A New Crack Predicting Method for Press Forming of Aluminum Thin Sheet Material

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Abstract

Aluminum thin sheet material is widely used for automotive heat exchange products. Cracks occur on the sheet metal parts in some cases during the press forming process. In this paper, a new effective crack predicting method using accurate CAE model and FLD is described.

Key Words: Press forming, Crack, Material, FLD, Strain, CAE

1. Introduction

In Calsonic Kansei Corporation (CK), aluminum alloy thin sheet metal (hereinafter, aluminum thin sheet metal) is widely used for the production of pressed components for heat exchangers and climate systems.

At the production site of these components, we ensure pressing quality through failure prevention activities such as regular die maintenance and operator’s adherence to the operation standards. However, since there have been some cases where cracks occurred when process changes such as material lot changeover was made. Fig. 1 shows an example of cracks.

![Fig. 1 Example of crack](image)

To eradicate aluminum cracks, it is necessary to design products and processes in consideration of material characteristics and press formability from the initial development phase. For this purpose, establishing an evaluation method of accurately predicting cracks is essential.

In this study, we built up a hypothesis of a crack occurrence mechanism and carried out a thorough experimental verification on actual aluminum pressed parts. As a result, we have established a highly accurate crack prediction method using CAE analysis through high-fidelity simulation of actual press forming mode. Fig. 2 illustrates an overview of the new prediction method.

![Fig. 2 Crack analysis process](image)

2. Issue with Highly Accurate Crack Prediction

To achieve highly accurate crack prediction using CAE analysis, there are two requirements we needed to tackle as follows:

1. Highly accurate CAE analysis
2. Optimal judgement criterion

Highly accurate CAE analysis requires high-fidelity material and tool models as well as high-precision forming conditions. Our CAE analysis had been carried out in light of these requirements but there were some cases where the analysis did not accurately simulate the forming conditions unique to aluminum thin sheet materials, partly due to an insufficient database of...
material models.
For the judgement criterion, a uniform thickness reduction rate had been used. However, there still remained an issue that the criterion was not always reliable in crack prediction under various strain modes. Thus, an optimal judgement criterion had been required.

3. Experimental Part and Process

3.1. Experimental part
The pressed part used in the experiment was a tube sheet (T/S), which is a component of an evaporator installed in automotive air conditioning units.

3.2. Experimental process
The pressing process applied to the experiment was the first drawing process of T/S production. Fig. 3 illustrates an outline of the drawn part, and Fig. 4 shows the die specification. As the experimental material was an aluminum thin sheet of just 0.3 mm thickness, press forming itself is difficult. In addition, the drawn portions arranged in a pair are close to each other, there is a high risk that cracks occur at the narrow area between the two drawn portions.

4. Approach to Highly Accurate CAE Analysis
We addressed the creation of a high-fidelity material model to achieve highly accurate CAE analysis.
In detail, we measured material properties in a tensile test and optimized a yield function based on the measurement results. Since some types of anisotropic materials exist among aluminum thin sheets, it is necessary to clarify whether the experimental material is anisotropic and then determine an appropriate yield function that can simulate the anisotropic characteristics.

4.1. Tensile test
In the tensile test, mechanical properties of each specimen were measured according to five different directions with respect to the rolling direction, in order to check the anisotropy of the material.
As shown in Fig. 5, the specimens were cut off from the material sheet by changing angles to the rolling directions with increments of 22.5 degrees, zero degrees to 90.

The mechanical properties measured were the true stress-true strain curve, the Lankford value (r value), and the work hardening coefficient (n value).
As shown in Fig. 6, the measured values of these mechanical properties varied between the five specimens. This revealed that the experimental material is anisotropic.
4.2. Study of yield function

A yield function is to mathematically represent how the material is deformed under a given stress. If an inappropriate function is selected, it cannot accurately reproduce an actual behavior of material deformation, which affects CAE analysis accuracy.

Since the tensile test found that the experimental material is anisotropic, a yield function that can factor in the influences of anisotropy was adopted in the new prediction method.

4.3. Study results of material model

From the results of the tensile test and the yield function study described above, the material model used for the CAE analysis was determined as shown in Table 1.

5. Study of Crack Judgement Criterion

As a crack judgement criterion, we applied not only thickness reduction ratio but also a Forming Limit Curve (FLC) in a Forming Limit Diagram (FLD) in order to take into account a forming process unique to aluminum thin sheet materials.

The FLC is a useful indicator in that it can clearly visualize whether strain modes exceed forming limits at each measured area.

5.1 Study of FLC

Although an FLC can be drawn by inputting the material characteristic values on CAE analysis software, we measured forming limits to derive an actual FLC and compared it with CAE analysis results to obtain more accurate data.

(1) Deriving FLC

For forming limit measurement, we conducted an FLD experiment. As shown in Fig. 7, strain modes were measured by in elastically deforming the specimen on which many overlapped small circles called scribed circles were drawn up to a given level of each pressing deformation mode. After press forming, the small circles are deformed in various oval shapes.

Strain in the long axis direction of an oval is called the maximum strain while strain in the short axis direction is the minimum strain.

The FLC of the experimental material was obtained in the diagram, where the maximum and minimum strains of each small circle were plotted on the vertical and horizontal axis, respectively. Thus, an area indicating constriction/fracture occurrence as well as an area indicating normal forming were formed in the diagram.

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Table 1 Material model

<table>
<thead>
<tr>
<th>Type</th>
<th>Thickness (mm)</th>
<th>Young’s modulus (GPa)</th>
<th>Poisson’s ratio</th>
<th>Density (kg/mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloy</td>
<td>0.3</td>
<td>74.3</td>
<td>0.36</td>
<td>2.70E-06</td>
</tr>
</tbody>
</table>

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**Fig. 6 Result of tensile test**

**Fig. 7 Derivation of FLC**
(2) Comparing FLC  We compared two FLCs, one calculated by CAE according to the material property values and the other obtained from the FLD experiment. The results showed the difference between these FLCs is slight, only 1 to 2% for tension and plane strain, while the difference is larger for equibiaxial tension. Fig. 8 illustrates the comparison results.

5.2. Determining FLC
Based on the comparison results, we decided to use the FLC derived from the measurement as a judgement criterion in the new prediction method.

6. Results
To verify the accuracy of the CAE analysis using the new material model, we compared the actual pressing results of the specimen and the CAE analysis results. In addition, to verify the adequacy of the crack judgement criterion, we also compared the actual crack results and the CAE analysis judgement results.

6.1. Fabrication conditions of experimental specimen
The specimen was fabricated with a 200t servo press machine equipped with a die for T/S drawing process. Table 2 shows the press forming conditions for obtaining the specimen.

<table>
<thead>
<tr>
<th>Table 2 Press forming condition</th>
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</thead>
<tbody>
<tr>
<td>Material set position</td>
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<tr>
<td>Lubricant layer thickness</td>
</tr>
<tr>
<td>Speed</td>
</tr>
</tbody>
</table>

6.2. CAE analysis conditions
(1) Element size  As shown in Fig. 9, the calculation region was limited to a minimum area to reduce the calculation time. The element size was defined by dividing the object into three layers of 0.2 mm × 0.2 mm × 0.1 mm cubes (Total number of elements: about 300 thousands).

(2) Die conditions  The calculation was performed under actual pressing die conditions (e.g., blank holder pressure, ejector pin pressure, distance). The coefficient of friction was 0.12 and the pressing speed was 3.0 mm/msec.

6.3 Comparison of actual pressing results and CAE analysis results
(1) Verification of thickness reduction  Fig. 10 illustrates the comparison of thickness reduction between actual pressing and CAE analysis results. The comparison revealed that the deviation between the measured values on the specimen and the CAE analysis data was only about 1% or less thanks to the fidelity improvement of the material model. This improvement was also observed when compared with the curve based on the conventional yield function. Thus, we confirmed that the CAE analysis using the new material model can achieve more accurate reproduction of thickness reduction.
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Fig. 10 Comparison result of thickness

(2) Verification of forming strain  Fig. 11 illustrates the comparison of strain mode in T/S bulged side walls between the experimental (yellow) and CAE analysis (white) results.

In both the experimental and CAE analysis results, strain occurred due to equibiaxial tension. Also, the strain amounts of those results were equivalent. This proved that the CAE analysis using the new material model can achieve more accurate reproduction of the strain mode.

Fig. 11 Comparison of forming strain

6.4 Verification of crack judgement criterion  Fig. 12 illustrates the crack judgement results based on the FLC through CAE analysis under actual forming conditions where cracks occur on the bulged side wall of the specimens. In the diagram, the strain modes after forming are dotted within the fracture area, which indicates crack occurrence. These results confirmed that using the FLC as a judgement criterion can lead to more accurate crack prediction.

Fig. 12 Comparison of forming strain (Crack)
7. Conclusion

From the verification results described above, we have introduced new CAE analysis conditions and crack judgement criterion required for predicting cracks of aluminum thin sheet materials.

(1) **CAE analysis conditions**  By creating a high-fidelity material model obtained through hypothesizing a crack occurrence mechanism and carrying out an experimental verification, we have achieved an accuracy improvement of CAE analysis concerning press forming of aluminum thin sheet materials. Table 3 shows the new CAE analysis conditions.

<table>
<thead>
<tr>
<th>Table 3 Calculation condition of CAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Solid analysis</td>
</tr>
<tr>
<td>Material model</td>
</tr>
<tr>
<td>Young’s modulus</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
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<tr>
<td>Density</td>
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<tr>
<td>n-value</td>
</tr>
<tr>
<td>s-value</td>
</tr>
<tr>
<td>Material law</td>
</tr>
<tr>
<td>Press forming condition</td>
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<tr>
<td>Coefficient of friction</td>
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<tr>
<td>Die specification</td>
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</table>

(2) **Crack judgement criterion**  By adopting the FLC as a judgement criterion, which takes into account the forming process unique to aluminum thin sheet materials, we have established a highly accurate crack prediction method. In addition, this study concludes that the FLC must be used as a judgement criterion and also obtained from the FLD experiment in every analysis.

8. Closing Remarks

As the application of the new prediction method is limited to cracks of aluminum thin sheet materials, we will carry out verifications to explore the possibilities of the applications to other materials such as steel and stainless steel. Thus, we will attempt to expand the range of the applications using this method as a new analysis standard, aiming to continuously accumulate our press forming technologies through experimental verifications.

Lastly, we would like to thank all concerned for their cooperation in the development of this method.

References

(2) Toshihiko Kuwabara and other authors: Hydraulic bulge forming simulation of 6000 series aluminum alloy sheets using anisotropic yield functions and experimental validation, Keikinzoku (Light Metals), Vol. 62, No. 1, p. 7-13