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Application News

No. i268

Material Testing Machine

Improvement of Profile Accuracy Coincidence Rate in Press-Forming Simulation of High Tensile Strength Steel Considering the Bauschinger Effect

Introductions

In order to improve the fuel efficiency of transportation machinery, reduction of vehicle body weight is demanded. Use of high tensile strength steel has attracted attention as one approach to weight reduction, as it is possible to design vehicle bodies with thinner materials. However, when using high tensile strength steel, shape defects easily occur after press forming, and the excessive time and cost required to manufacture press dies was a problem. Although springback is one factor in shape defects, accuracy in the predictions of the springback phenomenon has improved in recent years as a result of progress in CAE (Computer Aided Engineering) analysis technology and improvement of the computational speed of personal computers. CAE analysis is also used in production of press-forming dies, and is a focus of interest as a technique for shortening development time and realizing a large reduction in costs.

The property values (default values) of general metal materials are recorded in advance in the press-forming simulation analysis software used in CAE analysis, and simple analyses using these values are possible. However, the default values cannot be applied without modification because large differences with the ideal shape of press-formed products occur in simulations only using those values. This means that it is necessary to acquire various property values by using a material testing machine, and apply those values in simulations, in order to achieve high accuracy in press-forming simulations.

As described in this article, material property data obtained from a uniaxial tensile test and in-plane reverse loading test using a Shimadzu Autograph™ precision universal testing machine were applied in simulations. This article introduces an example in which high accuracy simulation of press-forming for an automotive part with a complex shape was successfully achieved by using data obtained from actual measurements, and the profile accuracy coincidence rate with actual press-formed parts was dramatically improved.

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Main Material Properties Influencing Press Formability

The material properties which express the press formability of steel sheets include not only the elastic modulus, which is evaluated by the uniaxial tensile test, the Lankford value (r-value), and the work hardening coefficient (n-value), but also the plastic strain dependency of the elastic modulus and the Bauschinger effect, which can be evaluated by performing an in-plane reverse loading test. In addition, the yield surface, which can be obtained by a biaxial tensile test using a cruciform test specimen, is also important for understanding the press formability of steel sheets.

The r-value is obtained by dividing the logarithmic strain in the transverse direction of a steel sheet when a tensile load is applied to the sheet by the logarithmic stain in the sheet thickness direction. However, because it is difficult to obtain the strain in the sheet thickness direction due to the limitations of measurement accuracy, a method in which the tensile strain and transverse strain assuming a constant test specimen volume are converted to logarithmic strain is generally used. The r-value is an index for judging drawing formability, larger r-values indicating a higher drawing formability. As described in the provisions concerning the average plastic strain ratio in ISO 10113 and JIS Z 2254, the r-value is generally evaluated by using test specimens taken along the three direction of 0°, 45°, and 90° relative to the rolling direction of high tensile strength steel (Fig. 1). Since these physical property values can be obtained by using a general-purpose material testing machine, an extensometer, and a width meter, this combination of devices has been widely adopted throughout the world as a test system.

On the other hand, the n-value is an index for judging stretch formability, and larger n-values indicate higher stretch formability.

Moreover, because the Bauschinger effect of steel sheets, which contributes to the springback phenomenon, is also one factor in shape defects, it is necessary to construct a simulation model that considers the Bauschinger effect in order to achieve high accuracy in simulations of press-forming. The Bauschinger effect is a characteristic in which the absolute value of compressive yield stress decreases greatly in comparison with that of tensile yield stress when stress in the opposite direction is loaded on a metal material in which plastic deformation has occurred as a result of pre-strain (cited from Application News No. i262A). Because steel sheets buckle easily under compressive loading, there was no technique for evaluation of the Bauschinger effect until now except use of a special test system which included some dedicated testing machines.

In-plane reverse loading tests of steel sheets can now be performed easily with a general-purpose material testing machine by using a Bauschinger effect measurement jig developed by Shimadzu as a dedicated jig for our company's Autograph universal testing instrument (Fig. 2). It is also possible to output the tensile-compressive stress-stain curve obtained by the test to the data format used by the press-forming simulation analysis software.

In this article, the elastic modulus and r-value in the uniaxial tensile test and the tensile-compressive stress-strain curve in the in-plane reverse loading test were obtained respectively and used in the analysis as material property values for application to the simulation.

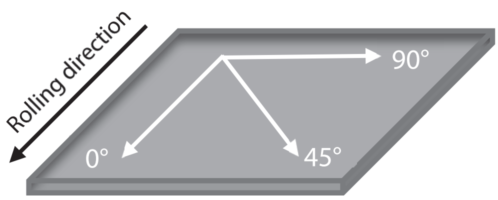


Fig. 1 Specimen Sampling Directions Relative to Steel Sheet Rolling Direction

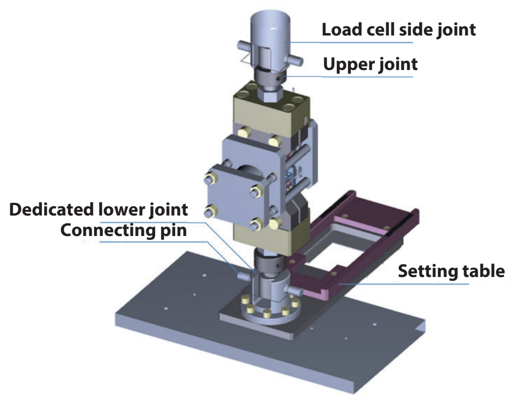


Fig. 2 Bauschinger Effect Measurement Jig

Acquisition of Material Property Values by Uniaxial Tensile Test

Tensile property data, including the tensile elastic modulus, tensile strength, and r-value of high tensile strength steel, were acquired by a uniaxial tensile test using a Shimadzu Autograph universal testing instrument, automatic extensometer, and width meter. Fig. 3 shows the scene of the uniaxial tensile test, and Table 1 shows the test conditions. The average of the r-values of specimens taken along the 0°, 45°, and 90° directions was also calculated and applied in the simulation.

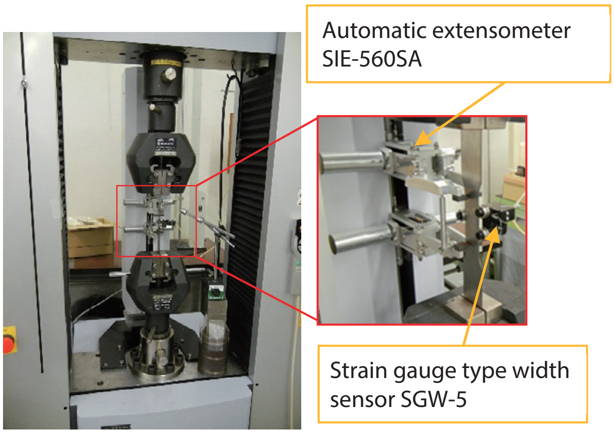


Fig. 3 Scene of Uniaxial Tensile Test

Table 1 Test Conditions of Uniaxial Tensile Test

Instrument	:	Shimadzu Autograph universal testing instrument
Extensometer	:	SIE-560SA (GL=50)
Width meter	:	SGW-5
Test speed	:	0.005 /s
Testing machine control method	:	Strain rate control
Software	:	TRAPEZIUM X (single)
Specimen shape	:	JIS Z 2241 Dumbbell-shaped 5

Acquisition of In-Plane Reverse Loading Test Data

An in-plane reverse loading test of a high tensile strength steel sheet was conducted using the Shimadzu Autograph universal testing instrument and Bauschinger effect measurement jig. Fig. 4 shows the scene of the in-plane reverse loading test, and Table 2 shows the test conditions. In this test, the in-plane reverse loading strain was set to +3 % and -3 %.

The Bauschinger effect measurement jig has a mechanism that makes it possible to attach a dedicated contact type extensometer, enabling accurate measurement of the strain generated in test specimens. An option that supports strain measurements using a strain gauge is also available with the Bauschinger effect measurement jig.

Fig. 5 shows the tensile-compressive stress-strain curve obtained by the in-plane reverse loading test. A press-forming simulation analysis considering the influence of the Bauschinger effect is possible simply by exporting the data necessary in the simulation using a standard function of the testing machine control software, and inputting the data to the simulation software.

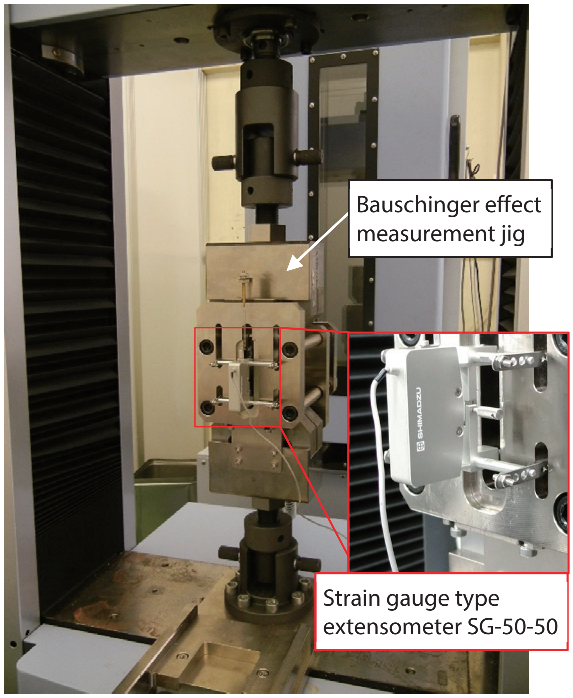


Fig. 4 Scene of In-Plane Reverse Loading Test

Table 2 Conditions of In-Plane Reverse Loading Test

Instrument	:	Shimadzu Autograph universal testing instrument
Jig	:	Bauschinger effect measurement jig
Comb grip pressure	:	5 MPa
Extensometer	:	SG-50-50 (dedicated device for Bauschinger effect measurement jig)
Test speed	:	1 mm/min
Software	:	TRAPEZIUM X (control)
Stress reversal strain	:	3 % ⇆ -3 %

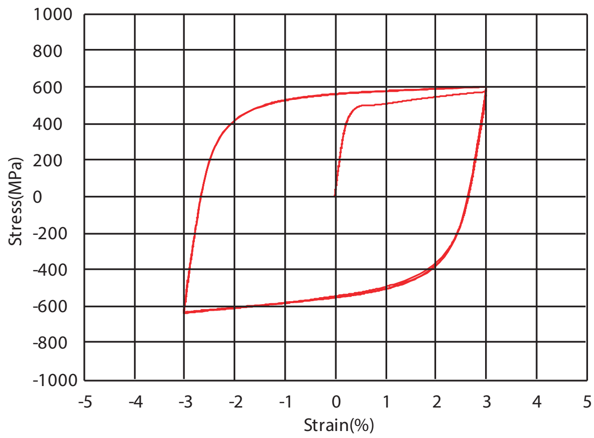


Fig. 5 Stress-Strain Curve Obtained by In-Plane Reverse Loading Test

Results of Press-Forming Simulation and Profile Accuracy Coincidence Rate

In order to compare the profile accuracy of a press-forming simulation and an actual press-formed product (actual panel), the coincidence rate of the simulation and the actual panel was evaluated at the 18 points shown in Fig. 6. Fig. 7 shows the relationship between the actual panel and the pressing direction. The profile accuracy coincidence rate is defined as the ratio of points where the difference between the actual panel and the simulation result is within ±0.5 mm, and is calculated using the following equation.

Profile accuracy coincidence rate (%) = N_P / 18 × 100   Eq. (1)

N_P : Number of points having error with actual panel of within ±0.5 mm

In the press-forming simulation, analyses were carried out under the following three conditions.

[Analysis condition I]

Use default values registered as standard values in the press-forming simulation software.

[Analysis condition II]

Use uniaxial tensile property data of high tensile strength steel.

[Analysis condition III]

Use uniaxial tensile property data and data obtained by in-plane reverse loading test of high tensile strength steel.

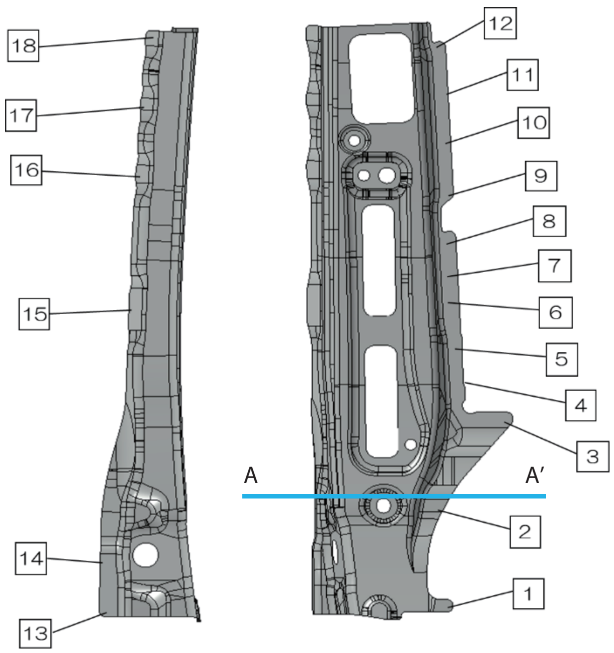


Fig. 6 Profile Accuracy Measurement Points

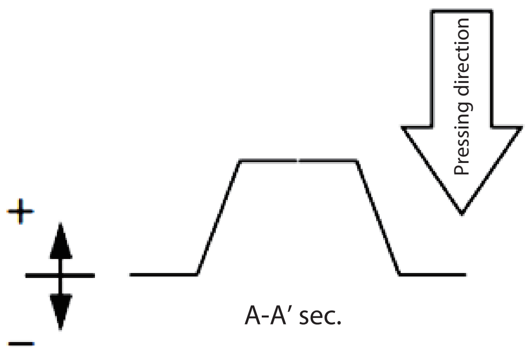


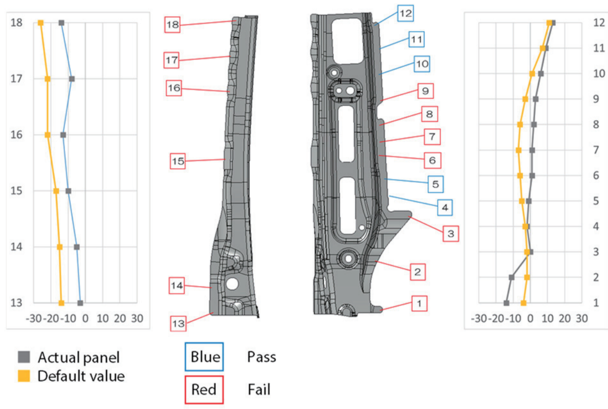
Fig. 7 A-A' Section and Pressing Direction

Simulation Using Default Values

Fig. 8 and Fig. 9 show the simulation results for analysis condition I. Fig. 8 shows the amount of deviation from the ideal shape at each of the measurement points for the actual panel and the simulation result. If the deviation between the actual and simulation results is within ±0.5 mm, the number indicating the measurement point is shown in a blue box, and if the amount of deviation is larger than ±0.5 mm, the measurement point number is shown in a red box. (The same notation is also used in the following Fig. 10 and Fig. 12.) In these results, the difference between the actual panel and the simulation tended to be large at measurement points 1, 2, 13, and 14, which are located at the edges of the part where blank-holding was applied. A maximum difference of 1 mm can be seen.

Fig. 9 shows contour figures, which visually represent the amount of difference from the ideal shape for actually-produced panel and the simulation result. The degree of coincidence of the actual part shape (actual panel) and the ideal shape and coincidence of the simulation result and the ideal shape are expressed by color, where warmer colors represent a larger error to the positive direction and cooler colors represent a larger error to the negative direction in comparison with the ideal shape.

Differences between the actual panel and the simulation result are apparent, even visually, as points which do not coincide can be seen at various places. The profile accuracy coincidence rate of the actual panel and the simulation result was 28 %.



* The dimensional accuracy shown on the horizontal axis in the above graph is denoted by numbers 10 times larger than the actual measured values.

Fig. 8 Deviation of Profile Accuracy for Analysis Condition I (Use of Default Values)

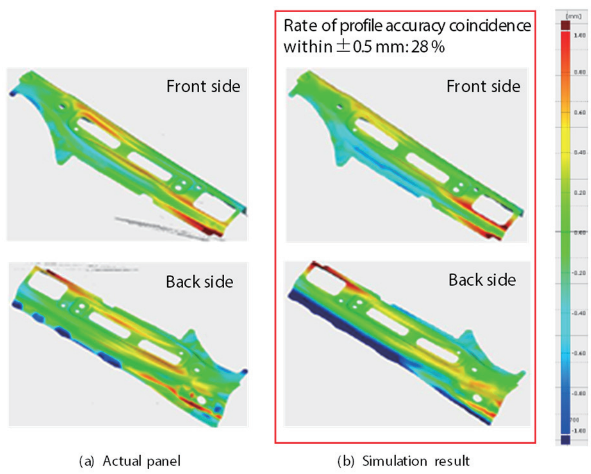
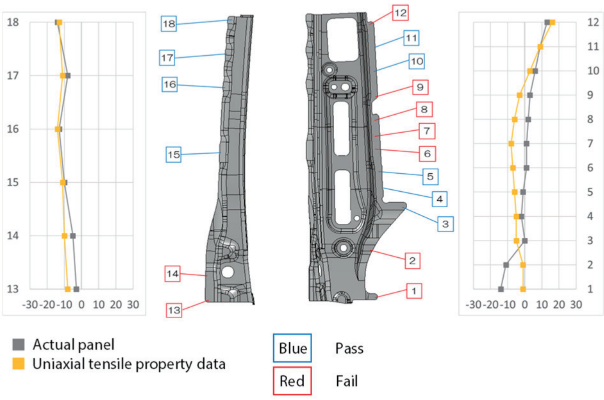


Fig. 9 Profile Accuracy Contour Figures for Analysis Condition I (Use of Default Values)

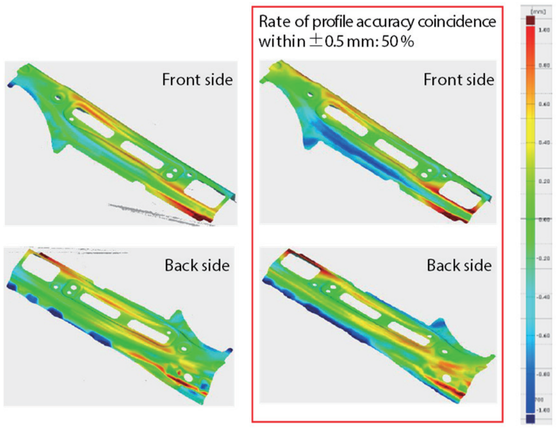
Simulation Using Uniaxial Tensile Test Property Data

Fig. 10 and Fig. 11 show the simulation results for analysis condition II. At measurement points 1 and 2, the amount of difference between the actual panel and the simulation result is similar to that in the simulation using the default values. However, the profile accuracy coincidence rate has improved to 50 %. Points which improved in comparison with the simulation using the default values could not be seen in the contour figures in Fig. 11.



* The dimensional accuracy shown on the horizontal axis in the above graph is denoted by numbers 10 times larger than the actual measured values.

Fig. 10 Deviation of Profile Accuracy for Analysis Condition II (Use of Uniaxial Tensile Property Data)

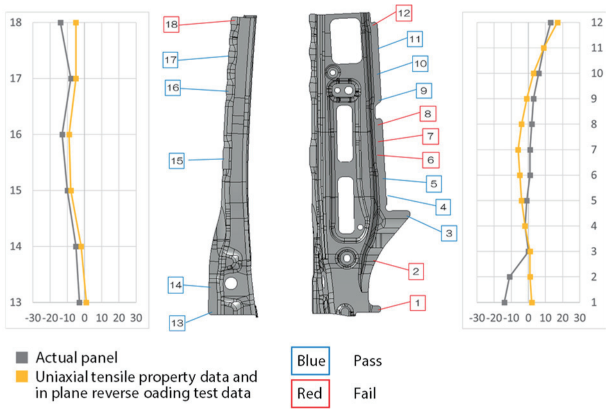


(a) Actual panel (b) Simulation result

Fig. 11 Profile Accuracy Contour Figures for Analysis Condition II (Use of Uniaxial Tensile Property Data)

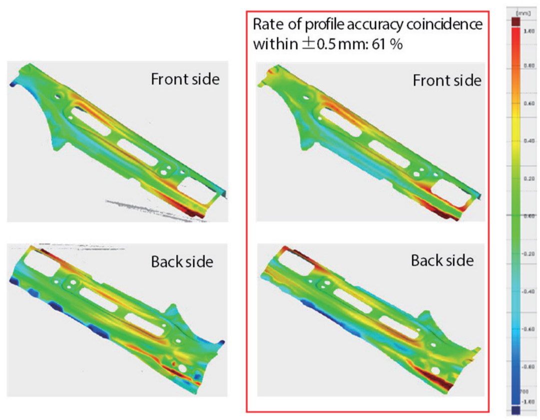
Simulation Considering Uniaxial Tensile Test Property Data and Bauschinger Effect

Fig. 12 and Fig. 13 show the simulation results for analysis condition III. The amount of difference between the actual panel and the simulation result increased at measurement points 1 and 2, but decreased at points 13 and 14. In addition to this, the number of measurement points where the amount of difference was held to within ±0.5 mm also increased, and as a result, the profile accuracy coincidence rate improved to 61 %. Comparing the simulation result using the default values and the result using the uniaxial tensile property data in the contour figures in Fig. 13, a particularly large improvement could be observed on the front side. Based on these facts, it was found that applying not only material property data obtained by the uniaxial tensile test, but also data obtained by an in-plane reverse loading test considering the Bauschinger effect is important for achieving high accuracy in press-forming simulation analysis.



* The dimensional accuracy shown on the horizontal axis in the above graph is denoted by numbers 10 times larger than the actual measured values.

Fig. 12 Deviation of Profile Accuracy for Analysis Condition III (Use of Uniaxial Tensile Property Data and In-Plane Reverse Loading Test Data)



(a) Actual panel (b) Simulation result

Fig. 13 Profile Accuracy Contour Figures for Analysis Condition III (Use of Uniaxial Tensile Property Data and In-Plane Reverse Loading Test Data)

Conclusion

This study clarified the fact that high accuracy can be achieved in press-forming simulations of automotive parts by applying material property values of high tensile strength steel obtained using the Shimadzu Autograph universal testing instrument, various extensometers and widthmeters, and the Bauschinger effect measurement jig.

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