On the die face design for stamping an automotive engine hood

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Abstract. Since the engine hood is mainly manufactured in the drawing operation, the die addendum design is the key to the success of manufacturing a defect free product. In this study, the existing die addendum designs corresponding to those engine hoods were reviewed and the design parameters were constructed. The preliminary study was then performed to examine the influences of the stamping die angle, binder surface shape, and die open line shape on the defects occurred in the part. Based on the simulation results, the optimum design for the die addendum face was then investigated and a systematic design guideline was proposed. In order to validate the proposed design guideline, actual engine hoods were stamped according to the finite element analysis and the production part shapes, thickness distributions, and the stretch at the central region were compared with those obtained from the finite element simulations. The consistent agreement between the product parts and the simulation results confirms the validity of the design guideline proposed in the present study for stamping an engine hood.

1. Introduction

Die face design is regarded as top secret by every mold factory. This is done by experienced designers who initially carve out a required die face in plaster mold and then construct a needed digital model by reverse scanning. Such design method is deemed non-scientific. In the current relevant literatures of die face design applications, Chen and Liao [1] have used the finite element software PAM_STAMP to analyze the reason causing the fold defect in the forming of motorcycle fuel tank, and then analyzed the results and designed a die face model that will not create the fold defect. The actual finished product was then used to verify the simulation. Hillmann and Kubli [2] have used the parametric design approach to rapidly design a die face for the rear trunk fender, and then explored the optimal parameter of all addendum shapes. In engine hood forming, Qiu [3] et al. have explored the impact on sheet material shape towards stamping without changing the die face’s addendum shape, and further proposed the best sheet material appearance. Yao [4] et al. have utilized the swept, through curves mesh, blend, bridge surface and other functions of UG software to construct the addendum shape, and then parameterized the commonly used addendum section shape to ease designers in amending and constructing addendum sections rapidly. Firat [5] presented an engineering methodology for the structural assessment of the stamping tooling and the die-face designs during the sheet metal forming, and found that the relative advantages of the die-face distortions on the formability and springback deformations. Bhatt and Bush [6] construct an expert system to design the multi stage deep drawing process, and the system contains material properties and die geometry parameters.
All the above die face design literatures are trying to parameterize the currently commonly used addendum shapes and rapidly construct the required addendum styles. However, as there has been little research on design flow, so most die face styles are designed according to experiences. Therefore, this study will make a summary of the current familiar addendum styles to construct a digitized die face design by coordinating current considering problems during the design state with Die Maker functions found in CAE PAM-Stamp 2008 professional sheet metal forming simulation software.

2. A summary of engine hood’s addendum shape
The engine hood style varies depending on car models, but can be classified as fender side, light side, front side and windshield side as shown in Figure 1. There is no fixed addendum style but it can be summarized into several common addendum shapes, and their parameterized designs are shown in Figure 2 to Figure 5.

![Figure 1. Classification of feature-based engine hood styles](image1)

![Figure 2. Section features of addendum at front side](image2)

![Figure 3. Section features of addendum at light side](image3)
3. A study on die face design parameters

3.1. Load research device selection
Shown in Figure 6 is a load device used in this study, provided by Gordon Auto Body Parts Co., Ltd. As the car’s engine hood outer sheet material is dominated by SPCC soft steel sheet, so it was adopted as the material in this study. Shown in Figure 7 is SPCC material supplied by China Steel Corp., with a thickness of 0.7mm and featuring mechanical stretch property.

![Load device part](image)

**Figure 6.** Load device part

![True stress-strain curve of 0.7mm-thick SPCC material](image)

**Figure 7.** True stress-strain curve of 0.7mm-thick SPCC material

3.2. Stamping angle
The part with minimum drawing depth design usually comes in flat and gentle shape with no special ridge feature. As no obvious changes can be seen on such part, so no acute pulling phenomenon will happen during forming. Shown in Figure 8 is the relationship between part placing angle and die face.
3.3. Binder face design of close resemblance to part design
While designing the binder surface, it is necessary to consider the sheet metal conditions when it is being held by the pressure plate and upper die during stamping. So, we can adjust the binder face design according to the part design while designing as shown in Figure 9. This will avoid creating a big design variance on the binder surface and folding phenomenon when the die is holding the material.

![Figure 9. The section diagram of binder surface design while referring to the part design](image)

4. A study on engine hood addendum shape
From velocity analysis we know that after the sheet metal has passed through the lower die fillet, the material flow velocity on part surface will slow down greatly as shown in Figure 10. This is due to friction between die face and sheet metal, and restrain on lower die fillet causing flow stoppage when the sheet panel is affixed to the lower die. Although stretching still continues, but it only extends to the lateral n-finished sides of the sheet material. In order to achieve the hardening goal of finished surface, it is necessary to perform secondary stretching of addendum shape. Therefore, we need to use a summarized and simplified addendum shape to find out the essential parameters that would affect the sheet metal to flow once again.

![Figure 10. The velocity distribution diagram when the sheet metal passes through the lower die fillet](image)

4.1. The engine hood addendum shape on the windshield side
From the addendum section shown in Figure 11, we know that the central indent (H) will decide the stretching extent; and from the forming process shown in Figure 12, we know that after the sheet material...
has passed through the lower die fillet, the sheet material between the pressure plate and lower die fillet will generate a binding force. When the sheet material of the finished surface is stretched at this moment, it will allow the sheet material to flow again.

Figure 11. Section size of addendum feature

Figure 12. Generation of secondary stretching of sheet metal at the banana-shaped position

4.2. Analysis results of engine hood’s light side and front side

There is no obvious light side’s style on this engine hood, so the front side and light side are grouped under a front side shape. As we know from Figure 13 that the die face without addendum design has a lower fillet extension, we must therefore raise the die face height to increase the stretching rate at this location. Such style is able to pull back the curve to the finished surface height to solve the low extension depth defect of this site. Meanwhile, the H height is also a parameter that will affect the secondary stretching of sheet metal. The principle for this addendum shape that generates the secondary stretch has a similar effect as the previous addendum shape; its forming condition upon the secondary stretching of sheet metal is shown in Figure 14. Through the velocity distribution of the sheet material, we are able to understand the significant sheet material re-flow effect at this feature location as shown in Figure 15.

Figure 13. Extension height at the front side fillet
Figure 14. Secondary stretching at the front side’s feature position

Figure 15. Distribution diagrams of material flow velocity

4.3. Analysis results of engine hood’s fender side

The fender side’s addendum shape is mostly formed by the extension of light side’s addendum style as shown in Figure 16. The method of increasing its stretching rate is similar to the previous one. From Figure 17, we know the sheet metal flow velocity distribution. When the fender side has started secondary stretching, the material on the finished surface will generate secondary stretching, prompting the originally non-flowing material to stretch and flow.

Figure 16. Section diagram of indented addendum at the fender side

Figure 17. Distribution diagram of material flow velocity

Sheet metal forming is divided into two stages. In the first stage, when the sheet metal is being held by the upper die and holder, the sheet metal will pass through the lower die fillet and generate a binding force to stretch the sheet metal and maintain it in a smooth and uniform shape. In the second stage, when the sheet metal passes through the lower die fillet, an addendum feature will start forming, and the
stretching target at the moment is the finished surface of the sheet material. This will generate a secondary stretching effect on the finished panel surface and further attaining the stretching effect on the finished panel surface to allow the material to achieve a work hardening goal. The above procedures can be summarized with a standard design flow as shown in Figure 18.

![Figure 18. Standard design flow chart](image)

5. Verification Analysis
The main objectives of this study are to explore the addendum design and design flow. Due to high mold costs, CAE software was used as the main research tool for verification analysis on an actual die face that has already been developed. The actual die face of which was reverse scanned with ATOS equipment and made into digital files simulation purpose. The SPCC material of thickness 0.7mm was used in actual stamping and grid etching. After forming, it was used to verify the strain conditions of the sheet material. The actual stamped sheet material was also reserve scanned to build up a digital model. After being analyzed by CAE, the shape results were compared.

An ultrasonic thickness gauge was used to conduct the verification analysis on the thickness and strain behavior of finished surface and compared with CAE simulated regions as shown in Figure 19 and Figure 20. The thicknesses of actual sheet panel were analyzed with CAE (Figure 21), the actual thicknesses of A and B paths were compared with CAE simulation values (Figure 22), and the strain analysis was then compared with CAE analysis. As the measurement resolution was 5%, hence the approximate value was taken as the actual sheet panel measurement. The strain values and actual sheet panel values in X direction and Y direction are shown in Table 1. From this verification analysis, we can say that the reliability of applying CAE in sheet metal forming is relatively high.

![Figure 19. Thickness measurement positions](image)

![Figure 20. Strain measurement positions](image)
Figure 21. CAE thickness analysis diagram

Figure 22. Thickness results comparison chart of simulation and actual finished product

Table 1. Strain values of actual finished product and simulation results

|                | C zone strain values | D zone strain values | E zone strain values | F zone strain values |
|----------------|----------------------|----------------------|----------------------|----------------------|
| Finished product | Major strain 0.025 0 | Major strain 0.025 0 | Major strain 0.025 0 | Major strain 0.025 0 |
| Simulation      | Major strain 0.028 0 | Major strain 0.028 0 | Major strain 0.028 0 | Major strain 0.028 0.005 |

6. Conclusion
The collection and summarization of part appearance and addendum shape are essential in establishing design database as they are able to provide us with a reference basis in design and development of new parts, and to cope with the current demand of large vehicle varieties and short development time. However, the current design development relies on experiences and lacks of systematic and scientific means. This study explores from the design point of view to establish an entire precautionous design flow, and the reason of obtaining addendum shapes from CAE simulation towards the generation of secondary stretch of sheet metal. By coordinating the research findings with graphic software, it will offer us a great help in designing addendum shapes to move towards the trends of digitization and parameterization. Meanwhile, the using of CAE analysis is able to shorten mold opening time and lower mold tryout costs.

7. References
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