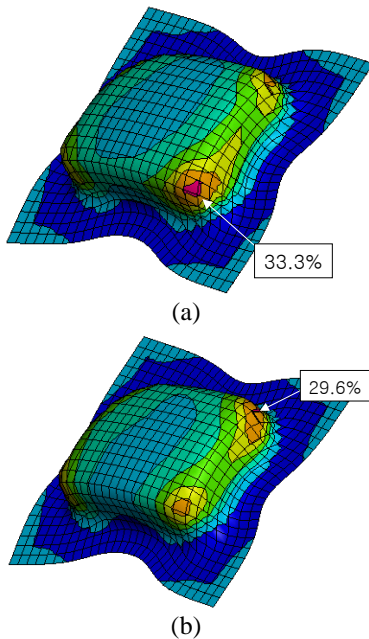


Figure 8: Thinning rate distribution of blank

Table 2: Initial and optimized rounding radius of die

Position	P0	P1	P2	P3	P4	P5	P6	P7	P8
Initial	10	10	10	10	10	10	10	10	10
Optimized	12.3	15	14.7	5.2	5.0	12.7	15	5.0	7.0

CONCLUSION

In this paper, we proposed a framework for the optimization of die rounding shape by integrating commercial CAD and CAE systems for die design and analysis. In this research, we developed an interface program that modify the die rounding shape in a CAD model and generate a finite element mesh model from the modified CAD model. Using this program, an optimization approach for stamping die rounding shape was implemented and applied to a sample automobile panel. By introducing this method, three steps of the current design-analysis iteration can be reduced to two steps: mesh modification and stamping process simulation, and the iterative optimization process can be performed without user interaction. Consequently, introduction of this method is expected to enhance the productivity for design and production of stamping tools so the manpower and facilities for CAD and CAE work can be largely saved.

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