Int J Adv Manuf Technol (2008) 35:1000–1013
DOI 10.1007/s00170-006-0785-y

ORIGINAL ARTICLE

Application of an integrated CAD/CAE/CAM system for stamping dies for automobiles

Bor-Tsuen Lin · Chun-Chih Kuo

Received: 2 March 2006 / Accepted: 4 September 2006 / Published online: 17 November 2006

Abstract The globalization and competition in the automobile industry makes it necessary to reduce the time spent on product development. Therefore, computer aided product development has become one of the most important techniques in the automobile industry. According to the concurrent engineering concept, an integrated CAD/CAE/CAM system for automobile stamping die development is established. The system is based on 3D surface construction CAD software STRIM, CAD/CAE software CATIA, stamping formability analysis software DYNAFORM, CAM software CADCEUS, a stamping design knowledge-based system, and a product database. This paper uses the development of trunk lid outer panels as an example to showcase the power of the system, in which the different development stages can be performed simultaneously. The system can greatly reduce the development time and cost, improve the product quality, and push products into the market in a relatively short time.

Keywords Integration · CAD/CAE/CAM · Concurrent engineering · Stamping die · Automobile · Drawing die

B.-T. Lin · C.-C. Kuo
Department of Mechanical and Automation Engineering,
National Kaohsiung First University of Science and Technology,
2 Juoyue Rd, Nantz District,
Kaohsiung, Taiwan, Republic of China

B.-T. Lin (✉)
Department of Mechanical and Automation Engineering,
National Kaohsiung First University of Science and Technology,
1 University Road, Yenchao,
Kaohsiung, 824 Taiwan, Republic of China
e-mail: bt_lin@ccms.nkfust.edu.tw

1 Introduction

Since stamping parts have considerable potential because of their competitive productivity and performance, they have been widely used in the automotive industry. However, the manufacturing industry has three major goals: to improve product quality, to reduce development cost, and to reduce the time spent on development. In order to achieve these goals, we need to bring in new technologies.

From the manufacturing viewpoint, the major requirement for most applications of sheet metal is good formability [1]. Given that part surfaces have become more and more complex and sharp-edged, we need to take advantage of formability analysis to understand their stamping properties. In 1963, Keeler and Backofen [2] introduced the concept of forming limit diagrams (FLDs). They analyzed the shape and size for an etched circle-grid of sheet metal after it had been stamped. This technique has been widely used in sheet metal formability analysis since then. Recently, software that uses a finite element method has been used to analyze and simulate sheet metal formability. Chen and Liu [3] combined circle-grid analysis with formability analysis to identify an optimal die face, so that the split defect at the drawn-cup wall in the rear floor panel could be avoided. Makinouchi [4] used formability analysis software to analyze four stamping parts—fenders, trunk lid outer panels, side frame outer panels, and tire disk wheels—and to predict their blank geometry, springback, sheet thickness, residual stress, and common defects after stamping. Bigot et al. [5] developed a methodology to validate the modeling of an aluminum forming process based on dimensional characterization and finite element comparison. Taking advantage of artificial neural network, knowledge based systems and finite element analysis, Pilani et al. [6] proposed a method for automatically generating an optimal die face design based on die face formability parameters.

Since die structures are becoming more and more complex and large-sized, we must use a solid model in die design to avoid any potential interference among the various components. Moreover, the solid model can be used for building dissolve models and estimating the fragile section of die structures. Therefore, it is necessary to use a 3D CAD/CAE/CAM system to build solid models, to develop CNC tooling path programs, and to analyze the stress of die structures when developing stamping dies. Nahm and Ishikawa [7] utilized the set-based design approach with the parametric modeling technique to handle the uncertainties that are intrinsic at early stages of the design. Park et al. [8] combined a CAD/CAM system with a knowledge-based system to develop deep drawing dies of the motor housing. Cheng et al. [9] used Visual C++ programming to create CAD software for the conceptual design of the scroll compressor, and fabricate a real orbiting scroll part on a CNC machining center.

The globalization and competition in the automotive industry makes it necessary to reduce the time spent on product development. Networks are widely used nowadays. As a result, Kao and Lin [10] designed a system that uses a local area network and the Internet to allow two geographically dispersed CAD/CAM users to simultaneously work on the development of products. Kong et al. [11] developed an Internet-based collaboration system for a press die design process for automobile manufacturers to shear design models and analysis results. Moreover, an integrated CAD/CAE/CAM system can tremendously improve productivity. Xu and Wang [12] used the multi-model technology and an integrated CAD/CAE/CAM system to develop cylinder head. Yue et al. [13] took advantage of the concurrent engineering concept and developed an integrated CAD/CAE/CAM system to develop die casting dies for water pumps, which successfully reduce the development time and cost, and improve product quality. Ferreira [14] developed an integrated CAD/RP/FEA system to improve the manufacturing process for Zn casting.

This paper illustrates an integrated CAD/CAE/CAM system for designing stamping dies of trunk lid outer panels for automobiles using concurrent engineering (CE).

2 Procedures for developing stamping dies for automobiles

Once receiving the surface model of a stamping part from an automobile manufacturer, the die manufacturer initializes the development process, which is shown in Fig. 1.

Die face design is a process that uses CAD software to create 3D die faces, which include stamping part surfaces, addendums, drawbeads and binder faces, and analyzes their stamping properties using formability analyzing software. Taking possible common defects into consideration, designers keep modifying the 3D surfaces until they obtain an optimal drawing die face, which will be used in designing dies and designing NC programs for processing die faces.

Layout diagram design is the process of developing the die layout diagram based on its surface model, which includes the following sub-tasks: identifying the central reference point, identifying the press direction, identifying the responsibilities of each process, designing drawing die faces, suggesting die height and indicating press lines.

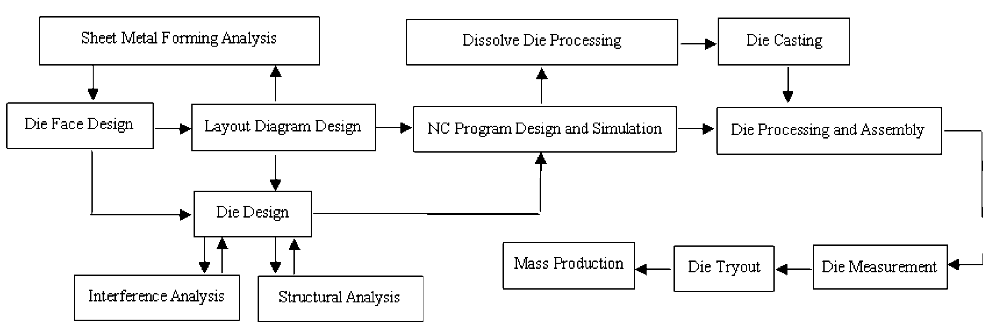
Since automotive stamping dies can be very large in size, they are processed by casting in order to minimize their weight and cost. 3D CAD/CAE software must be used to design the solid model to avoid any potential interference among various components, which includes cavity, punch, strengthened ribs, functional units and/or standard parts for upper and lower die sets, and blank-holder (BH).

After the die design process is finished, designers will perform motion and interference analysis on the 3D solid models and modify them if any problem is identified. Moreover, the stamping force is very large, modification and enhancement should be made to the die structural models where necessary through structural analysis.

Die manufacture includes dissolve dies manufacture, die dimension manufacture and die face manufacture. Dissolve dies are needed because die bodies are processed by casting. After identifying the information needed to construct 3D solid models, designers should develop NC tooling path programs to make dissolve dies using CNC machines. Then, the die bodies are cast through dissolve dies.

Die dimension manufacture is responsible for making all reference planes and holes, such as die base planes, guiding planes, stopper planes, assembling planes, positioning holes

Fig. 1 A development flowchart for stamping dies



and bolt holes. Die face manufacture generates all surfaces that will be completed in all subsequent sub-tasks. Designers use 3D CAM software to design tooling paths, including roughing, finishing, and corner finishing paths. Moreover, cutting simulation needs to be conducted to ensure the feasibility of the process. After the tooling paths have been identified, they will be posted into NC code to allow further processing by CNC machines.

When the dies have been manufactured and assembled, CMM (coordinate measuring machines) will measure the dimensions of the dies. If no faults are found, die tryouts will be produced. If the tryouts meet all requirements and specifications, mass production ensues.

3 The integrated CAD/CAE/CAM systems

Figure 2 shows the scheme of the integrated CAD/CAE/CAM system for stamping dies. This system includes a set of CAD die face design software, a set of stamping formability analyzing software, a set of CAD/CAE software, a set of CAM software, a stamping die design knowledge-based system, and a product database.

Die face design is the process of designing various supporting surfaces around the stamping part surfaces. These supporting surfaces are not part of the stamping part surfaces. Therefore, the die manufacturer is responsible for the die face design. In order to ensure consistency between the stamping part's surfaces and its supporting surfaces, specialized surface design CAD software must be used. Commonly used commercial software includes Icem Surf by Icem, STRIM by SGI, and CATIA by Dassault.

The surfaces of automotive parts are very complex and sharp-edged. Their formability cannot be predicted using previous experience. In order to ensure product quality, designers need to perform formability analysis on die faces before designing stamping die. Currently, this kind of software includes DYNAFORM by ETA, PAM-STAMP by EDS, and AUTOFORM by AFE.

Automotive stamping die structures include structural subcomponents, such as punch, cavity, strengthened ribs, functional units, and cam mechanisms, which are used to change the stamping direction and reduce die sizes. The die faces of punch and cavity are made up of thousands of surfaces. These components also make the design job extremely complex. When designing layout diagrams designers use plane diagrams to illustrate layouts of dies. When designing dies, designers use solid models to construct dies that are identical to real dies. Moreover, designers use motion and interference analysis to avoid any potential interference among various components. In the meantime, structural analysis is performed to understand their stresses and strains. Related software that is available in the market includes CATIA by Dassault, PRO/ENGINEER by PTC, and UNIGRAPHICS NX by EDS.

Due to the complex structure of automotive stamping dies, CNC machines should be used to manufacture stamping dies. Therefore, CAM software should be able to assist designers to generate tooling paths and provide cutting simulation. There are many CAM software packages

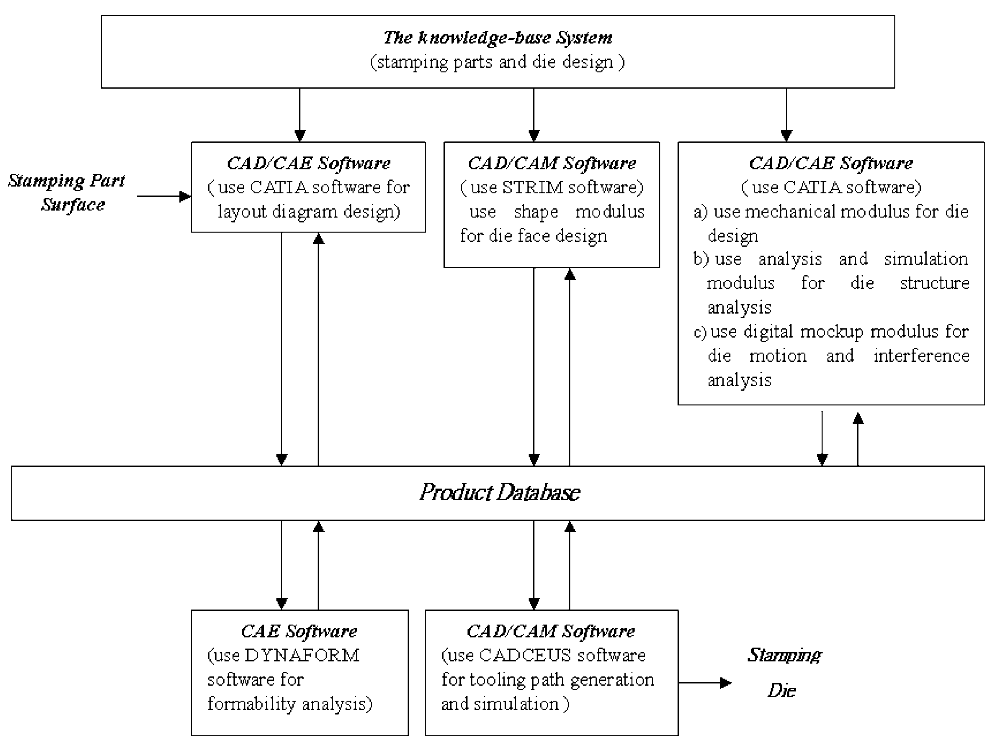


Fig. 2 The general scheme of the integrated CAD/CAE/CAM system of stamping product

that can support the aforementioned features, including POWERMILL by DELCAM and CADCEUS by UNISYS.

The construction of a stamping design knowledge-based system includes layout design and die design. The layout design includes the empirical formula for surface forming parameters, such as the thickness of sheets, die clearances, fillets radii and spring backs, and material parameters, such as modulus of elasticity, strain-hardening indices and anisotropy. The die design includes the design procedures of designing dies, and design criteria and design standards of each component and standard part.

Information that is needed throughout the process is stored in the product database, which can be accessed by all software in the system via the local network. In addition, in order to allow users to accurately and efficiently access data, all information is stored in a structured database and includes detailed information, including file names, versions, dates, and formats.

In the system, all the CAD/CAE/CAM software and a stamping design knowledge-based system were installed on the personal computers with a Pentium 4 3.4 GHz CPU, 1024 MB RAM, 128 MB graphics, and Windows XP operating system. The product database was built on the IBM server with a Pentium 3 1.0 GHz CPU, 1024 MB RAM, 128 MB graphics, and Windows NT operating system. The network connection is a 1 GB LAN (local area network).

In this paper, we use the trunk lid outer panel scaled 1/4 as an example to illustrate how to develop stamping dies. We use STRIM 100 to construct 3D surfaces for die faces. DYNAFORM 5.1 is used to perform formability analysis. CATIA V5 R13 is used to conduct die layout diagram design, die design, motion and interference analysis, and structural analysis. We use CADCEUS V5 R1 for tooling path generation and simulation, where NC programs are obtained. CNC machines use these NC programs to manufacture dies. At the same time, a stamping die design knowledge-based system is used to assist the layout design and 3D die design. Since all CAD/CAE/CAM software accepts IGES formats, we use them as communication formats between those software and the product database. Furthermore, the same 3D solid model is used throughout the entire development process, where different development stages can be conducted simultaneously. Therefore, the development time is fundamentally reduced.

4 The application of an integrated CAD/CAE/CAM system

4.1 Layout design

The layout design includes the die face design and the layout diagram design. The layout design process is shown in Fig. 3. The die face design is intended to design supporting surfaces for the stamping part surfaces. The purpose of this process is to improve the formability of the

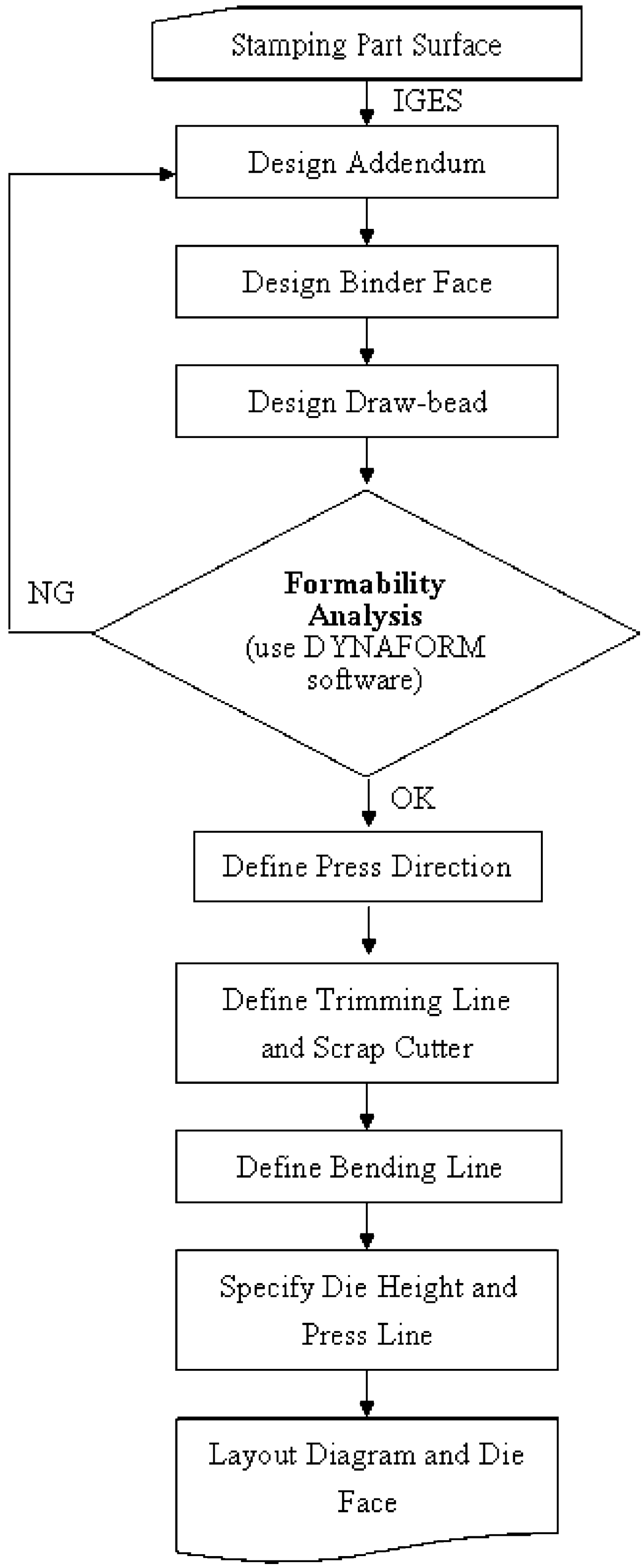


Fig. 3 The process of layout design

stamping part surfaces and to avoid stamping defects. The layout diagram design is intended to plan and identify the procedures and standards for the development process, which serve as the basis of the die development. The final design diagram is drawn using appropriate scales.

4.1.1 Die face design

The trunk lid outer panel has large flat surfaces surrounded by an edge with sharp corners. Common defects include surface deflection, poor denting resistance [3], and surface bulging, as shown in Fig. 4. Therefore, die face design becomes very important in the layout design. Die face design involves importing part surfaces into STRIM software using IGES format files, then die faces can be developed based on the stamping design knowledge-based system. Die face design includes addendum design, binder face design and draw bead design, as shown in Fig. 5. Addendum is designed to assist shaping and improve formability through equalizing cross section lengths of stamping part surfaces plus addendum in vertical parallels. At the same time, addendum is also designed for forward trimming for part profiles before their bending. Binder face is used to hold blanks to avoid wrinkle before feeding into drawing cavities. Generally, its shape is made by offset and extending profile of stamping part surface. Draw bead design is used to control blanks to be evenly fed into drawing cavities to elude any defects through changing its locations, lengths and cross sections. The resulting die face model will be imported into DYNAFORM using IGES files to have a formability analysis performed. This process will determine an optimal die face model.

4.1.2 Layout diagram design

Layout diagram design is the process of using CATIA software to develop a die layout diagram. The part surface, which is obtained from the vehicle manufacturer, usually

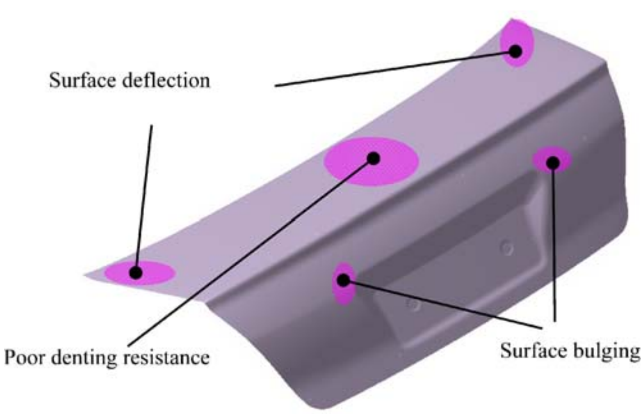


Fig. 4 The common forming defects of trunk lid outer panel

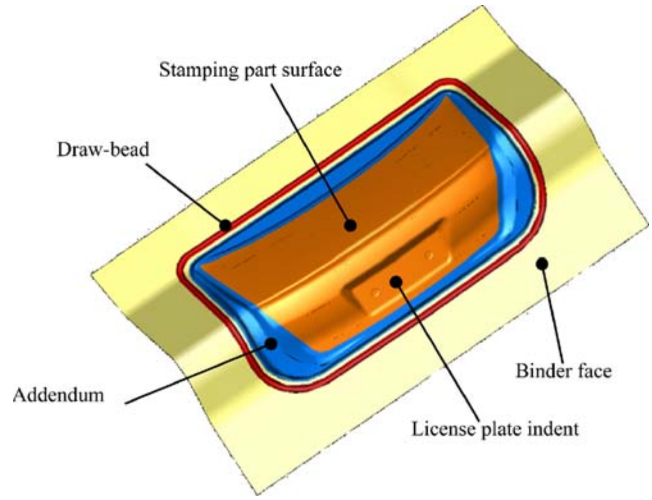


Fig. 5 The due face of trunk lid outer panel

uses vehicle-based coordinates and perspectives. In order to facilitate the die development tasks, we need to convert the vehicle-based coordinates and perspectives into stamping die-based coordinates and perspectives. The die center should be close to the part center. The press direction is arranged to shorten stamping stroke and no stamping shadow occurs. Moreover, the process for developing trunk lid outer panels includes drawing, trimming and punching, and flanging.

Then, trimming lines, and amount, positions and lengths of the scrap cutters are designated. Finally, we need to specify the die height, and specify the production press line.

4.2 Formability analysis

In the layout design stage, we perform the formability analysis on the 3D drawing die face using DYNAFORM. In order to ensure the success of the formability analysis, users must be able to not only feed the system with models and parameters that can faithfully reflect the actual forming process, but also accurately interpret the result and provide recommendations. The result of the analysis will be used to modify the die face model to get an optimal die face.

When performing formability analysis on trunk lid outer panels, we treat cavities, punches, and blank-holders as rigid bodies. The blanks are represented by their neutral planes. In addition, the example used in this paper is eudipleural. In order to save computation time, we only perform analysis on half of the model.

The procedure of formability analysis is shown in Fig. 6. The starting process of the formability analysis is to import an IGES format file for half of the die face model and punch open line into DYNAFORM software. Then, the imported surface will be meshed using shell elements to construct the mesh models of drawing cavities, drawing

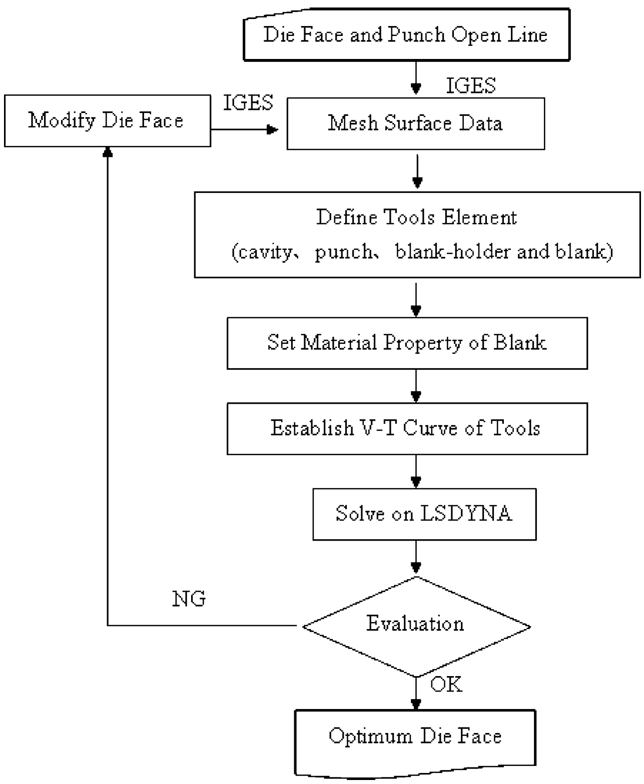


Fig. 6 The process of formability analysis

punches, and BHs. A mesh model of blanks will also be constructed based on the dimensions of the blanks. Contact elements need to be specified on blanks, drawing cavities, drawing punches, and BHs. In addition, equivalent draw beads and their forces must be specified on the central line of the draw beads. The simulated model is shown in Fig. 7.

Blank material is SPCC. Forming parameters and material properties need to be specified, which include sheet thickness (0.5 mm), the friction coefficient between blanks and dies (0.14), mass density (7800 kg/m^3), Young's ratio (207 MPa), yield strength (176 MPa), tensile strength (295 MPa), an anisotropic factor ($R=R_{0°}=R_{45°}=R_{90°}=1.7$), a strain hardening exponent (n=0.23), and the plastic stress-strain curve.

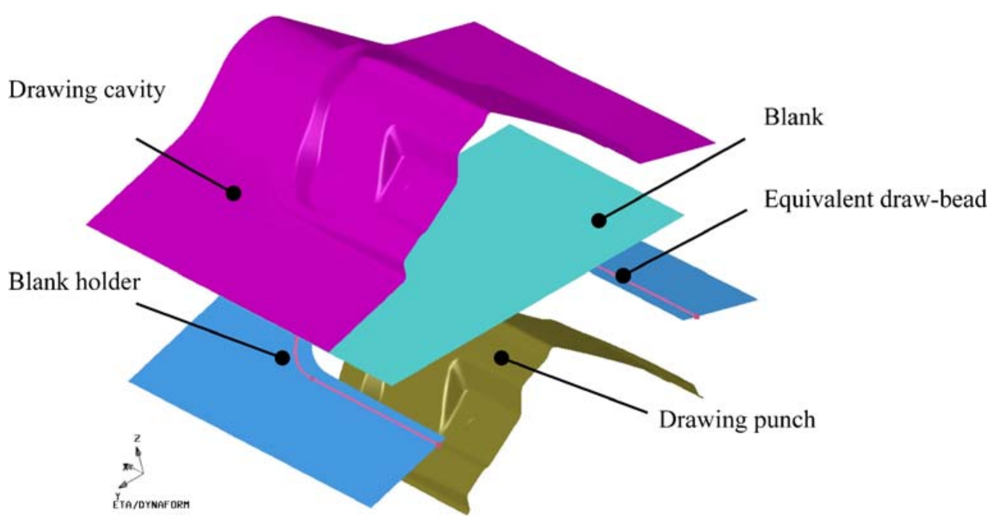
The drawing die is a single action press die. In performing a motion simulation, we need to identify the motion path: the upper die starts to move downwards to make the blank touch the BH, and the punch starts to move upwards to shape the blank. The total distance of the motion path is 300 mm. The stamping speed is 2,000 mm/sec. The result of the analysis is shown in Fig. 8.

Taking the result shown in Fig. 8 as an example, the guidelines of the formability analysis are as follows: to avoid a drawing break, the thinning ratio of the product form must be within 80 percent of the elongation ratio of the blank material; no crack or wrinkle is permitted in the product form; crack or wrinkle shall be minimized in the addendum, draw-bead and binder face; the stress of the product form shall be stronger than the yield strength of the blanking material to ensure that the stamping part has sufficient dent-resisting strength; and during the drawing process, the blank points at which the highest point and lowest point of the die touch shall be within their feature fillets radii to avoid blurring the feature.

4.3 Die design

Since stamping dies of car body panel can be very large in size, they are processed by casting in order to minimize their weight and cost. In addition, cam mechanisms are used in dies for different press directions to reduce the stamping processes and cost. Therefore, the die design can be very complex. Dies used in this paper include drawing dies, trimming dies, and flanging dies. A 3D solid model, which is identical to real products, is used in die design to avoid any interference and to facilitate design and modification, which fundamentally reduces the design time.

Fig. 7 The simulated model of trunk lid outer panel



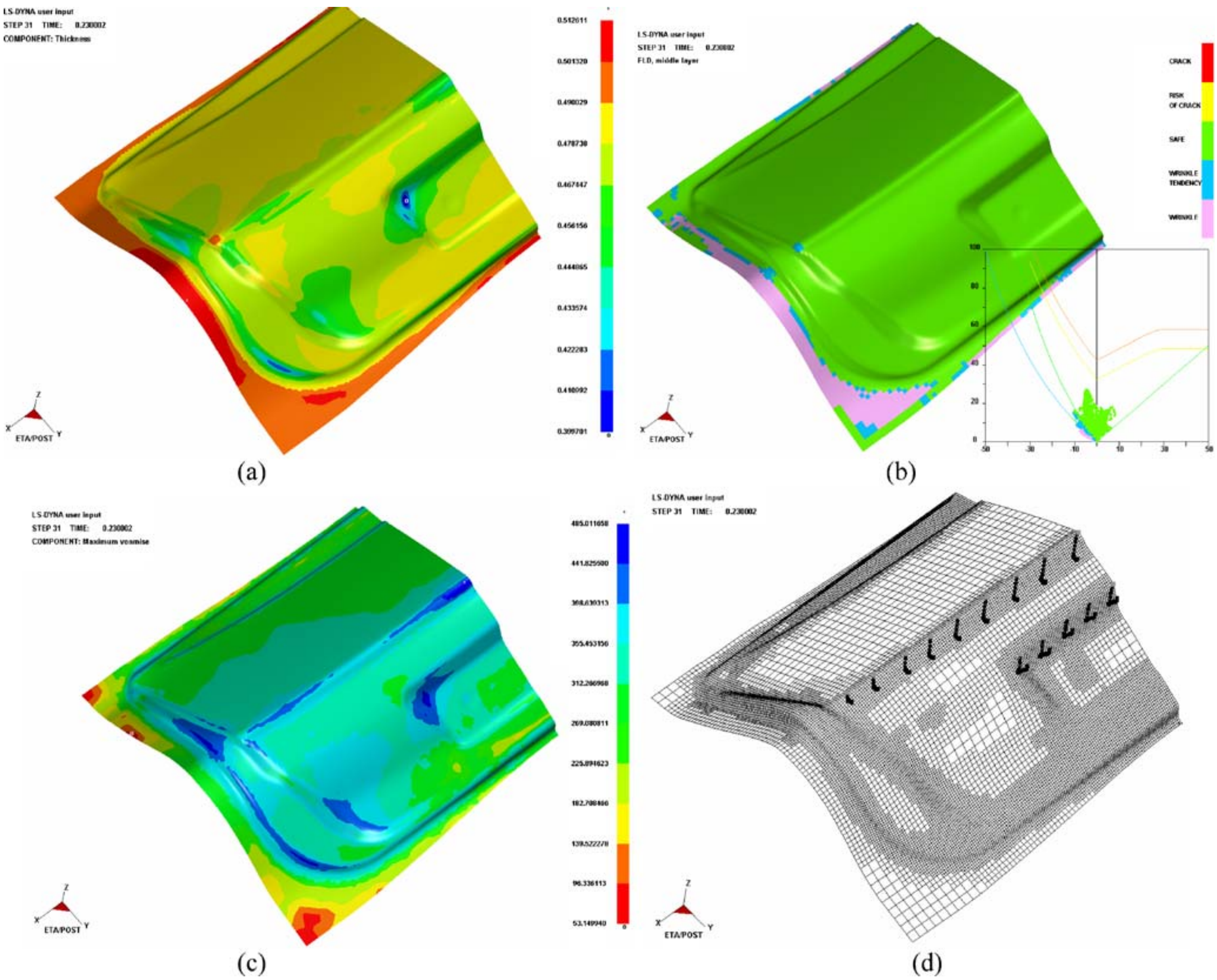


Fig. 8 Formability analysis results. **a** Thickness distribution. **b** FLD distribution. **c** von Mises stress distribution. **d** Traces of touched points

The design processes of each one of the aforementioned dies are based on the procedure outlines by the stamping die design knowledge-based system, as shown in Fig. 9.

Initial design: designers need to gather a minimum set of information about the die, including die faces, punch open lines (POL) and die layout diagram. In the die layout diagram, we can get blank sizes, drawing strokes, press machine specifications, die height, feed level, cushion pin stroke, machine center, die center and so on.

Skeleton design: the main responsibility of skeleton design is to identify the main structure of the die, including sizes of upper dies, lower dies and BHs, thickness of die faces, avoid structure, layout and thickness of ribs, positions and sizes of the guide box, and so on.

Functional unit design: functional unit design is the process of designing various functional units that are used to support die working. These functional units include U grooves, KEY grooves, hooks, and so on.

Standard parts design: standard parts, such as sliding boards, gas springs, and springs, are also used to support die working. These standard parts are available in the market with different sizes.

In the meantime, the designs of skeleton, functional units and standard parts are also based on the criteria and standards by the stamping die design knowledge-based system.

4.3.1 Drawing die design

Drawing dies are used to shape the parts. In order to obtain the desired shape, we need very strong forming force, which makes it necessary to evaluate its structural stresses. The structure of drawing dies includes: drawing punch, drawing cavity, strengthened ribs, guiding plane, hooks, positioning system, KEY groove, U groove, and/or blank positioning unit for upper and lower die set and blanks

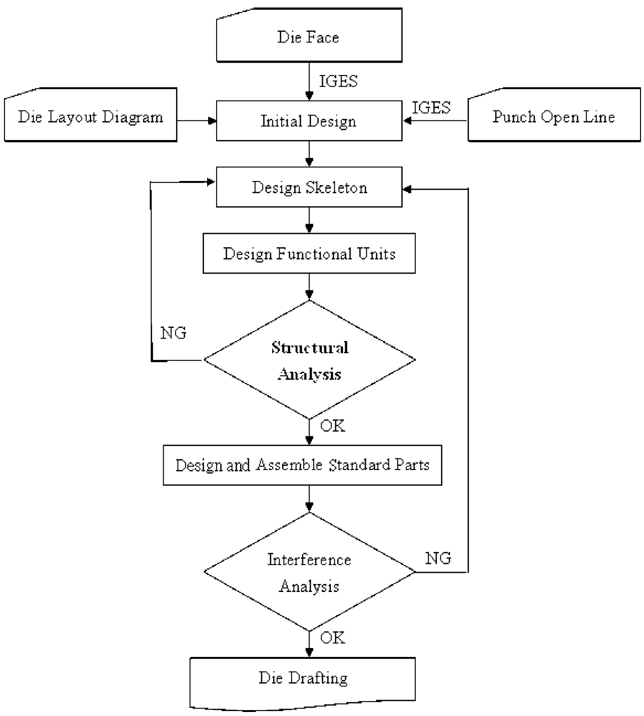


Fig. 9 The process of die design

holder. The selection and assembly of the standard parts for drawing dies include springs, screws, pins and guide plates. Figure 10 shows a 3D solid design model of the drawing die.

4.3.2 Trimming die design

Trimming dies are used to cut blanks. Since scraps will not be removed automatically, we need to add additional scrap

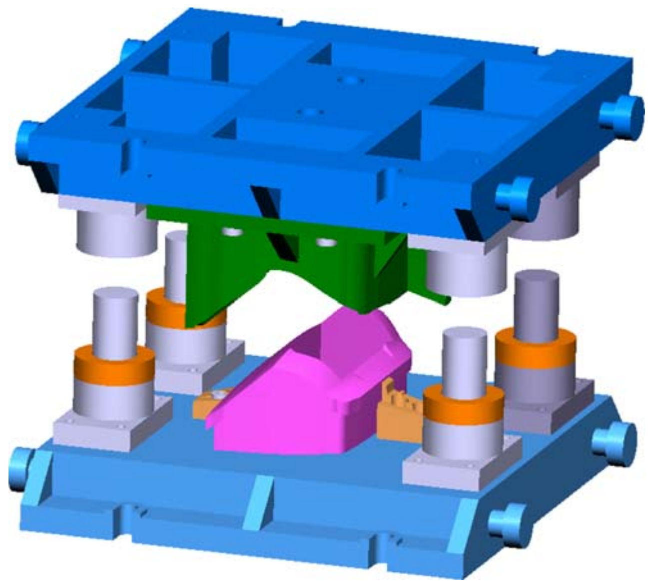


Fig. 11 3D solid model of trimming die

cutters where necessary. The structure of trimming dies includes strengthened ribs, upper and lower cutters, upper and lower scrap cutters, pad, guiding plane, hooks, position systems, KEY groove and/or U groove for the upper and lower die sets. The selection and assembly of the standard parts for trimming dies include springs, screws, pins and guide plates. A 3D solid design model of the trimming die is shown in Fig. 11.

4.3.3 Flanging die design

Flanging dies are used to form a 90-degree flange on the edge of the parts. Since there is a near 90-degree shape on the truck lid outer panel, in addition to the vertical bending,

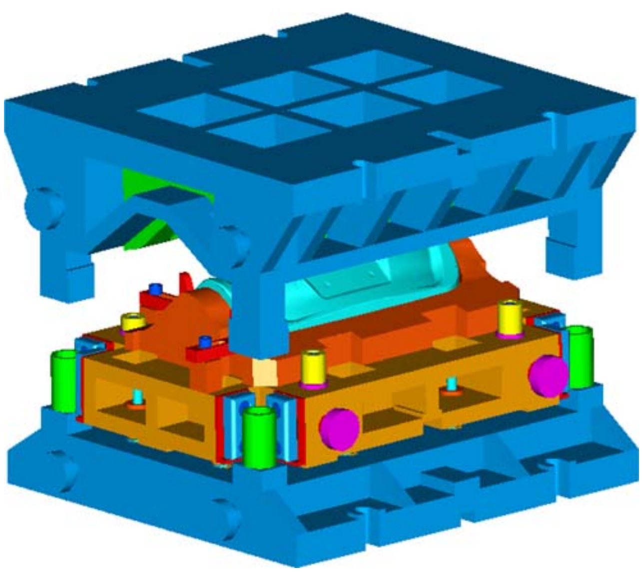


Fig. 10 3D solid model of drawing die

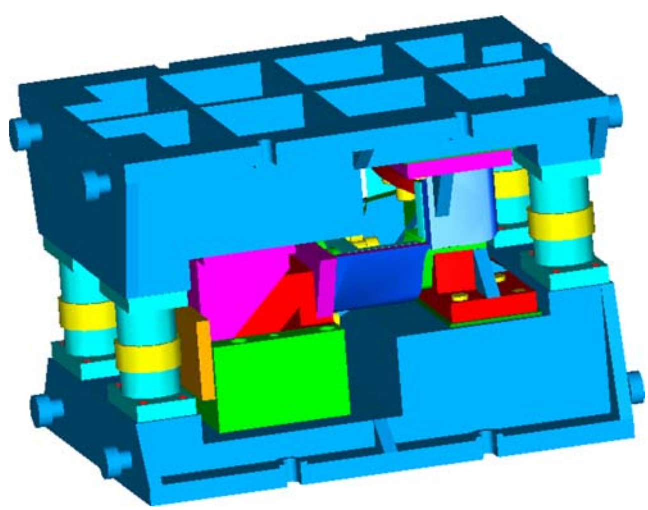


Fig. 12 3D solid model of flanging die

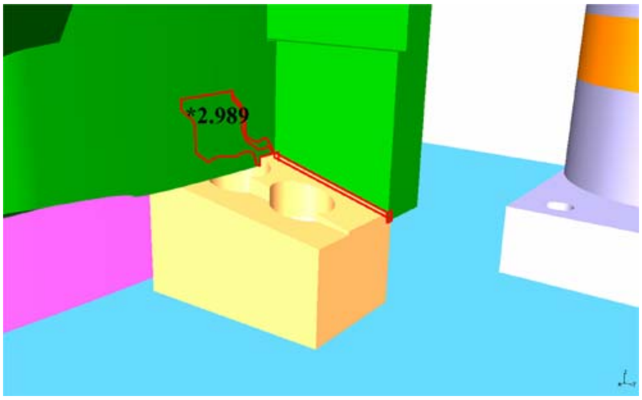


Fig. 13 Interference areas of the trimming die

we need to use a cam mechanism to perform a horizontal bending on the part. The structure of flanging dies includes strengthened ribs, upper and lower wipers, a pad, guiding plane, hooks, positioning systems, KEY grooves, and/or U grooves for the upper and lower die sets. The selection and assembly of the standard parts for flanging dies include springs, screws, pins and guide plates. A solid design model of the flanging die is developed as shown in Fig. 12.

4.3.4 Interference and structural analyses

The die structure shall have sufficient strength, and no interference is allowed among the various components. After the solid models have been developed, designers use the CATIA digital mockup module to perform motion and interference analysis on the models, as shown in Fig. 13. After performing this analysis, any potential interference can be identified and avoided. In addition, since the stamping force is very large, it is necessary to perform a structural analysis on the models. This analysis is performed using CATIA analysis and simulation modulus. In structural analysis, designers apply forming forces obtained from the formability analysis and the die's boundary conditions to determine the stress. Figure 14 shows the stress distribution for the blank holder of the drawing die. The evaluation criterion of the structure analysis is that the stress of the die must be less than the yield strength of the die material divided by the safety factor.

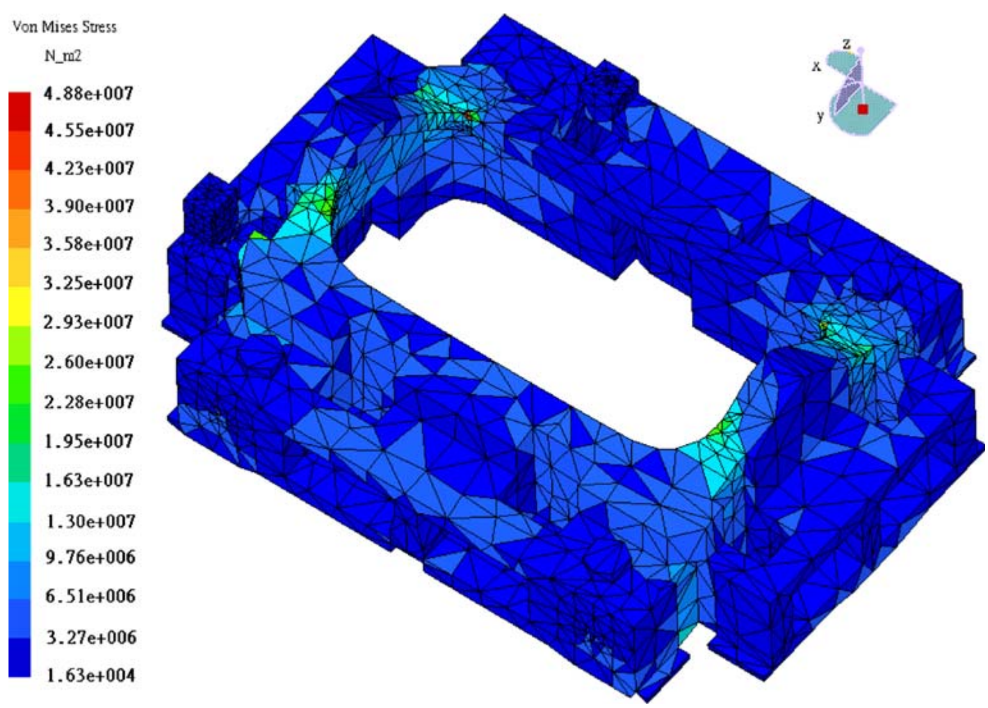
4.4 Die manufacture

The die manufacture includes the dissolve die manufacture, the die face manufacture and the die dimension manufacture. The process of die manufacture is shown in Fig. 15.

4.4.1 Dissolve die manufacture

Since the stamping die used in this paper is processed using casting, dissolve dies must be used. Since shrink and distortion cannot be avoided when casting, the size of the dissolve die shall be larger than that of the actual die. For example, since the material of the die base is FC25, the size of the dissolve die shall be 0.8 percent larger than that of the die. As a result of possible distortion, extra space, with a minimum of 10 mm, shall be reserved for every

Fig. 14 Stress distribution for the blank holder of the drawing die



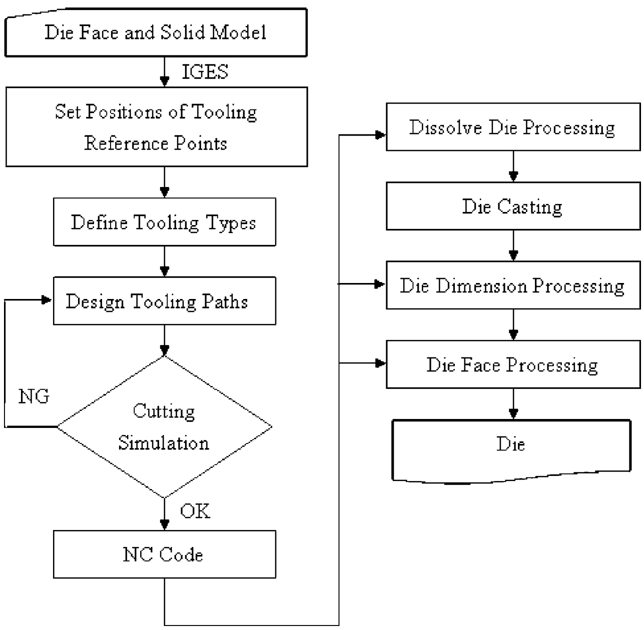


Fig. 15 The die manufacture process

processing location. The procedure for making dissolve dies is to use CADCEUS to develop an NC tooling path program for the dissolve dies. CNC machines use the NC codes to make dissolve dies, as shown in Fig. 16. The use of CNC machines successfully reduces the manufacture time and error rate, and improves the quality of the dies.

4.4.2 Die dimension manufacture

Die dimension manufacture is responsible for making all reference planes and holes. Die dimension processing also requires the die solid model to be fed into the CADCEUS software using the IGES format file. This process generates the tooling paths and specifies the type of cutter based on different processing types. At the same time, the lifting heights of the cutter must also be specified to avoid any contact with the die body. The guider plane is machined using the side mill in the vertical direction with even pitch to ensure its accuracy and flatness. When the tooling path design is finished, the CADCEUS software outputs the NC codes, which will be used by CNC machines.

4.4.3 Die face manufacture

Since the die face manufacture must be performed on a three-axis CNC machine, no undercutting is permitted on any surface. In order to achieve the desired precision, the processing path employs an equal-step approach. At the same time, the abrasion of the cutter must be taken into consideration when performing fine processing. Cutters shall be replaced using the ATC (automatic tool change) system when necessary.

The stamping die faces are fed into the CADCEUS software using IGES format files to develop NC tooling paths. Tooling path design requires a set of tooling conditions to be set, which include positions of tooling reference points, sizes of ball cutter, forms of tooling paths, rotational speed, feeding rate, and cutting pitch. In the meantime, the procedures of the process must also be identified, which include roughing, finishing, and corner finishing. Figure 17 shows the tooling path of the drawing punch. CNC machines use NC codes generated by CADCEUS to have the dies processed. In order to ensure the correctness of the tooling paths, a cutting simulation must be performed to identify any potential problems. Since the die surface processing is time consuming, ATC systems are used together with the CNC machines to ensure around-the-clock manufacturing without supervision, as shown in Fig. 18.

Fig. 16 The dissolve dies for drawing dies

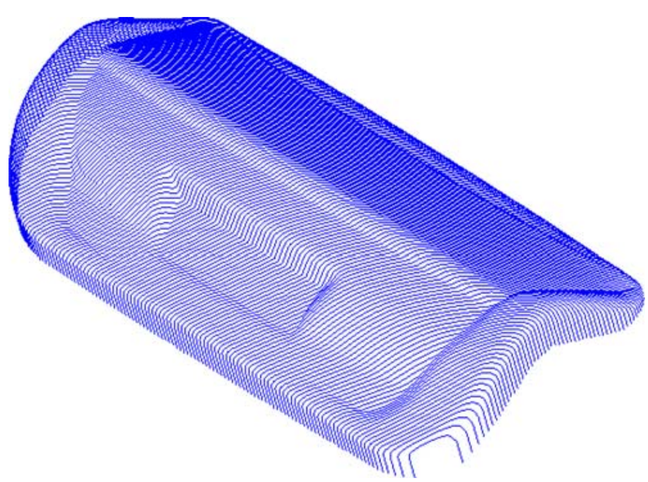


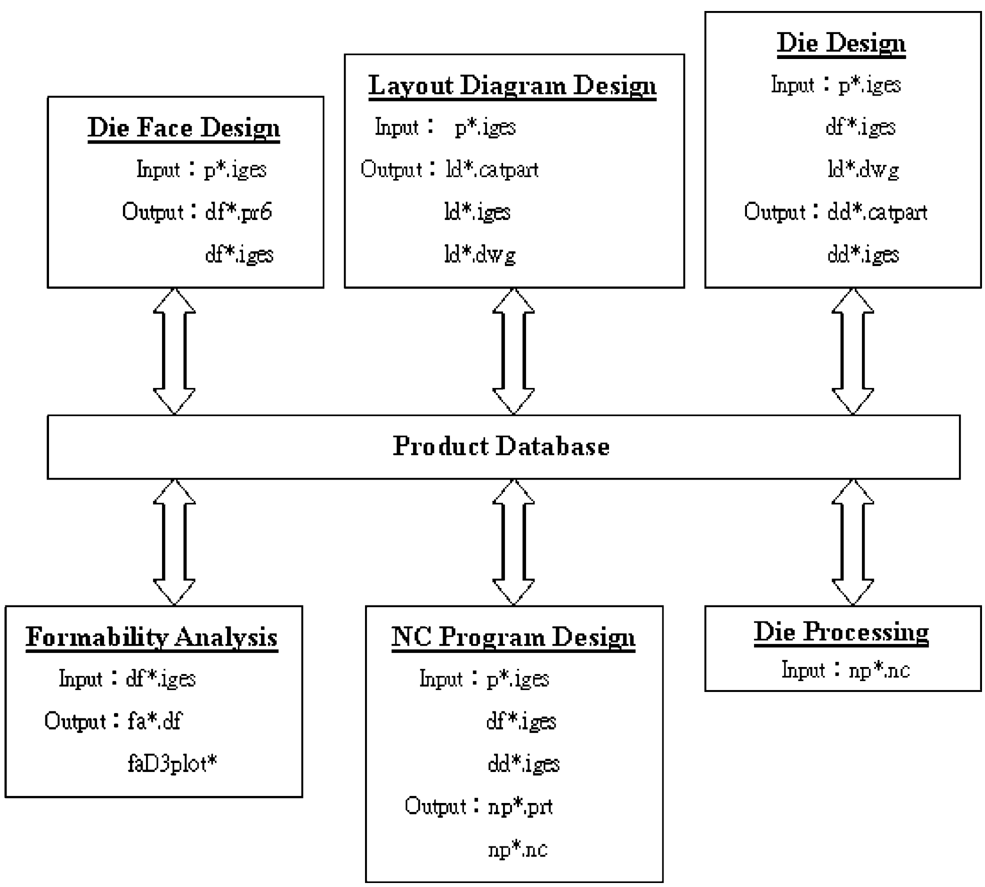
Fig. 17 Tooling path of the drawing punch

Fig. 18 CNC processing of the drawing punch

4.5 Building the database

A database is used in our system, which is organized in a tree structure. The root of a tree is a product, and branches of the tree comprise the procedures of process. As shown in Fig. 19, information is retrieved using the product name over a local network. Since files in IGES formats are acceptable by all CAD/CAE/CAM software, we use IGES format-based files to exchange information within our system. The layout diagram design uses CATIA software to get the product information in IGES format, and to achieve layout design and layout diagrams of the stamping die. In the die face design phase, STRIM software is used to read product information in IGES format, complete the die face design, and output the surface information of the drawing die. When performing the formability analysis, designers use DYNAFORM software to get the die face information in IGES format, perform formability analysis, and prepare an analysis report. In the die design stage, CATIA software is used to read product and die face information in IGES format, complete the 3D solid model design, the structure analysis, and the motion and interference analysis. At the end of this stage, we are able to obtain a 3D solid model design and reports on the results of the various analyses. CADCEUS software is used to get the 3D solid model and die face information in IGES format in the die manufacture phase. During this phase, designers perform tool path generation and simulation, and complete the NC code and the CNC operating sequence. All aforementioned information is saved in the database as soon as it becomes available.

Fig. 19 The communications of product information



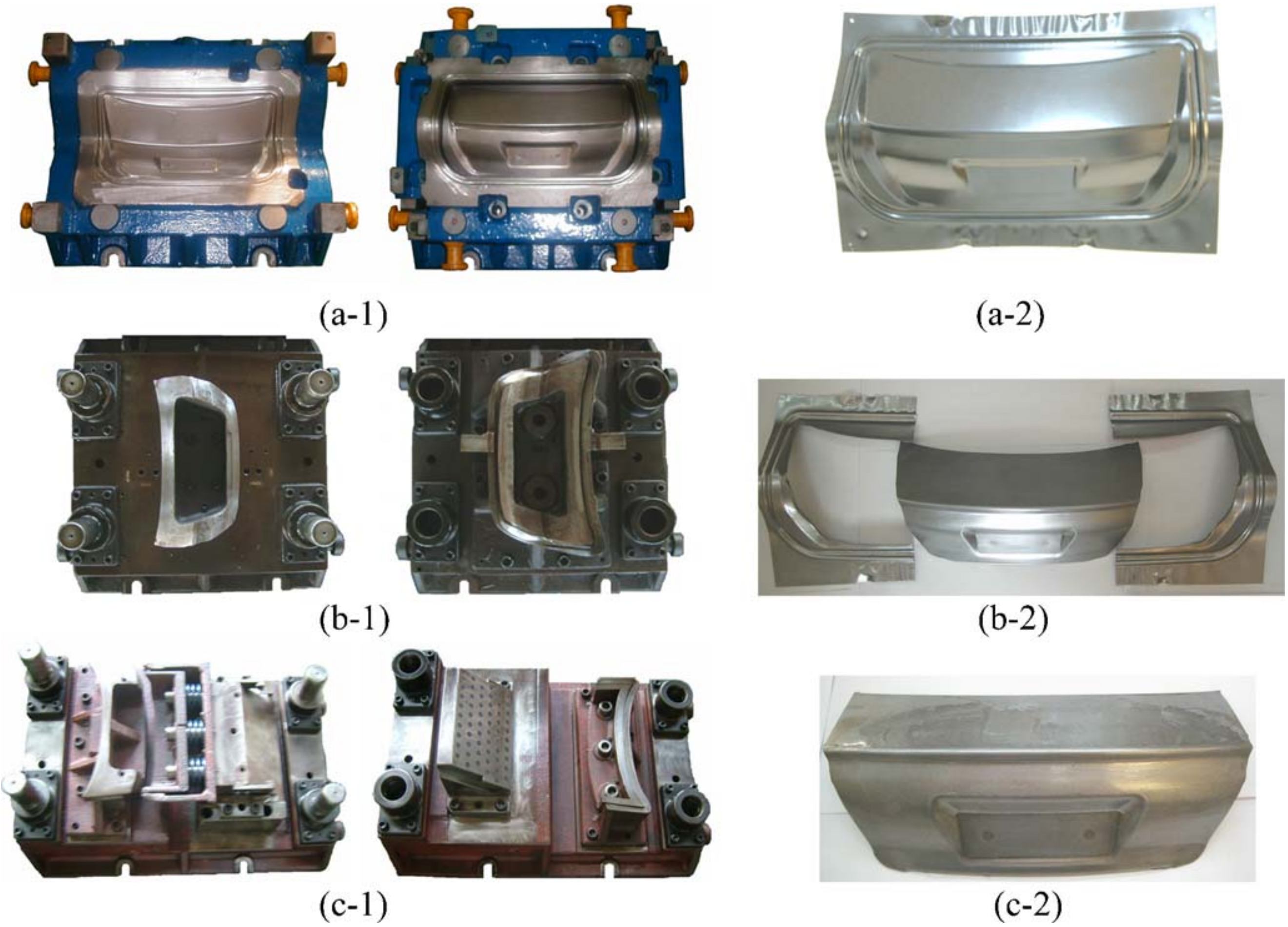


Fig. 20 Stamping dies and sample parts. **a**1 Drawing die. **a**2 Drawing sample. **b**1 Trimming die. **b**2 Trimming sample. **c**1 Flanging die. **c**2 Flanging sample

5 Results and discussion of the integrated system

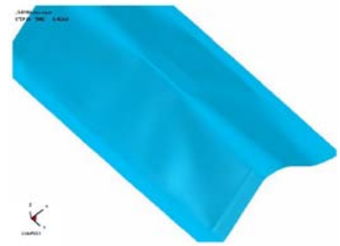
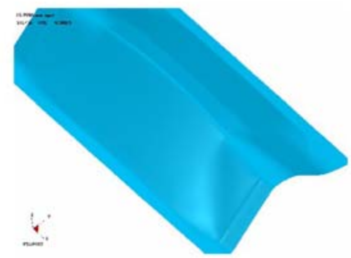
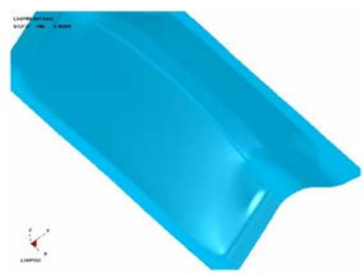
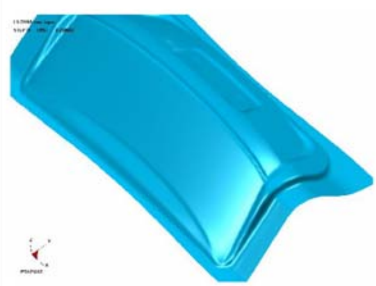
5.1 Results

As introduced in the previous sections, once the part surface is available, stamping die faces are constructed by STRIM. An optimal stamping die face is identified after a formability analysis is performed using DYNAFORM. In the layout diagram design, a die layout diagram is developed by CATIA based on the stamping die design knowledge-based system. All of the remaining sub-tasks are based on this die layout diagram. Solid models of stamping dies are constructed using CATIA based on the stamping die design knowledge-based system. The motion animation and interference analysis are performed on this model to find any potential interference. In the meantime, a structural analysis gives designers a good understanding of the stress distribution of the die. NC programs are developed using CADCEUS based on the stamping die faces and the solid model. After NC programs have been developed, the cutting simulation is performed to find any potential problems. Since the entire development process uses the same part data in the database, the sub-tasks can be performed simultaneously. In addition, IGES format files are used to exchange information among CAD/CAE/CAM software and the product database. Figure 20 shows the result of the development.

5.2 Comparison between results from formability analysis and actual drawing samples

This paper uses formability analysis to avoid surface deflection, poor denting resistance, and surface bulging. As shown in Table 1a, no wrinkle occurs when the blank is tightly held between the blank-holder and upper die. Table 1b shows that ripple phenomena occur when the top of the punch touches the blanks. When the ripple phenomenon is serious, it will leave scars on the surface of the parts. As shown in Table 1c, the bulge phenomena come about when the bottom of the upper die set touches the blanks. When the bulge phenomenon is serious, it will leave surface bulging on the outside corner of the license plate indent. Table 1d shows that no defect is found on part surfaces except for the wrinkles found on the binder faces.

Table 1 Comparison of the forming procedures of drawing dies

		Analysis results	Sample parts
a	Holding situation		
b	10mm up		
c	5mm up		
d	Dead point		

6 Conclusions

This paper illustrates an integrated CAD/CAE/CAM system for stamping die development of trunk lid outer panels using a concurrent engineering approach. The system can greatly reduce the development time and cost, improve the product quality, and push products into the market in a relatively short time.

The surfaces of the stamping parts are very complex and sharp-edged. When designing die faces, an optimal die face can be identified after formability analysis is performed. This analysis can greatly reduce the die tryout time and forming failure rate.

The entire design process uses a solid model, which greatly reduces design time. This model will go through motion and interference analysis, as well as structural analysis to avoid any defects.

Acknowledgements This project is sponsored by the National Science Council of the Republic of China (contract number: NSC92-2511-S-327-001).

References

1. Wick C, Benedict JT, Veilleux RF (1984) Tool and manufacturing engineers handbook, vol 2, forming. Society of Manufacturing Engineers, Michigan
2. Keeler SP, Backofen WA (1963) Plastic instability and fracture in sheets stretched over rigid punches. Trans ASM 56:25–49
3. Chen FK, Liu JH (1995) Analysis of die designs for the stamping of an automobile rear floor panel. J Mater Process Technol 55:408–416
4. Makinouchi A (1996) Sheet metal forming simulation in industry. J Mater Process Technol 60:19–26
5. Bigot R, Leleu S, Martin P (2003) Forming machine qualification by analysis of manufactured parts geometry: application to aluminum forming process. Int J Adv Manuf Technol 21:476–482
6. Pilani R, Narasiman K, Maiti SK, Singh UP, Date PP (2000) A hybrid intelligent system approach for die design in sheet metal forming. Int J Adv Manuf Technol 16:370–375
7. Nahm YE, Ishikawa H (2006) A new 3D-CAD system for set-based parametric design. Int J Adv Manuf Technol 29:137–150
8. Park SB, Choi Y, Kim BM, Choi JC (1999) A CAD/CAM system for deep drawing dies in a simple-action press. J Mater Process Technol 87:258–265
9. Cheng K, Harrison DK, Jiang Z (2002) An integrated concurrent engineering approach to the design and manufacture of complex components. Int J Adv Manuf Technol 20:319–325
10. Kao YC, Lin CI (1998) Development of a collaborative CAD/CAM system. Robot Comput-Integr Manuf 14:55–68
11. Kong SH, Noh SD, Han YG, Kim G, Lee KI (2002) Internet-based collaboration system: press-die design process for automobile manufacture. Int J Adv Manuf Technol 20:701–708
12. Xu XY, Wang YY (2002) Multi-model technology and its application in the integration of CAD/CAM/CAE. J Mater Process Technol 129:563–567
13. Yue S, Wang G, Yin F, Wang Y, Yang J (2003) Application of an integrated CAD/CAE/CAM system for die casting dies. J Mater Process Technol 139:465–468
14. Ferreira JC (2005) A study of advanced die-casting technology integrating CAD/RP/FEA for Zn Castings. J Mater Process Technol, Online Nov. 24, pp 1–9