

Establishment of a Method for Formability Evaluation on Motorcycle Fuel Tank

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ABSTRACT

The “Press map method” for simplicity and high speed and the “Press CAE analysis method” for depth and high accuracy were developed as tools for achieving a press formability of motorcycle fuel tanks. The methods enabling evaluation of press formability in the design stage were established. The effectiveness and reliability of the methods were verified by confirming the correlation of actual measurement data with the analysis result in applying the method to the actual models.

1. Introduction

Fuel tanks are sealed containers that hold fuel. At the same time, the outer tank is also a part that comprises the functional beauty of the overall motorcycle, and various shapes are required depending on the engine and frame shapes. Particularly in recent years, demands for new fuel tank shapes are increasing due to diversifying user needs and support for environmental issues, etc. Therefore, in order to reduce time and cost when manufacturing a new shape fuel tank, development of a method capable of investigating manufacturing requirements in the design stage is required in place of the conventional trial-and-error tool manufacturing method.

2. Formability Evaluation during Product Development

2.1. Press Forming

Figure 1 shows the tool structure when press forming a fuel tank. A panel is clamped between the die and the blank holder, then the desired shape is formed by plastically deforming the panel between the die and the punch. Typical problems occurring at this time include cracks and wrinkles. Forming can be performed well within the stretching and shrinkage tolerance limits of the steel plate, but cracks and wrinkles occur when these limits are exceeded. Figure 2 shows actual examples of these press defects. Cracks and wrinkles have an inverse relationship, and measures to

prevent cracking often lead to wrinkles. Wrinkles not only mar the appearance, but can also lead to a drop in the part strength or tool damage. These defects are mainly caused by sudden or uneven changes in the tool shape, and various countermeasures are taken to ease these changes.

These countermeasures are broadly divided into the following two methods.

- (1) Changing the press machine settings, adjusting the draw bead height, or otherwise modifying the forming conditions.
- (2) Changing the tool shape including the product shape and the die addendum.

Changing the forming conditions and modifying the die addendum have no effect on the product shape, but the product shape may also need to be changed depending on the nature of the trouble. These changes may not be limited to just the fuel tank, and may lead to changes in the design aspects or functional shapes of other parts, resulting in significant modification process time and costs.

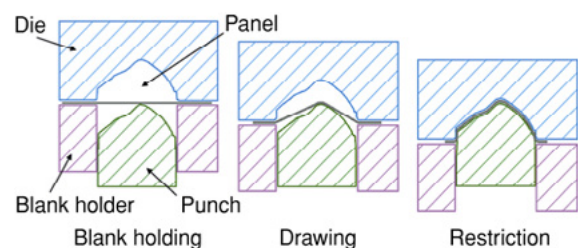


Fig. 1 Press die structure and motion

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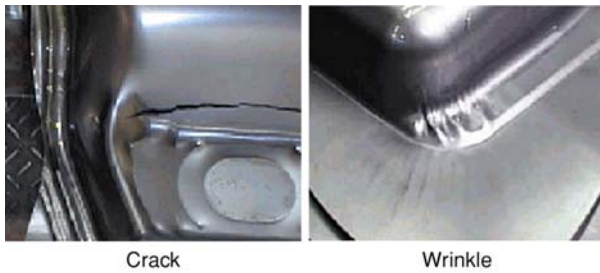


Fig. 2 Press defect

2.2. Formability Prediction Tools and Their Application Timing in Development

When using formability prediction tools in product development, different functions are required in the product design stage and in the tool design stage. In the product design stage, the formability must be investigated simultaneously with the functional design of the tank and related parts. Thus, it is important that the prediction tool be able to easily and quickly investigate the formability of various shapes, and propose measures for major problems regarding formability.

On the other hand, in the tool design stage, the tool shape and forming conditions must be investigated in order to accurately manufacture the product-designed parts in the mass production process. Thus, it is important that the prediction tool be able to simulate and predict the actual press forming process, and accurately evaluate the forming results in detail. Therefore, the simple and high-speed "Press map method" and the in-depth and high accuracy "Press CAE analysis method" were developed as desktop investigative tools that can be used in the product design and tool design stages. Figure 3 shows the position of each design stage and the tool application timing within the development flow.

3. Development of the Press Map Method

As described in section 2, sudden unevenness in the product shape is unfavorable for formability, and taking measures to deal with this in the product design stage reduces subsequent problems. The press map method was developed by applying the difference of the peripheral length method, which had been used as a tool design method that allows easy investigation of various shapes by quantifying sudden unevenness.

3.1. Press Map Method

When press forming a shape such as that shown in Fig. 4, the panel is deformed by the protrusion having the level difference D . Plate A is formed while being pulled toward plate B, and conversely plate B is pulled toward plate A and formed by that reaction. The condition of plate A at this time can be approximated by assuming that the load P_i per unit length in the in-plane direction of the flat plate is applied

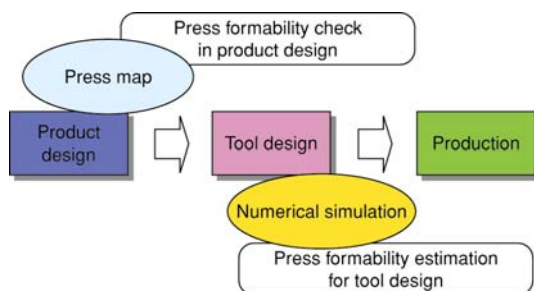


Fig. 3 Simulation map in a product flow

over the range of length C as shown in Fig. 5. If the load when the plate is stretched to the breaking limit is kept constant, the level difference d_a is proportional to the load application length C , and d_a is also proportional to the length E which uses the deformation start point O as the reference.

Figure 6 shows a graph of the relationship between length E and d_a . This figure shows three types of deformation patterns (i, j and k). Patterns i and j show the shape at the breaking limit, and pattern k represents the case when a further load is applied to pattern i, and shows the broken condition. When lines a and b are drawn through both shoulders of the deformed shape to divide the graph into the three areas I, II and III, each area has the following characteristics.

- Area I is the area in which deformation of an arbitrary point Q on the plate is possible.
- Area II is the area in which all of patterns i, j and k exist, and deformation may or may not be feasible depending on the loading length C .
- Area III is the area where deformation is impossible.

Based on these characteristics, the feasibility of deformation for an arbitrary point Q on the plate can be expressed by length L and level difference d_a . Next, plate B is also pulled and deformed by the plate A breaking load P_b , and the amount of deformation d_b is proportional only to sectional width W . The maximum deformation level difference D that can be formed can be obtained by combining the displacements of plates A and B.

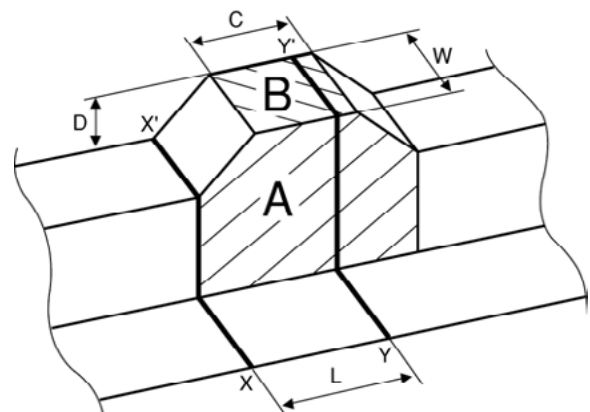


Fig. 4 Typical press shape

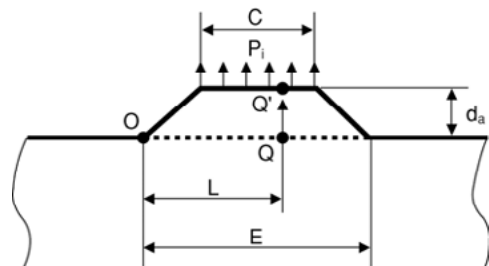
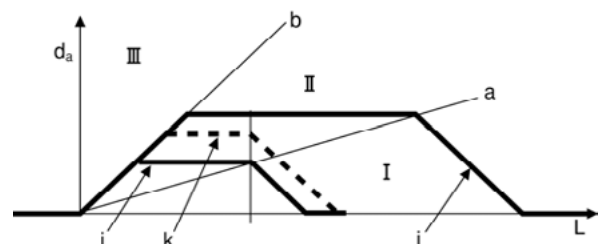


Fig. 5 Deformation of plate A

Fig. 6 Relationship between L and d_a

$$D = d_a + d_b \quad (1)$$

In other words, the maximum deformation level difference D that can be formed can be expressed by length L and sectional width W . At this time the difference F (difference of peripheral length) between the length of the two sections $X-X'$ and $Y-Y'$ in Fig. 4 is identical to level difference D , so this level difference can be replaced with the difference of peripheral length. This relationship is shown by L and F in Fig. 7, with W held constant. This relationship is called a press map, and the above-mentioned areas I, II and III are the stability (stable forming), feasibility (production technology investigation) and impossible (forming impossible) areas, respectively.

To judge the formability of the shape shown in Fig. 8, the distance between sections and the difference of peripheral length of sections x , y and z relative to the reference section are measured and plotted on the press map. Figure 7 shows the values for each section. Sections x and z fall within the stability area, but section y lies within the feasibility area where formability may or may not be achieved. However, the level difference stretches to section z , so in this case the level difference is judged to be formable.

Actual products have complex shapes, but this method can be applied by viewing complex shapes as an aggregate of these level difference shapes. Therefore, the differences of peripheral length were measured for an actual formed part, and formability was confirmed for each section. Figure 9 shows these results. The map judgment values match closely with the actual phenomena, confirming that this method can also be applied to actual parts.

3.2. Construction of a Press Map System

A CAD-based press map system was constructed as a tool for efficiently performing press map judgments. This system creates multiple parallel sections passing in the press direction for a product shape such as shown in Fig. 10, and calculates the length (peripheral length) of each created section. When any two optional sections are selected from among the multiple created sections, the difference of peripheral length = $L_a - L_b$ and the distance between the sections = L_c are obtained.

These values are then plotted on the aforementioned press map to determine whether problems will occur during press forming. The judgment values are displayed as section lines of different colors and thickness. The thickness indicates the formability judgment area, and the color indicates the relative peripheral length. This length distinction provides pointers for shape modification.

When the product shape has large level differences that make forming difficult, the die face portions are generally

curved to ensure formability, and these curved die faces are also supported. Conversely, a function for calculating the excess peripheral length in case of flat die faces and creating curved die faces has also been added. The formability judgment takes approximately one to two minutes, so this system is used to investigate shapes or design die faces.

3.3. Example of Applying the Press Map System

Figure 11 shows an example of applying the press map system. In this application example, tool specifications with flat die faces were initially considered, but investigation with the press map system showed that there were many impossible areas, so this was changed to curved die face specifications. The red and yellow section lines both show impossible area sections, with red indicating a short peripheral length and yellow a long peripheral length. As a countermeasure, the die face was built up to shorten the yellow sections. The prototype results at this time show that forming was possible without major problems as shown in Fig. 12.

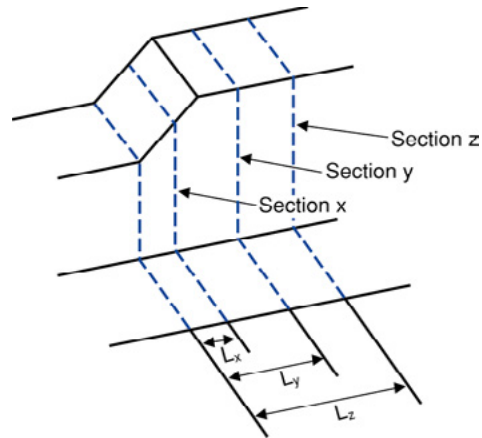


Fig. 8 Sections on a shape

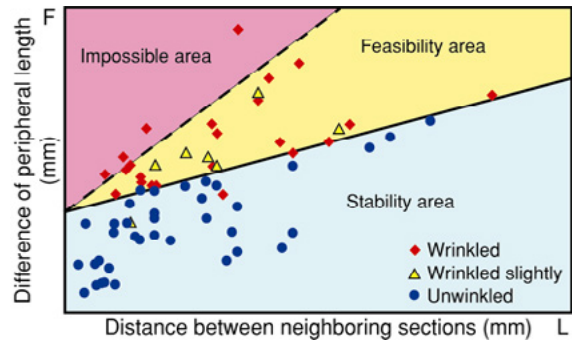


Fig. 9 Measured data on press map

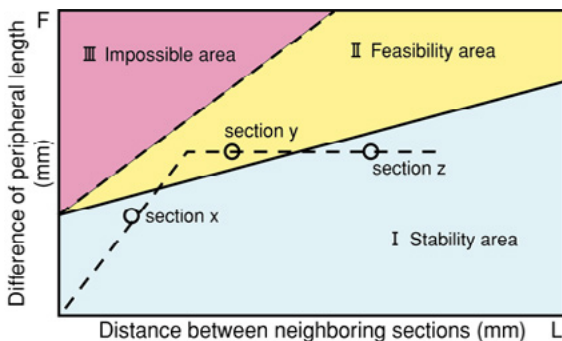


Fig. 7 Press map

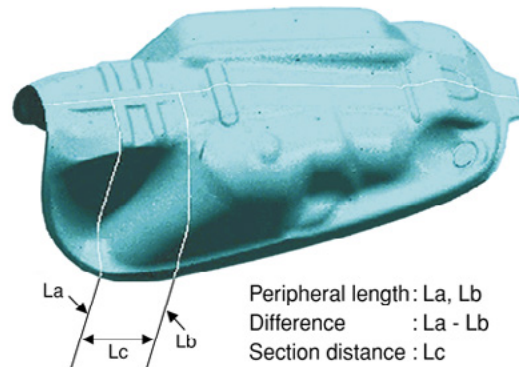


Fig. 10 Press map system

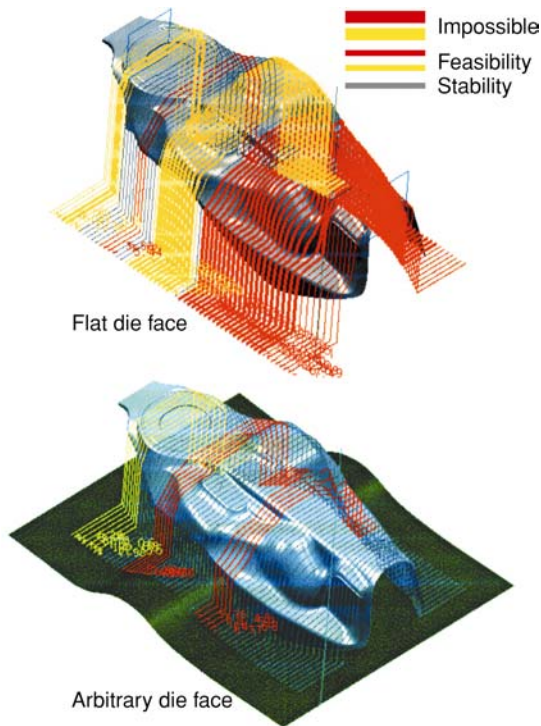


Fig. 11 Example of product shape



Fig. 12 Result of press forming with arbitrary die face

These results verified the effectiveness of the press map system as a formability judgment tool. In addition, using the same curved die faces for the prototype as for mass production made it possible to incorporate countermeasures into the tool specifications based on the prototype results, thus helping to improve the tool design efficiency.

4. Development of the Press CAE System

In the tool design stage, it is necessary to investigate the tool shape including the product shape, and the formability including the forming conditions. Thus, it must be possible to perform simulations under the same conditions as the actual press forming process. In addition, functions capable of evaluating panel cracking, wrinkling and strain in the

forming process are also demanded. Elastic and plastic deformation analysis (press CAE) that uses finite element method (FEM) is utilized as a system for achieving these functions.

4.1. Press CAE

The following functions are required to simulate the press forming process.

- Handling of complex product shapes
- Analysis of nonlinear phenomena (large deformation, plastic deformation, contact with the tool) occurring in the materials
- Handling of issues unique to press forming such as the draw bead and trim
- Stable analysis in a practical length of time
- Accurate evaluation of formability

A number of methods using FEM have been proposed as methods that satisfy these requirements, and these can be broadly divided into dynamic explicit analysis and static implicit analysis. Each method has advantages and disadvantages, but dynamic explicit analysis software was selected from the viewpoints of analysis time and accuracy. This method was originally developed for shock analysis and crash analysis simulations. However, it has been adapted to quasi-static press forming analysis and features stable calculation with reliable solutions for nonlinear analysis such as large deformation and contact. On the other hand, this method requires extremely small analysis time steps (approximately 10^{-6} seconds), and an enormous amount of time is required to analyze press processes lasting several seconds. Therefore, some means were needed to allow practical simulations, and this is currently achieved by increasing the forming speed by a factor of 10 to 100 times over the range that does not affect the accuracy of the analysis results.

4.2. Introduction and Customization of the Press CAE System

In order to efficiently predict formability using dynamic explicit analysis, a pre-post system was introduced and customized. This system has the following features.

- This system is designed specially for press forming, and parameter input uses press forming terminology such as single action press, die, punch, bead, and so on to make the system easy to use for press designers. In addition, default values are set for the internal parameters used for analysis, which allows analysis to be executed without having to concentrate on the dynamic explicit analysis software.
- The panel deformation resistance due to the draw bead can be input as a numerical parameter. This greatly reduces the calculation time compared to modeling the draw bead based on the die shape. This parameter value is identified with experiments and analysis to derive the accurate value.
- The system has a material database function, and data unique to the company can be registered. Tensile tests are currently being performed with materials used in products to measure and register stress-strain curves and r values (anisotropic parameters).
- The system has abundant results display functions, and formability can be evaluated from various viewpoints. Display functions include plate thickness reduction rate distribution, forming limit diagram (FLD), scribed circle,

shock line, forming pressure, distribution of contact between the panel and the die, etc.

- A database is constructed within the in-house intranet, and stores the analysis conditions and analysis results. These data are opened to product and tool designers, and used for tool design.

Figure 13 shows the analysis procedure using this system.

(1) 3D model creation

The die addendum and die face shape are added to the product model to create the tool shape. Here, the fillets that are essential for press forming must be faithfully created.

(2) Mesh creation

The die, blank holder, punch and panel are all expressed by polygon using a finite element mesh.

(3) Forming condition setting and analysis

The material characteristics, cushion pressure, friction, draw bead load, stroke amount and other forming conditions are set, and analysis is executed.

(4) Results evaluation

The strain, deformation, plate thickness, stress and surface pressure of the plate during the forming process are output, and the tool shape, the material type, plate thickness, shape and placement of panel, cushion pressure, friction and draw bead parameters are investigated based on these results.

(5) Accumulation of results

These results are saved in the aforementioned analysis database.

Figure 14 shows an example of analysis results. This graph outputs the fuel tank thickness along the symmetrical plane, and shows both the measurement and analysis results. Both results show an excellent correlation over the entire graph, thus confirming that the system can be applied to actual products.

4.3. Example of Applying the Press CAE System

An example of applying the press CAE system to wrinkles and cracks is shown below.

4.3.1 Predicting wrinkles

Figure 15 shows the deformation shape based on the analysis results. The upper figure is before and the lower figure is after the countermeasures. Plate overflow occurred in concave areas before the countermeasures, but this plate overflow could be prevented by changing the die face shape.

The die is a rigid body so the analysis shows less wrinkling at the bottom dead point than for the actual product. Therefore, plate deformation, wrinkle timing, wrinkle height and other phenomena in the forming process are currently used in reference to fuel tank shapes for similar models from the aforementioned database to assist designers in their wrinkle judgments.

4.3.2. Predicting cracks

Figure 16 shows the plate thickness distribution and a graph of the minimum plate thickness for each specification based on the analysis results. Although the initial specifications cleared the cracking judgment value, it is close to the limit value and leaves no forming margin in consideration of variance during mass production. Therefore, in this case the panel placement and shape were modified to increase the forming margin. The minimum plate thickness was compared for the base specifications and improvement proposals 1 and 2. The comprehensive cracking judgment also uses the plate thickness reduction rate, forming limit line diagram and plate thickness reduction history.

5. Future Themes

- (1) The next most common forming defect after cracks and wrinkles is surface deformation. This occurs as minute wrinkles or waves on the product shape and leads to a drop in appearance quality. There are methods for judging surface deformation by the deformation shape, stress, strain, and so on, but the accuracy is still insufficient. The number of case examples must be increased and judgment technology established in the future.

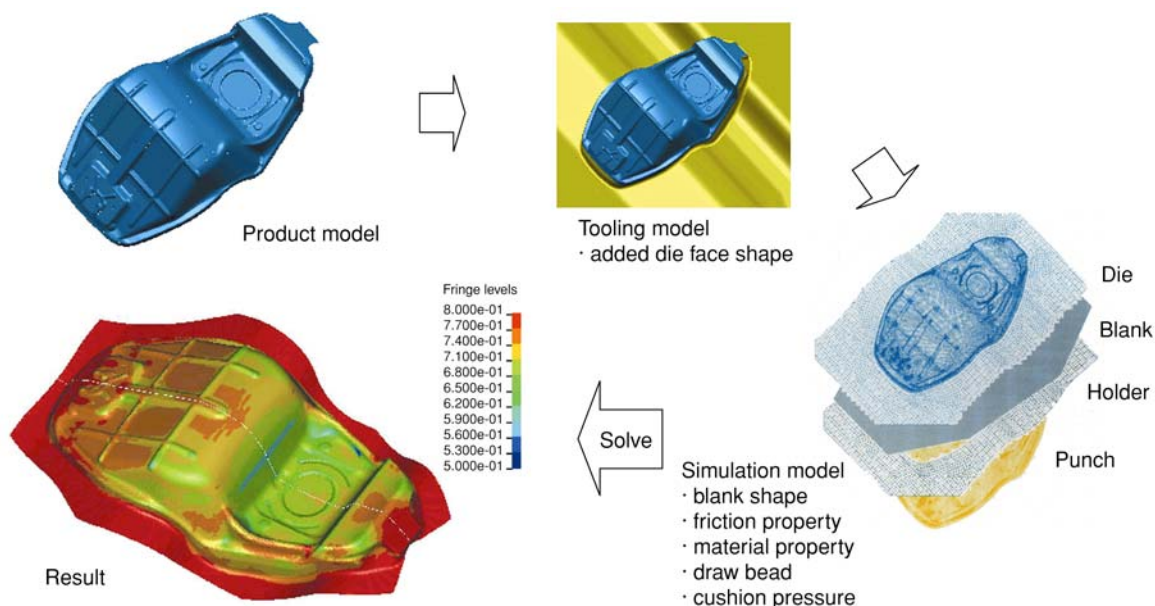


Fig. 13 Simulation flow

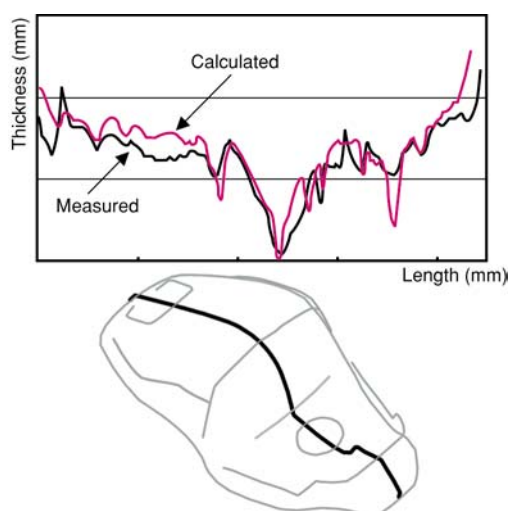


Fig. 14 Measured and calculated thickness distribution on a product shape

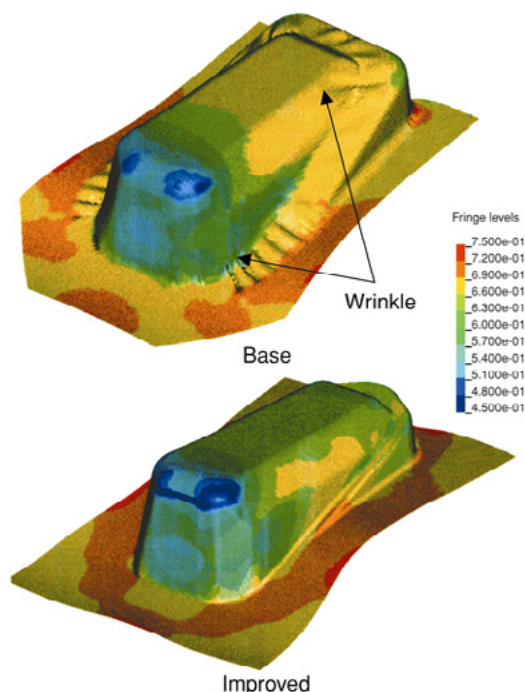


Fig. 15 Countermeasure implementation for wrinkle

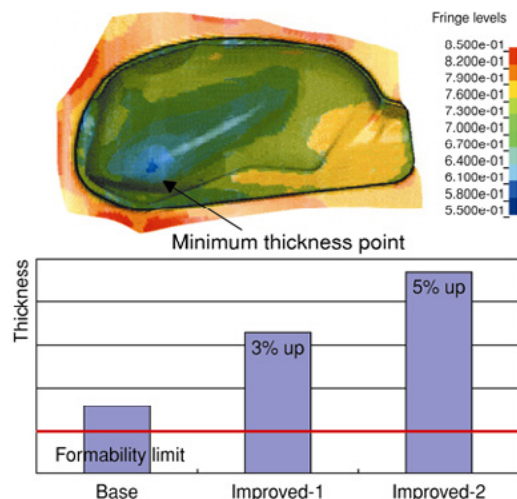


Fig. 16 Countermeasure implementation for crack

- (2) Within the tool shape, the die addendum is a part that has a large effect on formability. The difference of peripheral length can be adjusted and plate inflow can be controlled according to the die addendum shape. However, unlike tuning with the analysis parameters such as for the cushion pressure, investigating the die addendum shape requires multiple die addendum models. Simpler tools to create them are currently being investigated.
- (3) With the shift to overseas production, press forming is increasingly using local facilities and materials. However, the formability of the materials in each location differs, so the material properties of local materials must be acquired in the future.

6. Conclusion

The following two systems were constructed as methods for evaluating press formability.

- (1) Simple and high-speed "press map method"
The press map method was developed focusing on the deformed condition of a plate with level differences. This system is used to investigate shapes in the product design stage and to design die faces in the tool design stage, and its effectiveness was verified.
- (2) In-depth and high accuracy "press CAE analysis method"
The press CAE analysis method using FEM was developed. This system is used to investigate tool shape and forming condition settings in the tool design stage, and its effectiveness was verified.

These two systems make it possible to quantitatively investigate manufacturing requirements in the design stage.

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